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Spatial habitat preference of smallmouth bass (*Micropterus dolomieui*), roundtail chub (*Gila robusta*), and razorback sucker (*Xyrauchen texanus*)

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The University of Arizona, 1992
SPATIAL HABITAT PREFERENCE OF SMALLMOUTH BASS (MICROPTERUS DOLOMIEUI), ROUNDTAIL CHUB (GILA ROBUSTA), AND RAZORBACK SUCKER (XYAURCHEN TEXANUS).

by

Paul James Barrett

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A Dissertation Submitted to the Faculty of the
DEPARTMENT OF RENEWABLE NATURAL RESOURCES
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In the Graduate College
THE UNIVERSITY OF ARIZONA
1992
As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Paul James Barrett entitled: SPATIAL HABITAT PREFERENCE OF SMALLMOUTH BASS (MICROPTERUS DOLOMIEUI), ROUNDTAIL CHUB (GILA ROBUSTA), AND RAZORBACK SUCKER (XYRAUCHEN TEXANUS) and recommend that it be accepted as fulfilling the dissertation requirements for the Degree of Doctor of Philosophy

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ABSTRACT

Instream Flow Incremental Methodology (IFIM) and Habitat Evaluation Procedure (HEP), require the use of habitat preference curves to model the habitat requirements of fish. The accuracy of these curves has been questioned, particularly when they are applied outside the geographic area for which they were developed.

Depth, velocity, substrate, and cover preference curves were developed for adult and juvenile smallmouth bass (*Micropterus dolomieui*) in Wet Beaver Creek, Arizona, and were compared to those from previous habitat preference studies in Virginia, Oklahoma, and Arizona. Curves for fishes in Wet Beaver Creek also were compared to curves developed using information from the scientific literature.

Additionally, curves were developed for adult and subadult roundtail chub (*Gila robusta*) in Wet Beaver Creek, and adult roundtail chub and razorback sucker (*Xyrauchen texanus*) in Fossil Creek. The curves for adult roundtail chub were compared between these two locations.

Velocity and depth preference curves, for both adult and juvenile smallmouth bass, appeared applicable among locations. Minor differences between the depth curves were attributable
to sampling techniques. Substrate preference curves were not transferrable; smallmouth bass seemed to use whatever substrates were locally available. No conclusion concerning the transferability of cover curves could be made because the definitions used for cover varied widely among investigators.

Depth, velocity and substrate preferences of roundtail chub differed between the two streams studied, even though these streams were in the same drainage. The differences may have been related to the presence of smallmouth bass in Wet Beaver Creek; smallmouth bass were not present in Fossil Creek.

Habitat preference curves based on depth, velocity, substrate, and cover parameters were developed for razorback suckers in Fossil Creek. No curves have been developed previously for razorback suckers in the lower Colorado River Basin; therefore, no comparisons were possible. This species was probably introduced into Fossil Creek and the habitat preference defined in this study may not be representative of razorback suckers throughout their range.

Razorback suckers do not appear to have successfully spawned in Fossil Creek. This lack of success may reflect the absence of suitable habitat or simply indicate the fish have not reached sexual maturity.
INTRODUCTION

Water rights in many of the western states are based on appropriative water law (i.e., the first person or entity to put water to a legal, beneficial use [specifically defined by the law] has senior rights to the water). Leaving water in the stream bed (i.e., instream flows for maintenance of fish and wildlife populations) initially was not recognized as a beneficial use, and the law precluded resource managers from establishing a water right.

In the early 1970's, coalitions composed of conservation groups, state fish and game agencies, federal agencies and legislative groups were successful in adding instream flows for fish and wildlife to the list of recognized beneficial uses. Legal recognition of the need to maintain instream flows forced resource managers to define what constituted necessary instream flows in federal projects. The amount and timing of water releases became controversial. Several techniques were developed to estimate instream flow requirements for fish, wildlife, and riparian ecosystems. These included single flow estimates based on average stream width and pool width (Sams and Pearson 1963), simple hydrological methods such as the Montana method (Tennant 1976) and subsequent modifications (Bayha 1978, Hilgert 1982), and the wetted perimeter method (Collins et al. 1970).
Despite concurrence that environmental factors may limit populations (MacArthur and Pianka 1966, Schoener 1971, Lawlor and Smith 1976, Pyke et al. 1977, Wallace 1987) and that flow requirements needed to be set, there was little agreement on the validity of the early methods for defining appropriate levels of instream flow. This early controversy stimulated a great deal of work defining the relationship between population status and environmental factors. Hoppe and Finnell (1970) and Thompson (1972) recognized that many of the early methods assumed incorrectly that all species required the same types of environment and responded in similar ways to flow modifications. They provided some of the first quantitative information relating flow conditions to habitat requirements of individual species.

The recognition that each species had different habitat requirements as well as the continuing controversy over the establishment of instream flows, led the U.S. Fish and Wildlife Service to develop the Instream Flow Incremental Methodology (IFIM) (Bovee and Milhous 1978). The IFIM was designed to quantify the flows necessary to maintain an aquatic community. This approach assumed that within a particular area, animal populations were always at carrying capacity, that limiting factors for the target species were flow related, and that knowledge of habitat elements could be
related to frequency of occurrence of a given species. Although this approach did not address many of the concerns expressed about earlier methodologies, it formalized the procedures for defining instream flow requirements and was widely adopted.

IFIM required as input, graphical representations (curves) of the relationship between flow related factors and the standing crop of the target species. Initially curves were derived either from information in the technical literature or expert opinion. Additional curves were incorporated into IFIM from the Fish and Wildlife Service Habitat Evaluation Procedures (HEP, U.S. Fish and Wildlife Service 1980). HEP and IFIM both required curves relating physical factors to population characteristics as input; however, HEP related physical factors to biomass, and IFIM related physical factors to frequency of occurrence.

The adoption of IFIM as the principal model for defining requirements for instream flow led to uniform definition of terminology and procedures. The level of "utilization" of a particular environmental setting was defined as the proportion of all fish sampled which were occupying that particular condition (e.g., depth, velocity, substrate type). In contrast, "availability" was defined as the relative proportion, by surface area, of each condition in the study
area. Preference was determined by dividing utilization-availability ratios by the largest utilization-availability ratio calculated. For example, 30 fish out of a total of 100 observed are seen in water 5 m deep. When the study site is mapped, 60 out of 100 point measurements have depths of 5 m. Fish utilization of 5 m depths equals 30/100 or 0.30. Availability of 5 m depths equals 60/100 or 0.60. Fish preference of 5 m depths equals (0.30/0.60)/(largest depth utilization-availability ratio calculated from the data for the study site and species of interest).

Under these definitions, when a species is reported to "utilize" a given condition, it implies that only frequency of use data have been used in the analysis. When a species is reported to "prefer" a given condition, the utilization-availability ratio has been incorporated into the analysis. When either utilization or preference data are graphically represented as either histograms or two dimensional curves, both are referred to as "suitability" curves. When all suitability curves for a species are combined and merged with models of flow conditions or other physical factors, it is referred to as a Habitat Suitability Index or HSI.

Although IFIM has been used widely, biologists are still criticized for not validating the underlying assumptions of the methodology. Currently there are two major controversies
concerning the continued use of IFIM to quantify flow requirements for fishes. The first deals with what factors of the environment limit fish populations. Theoretically, IFIM models have always allowed for inclusion of a suite of factors (including non-physical aspects such as food availability or density of competing species) but in practice, non-flow related factors are seldom incorporated. Many individuals question the assumption that only physical factors limit animals (Mathur et al. 1985, 1986; Leonard and Orth 1988).

A second criticism centers on whether populations are constantly or intermittently constrained by the environment. Generally, IFIM is applied as if populations are always at carrying capacity, but there is considerable debate about whether this is a reasonable assumption. Data collected when populations have been reduced below carrying capacity, might not define real habitat preferences because populations are not limited by the physical characteristics which are occurring when the data are collected. In practice, the times when populations are at carrying capacity are seldom known or data are not available for that period.

Critics of IFIM cite violations of these two assumptions to explain why predictive models based on IFIM generally have not been very reliable. Conder and Annear (1987) used standing
stocks and the Habitat Quality Index (HQI) to test the validity of predictions of Weighted Usable Area (WUA) resulting from the IFIM procedure. They found little correlation between WUA and HQI or standing stock of trout, *Salvelinus* and *Salmo* ssp., except where velocity was the dominant factor in the HQI. They concluded that the HSI procedures needed refinement and that better curves would not improve predictions.


Other researchers have argued that, although the procedure may be inaccurate on any specific evaluation, it can still provide
accurate measures of habitat potential. Gore and Nestler (1988) contended that it was not reasonable to expect good habitat/biomass curves because IFIM habitat-discharge relationships were not linearly correlated to habitat-biomass relationships. Second, they argued that there are nonlinear responses by some organisms to changes in discharge (e.g., some aquatic invertebrates may enter the drift only above a certain threshold velocity). Finally, they believed that most streams were too complex for hydrologic models to offer good predictions of habitat quantity. In spite of these problems, they concluded that IFIM is a useful tool for predicting habitat changes if site specific suitability criteria were developed.

There are some studies that indicate standing crop can be predicted based on physical characteristics of the environment. For example, Weshe and Goertler (1987) obtained reliable predictions of standing stock using multiple regression models containing between two and seven habitat factors. Layher (personal communication) has even obtained reliable predictions of standing stock with one variable models in several streams in eastern Kansas. In streams slated for hydrological modification (channelization, thermal input, etc.) Layher made standing crop estimates prior to that modification. He then estimated which physical factor in the stream would be most modified by the hydrologic action and
predicted standing crop based on habitat suitability curves for that single factor. Samples taken subsequent to the hydrologic modification showed good correlation between predicted and actual standing crops.

Results of this type have caused Layher and Maughan (1984, 1985a, 1987a, 1987b) to argue that evaluations of IFIM should be directed at two questions: 1. Do curves accurately relate habitat parameters to habitat utilization? 2. Do habitat changes result in predictable changes in fish populations? If the curves do not accurately reflect habitat utilization, then the entire methodology is flawed and should be abandoned. However, if the curves reflect real relationships, then they should be able to be incorporated into future efforts to develop predictive models.

When curves were originally constructed, it was thought that a single curve could be applied throughout the range of fish species (Annear and Conder 1984). However, the applicability of curves to areas outside of the range from which they were developed has been questioned (Wegner and Williams 1983, Bowlby and Roff 1986a, Hubert and Rahel 1989). The current study was initiated to determine whether curves developed for smallmouth bass had general application or should be applied on a more limited basis.
There are data to indicate that some curves should not be applied across broad geographic ranges (Wegner and Williams 1983). For example, Annear and Conder (1984) and Leonard and Orth (1988) suggested that differences in hydraulic processes may make it impossible to apply curves developed in large rivers to small streams. Bain et al. (1988) further suggested that large flow fluctuations that are more common in large rivers than in small streams preclude the application of curves between streams of different sizes.

It also has been shown that habitat suitability curves may vary by location. Bowlby and Roff (1986a) showed differences in habitat suitability curves for both rainbow trout, *Salmo gairdneri* (sic) and brook trout, *Salvelinus fontinalis*, between Ontario and Wyoming. They attributed these differences to the importance of groundwater inflow in the two areas.

Predators and competitors are seldom included as elements in the development of habitat suitability curves, but Bowlby and Roff (1986a, 1986b) indicated that differences in predator density explained 62% of the total variation in all fish biomass. Moyle and Baltz (1985) suggested that biological factors sometimes preclude the applicability of habitat suitability curves from one site to another. They cautioned that intraspecific interactions and local changes in physical
habitat characteristics could cause shifts in microhabitat use that could not be incorporated in general habitat curves. Leonard and Orth (1988) hypothesized that stochastic flow events could force an overlap in physical habitat use by several species and cause interspecific interactions and predation to limit populations.

There also are indications that habitat suitability curves for some species can be applied over large geographic areas. Layher and Maughan (1987a) found good comparability between habitat curves for spotted bass (*Micropterus punctulatus*), a habitat specialist, in Kansas and Oklahoma but low comparability for other species. Layher and Maughan (1987b) concluded that curves would more likely be applicable across geographical sites for habitat specialists than for habitat generalists.

The objectives of my study were (1) to determine the general applicability of habitat suitability curves for smallmouth bass (*Micropterus dolomieu*) at several locations across the United States and for roundtail chub (*Gila robusta*) at two locations in Arizona and (2) to use this information to address the question of the applicability of habitat suitability curves between sites.

**Study organisms**
Smallmouth bass originally ranged from Minnesota and southern Quebec to the Tennessee River system in Alabama and west to eastern Oklahoma (Lee et al. 1980). By at least the 1940's, they had been introduced to Arizona (Miller and Lowe 1967).

Historically, roundtail chub inhabited most warm streams within the Colorado River basin, but the extent of their distribution has been greatly reduced in recent times (Minckley 1973). Currently, roundtail chub are considered a threatened species by the State of Arizona (Arizona Game and Fish Department 1988). This classification means that this species could soon be in jeopardy in Arizona.

Both smallmouth bass and roundtail chub seem to prefer pools and eddies with access to cover (Vanicek and Kramer 1969, Covington et al. 1983). Minckley (1973) described a "population explosion" of smallmouth bass in the upper Salt River and its tributaries soon after it was introduced to the river in the mid-1960s. He contended that this explosion is the cause of suppressed reproductive success and declining populations of roundtail chub in the Black River, an upstream branch of the Salt River in eastern Arizona.
Study areas

Smallmouth bass and roundtail chub presently co-occur throughout most of the Verde River drainage. However, Fossil Creek, a tributary of the Verde River (Figure 1), contains roundtail chub but no smallmouth bass. Arizona Public Service, a utility company serving the Phoenix metropolitan area, operates two hydroelectric generating stations on Fossil Creek. Below an impoundment which diverts the flow of the stream at the Irving Power Plant (elev. 1286 m), roundtail chub are sympatric with green sunfish \((\text{Lepomis cyanellus})\). Above this impoundment, roundtail chub exist along with three native species, speckled dace \((\text{Rhinichthys osculus})\), Gila mountain-sucker \((\text{Pantosteus clarki})\), and razorback sucker \((\text{Xyrauchen texanus})\). I studied only the area of Fossil Creek upstream from the Arizona Public Service Irving Power Plant diversion.

Wet Beaver Creek, another tributary of the Verde River, historically was habitat for roundtail chub and continues to support a few individuals. Arizona Game and Fish Department previously stocked smallmouth bass (and perhaps spotted bass) in the creek and bass appear to be reproducing successfully. Arizona Game and Fish no longer stocks bass in the stream but does continue to stock rainbow trout \((\text{Oncorhynchus mykiss})\). Upstream from the trout stocking locations, a United States
Geological Survey weir stream gage (gage 09505200) forms a drop structure which may restrict upstream movement of fish. Above this weir (elev. 1225 m), there is a large population of smallmouth bass, as well as a population of roundtail chub. Roundtail chub historically occurred above the weir. Private individuals likely transferred smallmouth bass above the weir. Diverse environments (e.g., runs, riffles, and pools) exist in both Wet Beaver and Fossil Creeks.

Although the systematics of the Gila complex are problematic, it is likely that the Gila populations in Wet Beaver and Fossil Creeks are the same species and subspecies (W.L. Minckley, personal communication).

Study overview

I developed preference curves for a variety of environmental conditions for smallmouth bass and roundtail chub in Wet Beaver Creek, and curves for roundtail chub in Fossil Creek. The conditions preferred by roundtail chub were compared between the two streams to test the site specific nature of habitat suitability curves of roundtail chub. Habitat suitability curves for smallmouth bass in Wet Beaver Creek were compared to a model of habitat suitability developed for all smallmouth bass (called "the general model") by Edwards.
Figure 1. Study location.
et al. (1983) and specific models of habitat suitability developed by Orth et al. (1982) in Oklahoma, Leonard et al. (1986) in Virginia and Barrett (unpublished data) in Arizona (Appendix A). This comparison was designed to test the site specificity of habitat suitability curves for smallmouth bass. I also evaluated the population structure of, and constructed preference curves for razorback sucker in Fossil Creek (Appendix B).
MATERIALS AND METHODS

I used the definitions of utilization (sometimes called use), availability, and preference given earlier (pages 14-15). In addition, I used English units to specify flow because most state water rights statutes specify instream flows in English units (gallons per minute, cubic-feet per second, or acre-feet per year) and because the majority of the technical literature on instream flow follows this convention.

I selected one sample site on Wet Beaver Creek and one on Fossil Creek. On Wet Beaver Creek, I walked the stream until I identified the location where I could consistently visually observe the highest density of co-occurring smallmouth bass and roundtail chub. I then made underwater verifications of my surface observations concerning density. I selected the riffle, run and pool complex, that included this high density area of co-occurrence, as the study site. This riffle, run, pool complex encompassed about 150 meters of stream. I followed the same procedure for selecting the study site on Fossil Creek, except that I chose the run, riffle and pool area which contained the highest density of roundtail chub.

A transect was established perpendicular to the direction of flow at the downstream end of each study site. Subsequent transects were located at 5-m intervals upstream and parallel
to the initial transect for the entire length of the study site. The amount of available physical habitat was quantified by measuring depth, velocity, substrate, and cover at 1-m intervals along the transects. Depth was measured with a wading rod, and current velocity (ft/sec) was determined at 0.6 of the depth from the water surface to the stream bottom with either a pygmy-Gurley or Marsh-McBirney water current meter. Substrate within a 1-m² area centered on the point was classified according to a modified Brusven index (Appendix C). This index requires a three digit code to define substrate (Bovee 1982). The ten’s place integer refers to the dominant particle size. The one’s place refers to the subdominant matrix, the material surrounding the dominant particles. A decimal place describes the percentage embeddedness of the dominant particles in the subdominant matrix. Cover characteristics were determined within the 1-m² area using the criteria in Appendix D. Although a single depth, velocity, or dominant substrate was recorded for each point, it was possible to record multiple cover types.

The location of sites occupied by individual fish was determined by underwater observation. The time allotted to observation of fish in each of the major environments (e.g., runs, riffles, and pools) was proportional to the amount of that environment throughout the stream (i.e., a modified cluster sampling design of Bovee, 1986). After fish became
accustomed to my presence, (i.e., they neither avoided nor were attracted to me) I placed markers at the locations occupied by individual fish. Stream attributes were measured at each point a fish was observed with the same techniques used to measure habitat availability.

Microhabitat use was compared between smallmouth bass and roundtail chub in Wet Beaver Creek, roundtail chub in Wet Beaver and Fossil Creeks, and different life stages of roundtail chub in Fossil Creek. These utilization (sometimes called category II) data are most appropriate for comparisons within a single stream or study area because all fish are restricted to the same available habitats.

I used univariate F tests to determine whether there were significant differences in the habitats used by 1) smallmouth bass and roundtail chub in Wet Beaver Creek, 2) adult roundtail chub in Wet Beaver Creek and Fossil Creek, and 3) different life stages of roundtail chub in Fossil Creek. The SYSTAT statistical program was used to conduct the univariate F statistics (Wilkinson 1990).

Preference (or category III) curves were produced by grouping preference categories by intervals for a given parameter (Bovee 1986). The procedures used to develop preference curves eliminates information about the variance of each point
on a given curve.

The sample size and variance for habitat use data for each species, life stage, and stream were used to determine the statistical confidence of the sample size used to calculate each curve based on the category ranges (Jakle and Barrett 1988). All curves were produced with sample sizes sufficiently to give 95% confidence that the true mean value of the variable was within the interval range used to construct the preference curves.

Curve smoothing techniques were used to reduce the noise in the data. Depth and velocity curves were smoothed by grouping data into intervals whose sizes were determined by an algebraic formula, known as the Sturges method, based on sample size and the range of the observations (Cheslack and Garcia 1988). The resulting coordinates were subjected to one pass of a three point running mean and all plots and histograms were normalized to index values (range 0.0-1.0) following Cheslack and Garcia (1988). The centerpoints of intervals were used to compare curves between locations and species.

Curves were developed for adult fish of all three species, as well as for subadult roundtail chub and juvenile smallmouth bass. Adult fish were defined as individuals over 150 mm for
roundtail chub and razorback suckers and over 200 mm for smallmouth bass (Lee et al. 1980). In Fossil Creek, roundtail chub range from about 75 to 150 mm and were all "subadults". No subadult roundtail chubs were captured or observed in Wet Beaver Creek.

Statistical techniques for comparing HSI curves violated assumptions for parametric and nonparametric statistics because the curves are not normally distributed and do not represent frequency distributions. Therefore, the curves were compared visually, and a qualitative judgement of similarity was made.

A Chi-square goodness of fit test (Conover 1980) was applied to compare curves of preference for smallmouth bass. This comparison generally requires that the data represent a frequency distribution. Violation of this assumption requires that the test be used only as a general indicator of similarity (personal communication, D. Myers, Univ. of Ariz. Department of Mathematics). Chi-square is based on a ratio of the squared difference between expected and observed occurrences versus the expected occurrences. The denominator of the test statistic is the expected frequency. Because division by zero is not possible, when an expected frequency of zero was encountered, adjacent classes were combined. As a result, the degrees of freedom associated with each run of
the chi-square test varied with life stage and habitat parameter as well as between comparisons.

Each of the studies cited used a different number of substrate categories. However, by using the particle sizes that defined each category in each study, I was able to reassign the data from each study into equivalent substrate categories that I used on Wet Beaver Creek and Fossil Creek.
RESULTS

Smallmouth Bass

Habitat use estimates were based on 219 observations of juvenile fish and 426 observations of adult fish. Habitat availability estimates were based on environmental measures made at 739 transect points.

Preference values were high at low velocities for adult smallmouth bass from Wet Beaver Creek. They declined rapidly as velocities exceeded 0.3 fps and were near zero at velocities > 1.0 fps (Figure 2). Preference values for shallow depths also were low. They reached one at 4.4 ft, then declined rapidly until they reached zero at depths > 9.0 ft (Figure 2).

The preference value was high for sand (0.62-4.00 mm diameter) for adult smallmouth bass in Wet Beaver Creek (Figure 2). However fines (0.00-0.62 mm) had a low preference value. Both sand and fines were characteristic of low velocity areas. The preference value was high for areas with instream cover but low for areas of stream turbulence (Figure 2).

Low velocity areas had a high preference value for juvenile smallmouth bass from Wet Beaver Creek (Figure 3). Preference
Figure 2. Preferences of adult smallmouth bass for selected environmental conditions in Wet Beaver Creek, AZ. Category III curves. SUIT = suitability.
Figure 3. Preferences of juvenile smallmouth bass for selected environmental conditions in Wet Beaver Creek, AZ. Category III curves. SUIT = suitability.
values increased from near zero at shallow depths to one at about 2 ft and then declined steadily until they approached zero at depths > 5 ft (Figure 3).

The preference value for gravel was high for juvenile smallmouth bass from Wet Beaver Creek (Figure 3). Preference values were highest for instream cover, and relatively high for overstream cover and for large and small objects adjacent to cover (Figure 3).

**Comparison of preference values across geographic areas**

Preference values for substrate for adult smallmouth bass from Wet Beaver Creek, were significantly different (P < 0.05) than those from the general curve. Preference values for velocity based on data from the Verde River, Arizona, were also significantly different (P < 0.05) from those based on data from Wet Beaver Creek (Figures 4-6).

Preference values for depth were similar for adult smallmouth bass from all locations (Figure 5, Table 1). They were also similar for velocity at all locations; they were highest at low velocities, then decreased rapidly. Preference values from Virginia peaked at higher velocities than those from other locations (Figure 4). Cobble and larger sized substrates had the highest preference values for adult
Figure 4. Curves of the suitability of different water velocities for adult smallmouth bass developed from 5 data sets. SUIT = suitability.
Figure 5. Curves of suitability of different water depths for adult smallmouth bass developed from 5 data sets. \( \text{SUIT} = \text{suitability.} \)
Figure 6. Histograms of the suitability of different substrates for adult smallmouth bass developed from 5 data sets. SUIT = suitability.

**DOMINANT SUBSTRATE**

- WET BEAVER
- VIRGINIA
- GENERAL
- ARIZONA
- OKLAHOMA
- OKLAHOMA
Table 1. A comparison of the wet Beaver Creek, Arizona model of smallmouth bass preferences for depth, water velocity, and substrate size with four models from other areas based on the chi-square test. D of F equals degrees of freedom; GEN is the Edwards et al. 1983 model; VA is the Leonard et al. 1988 model; AZ is an unpublished model based on data from the Verde River, Arizona; and OK is the Orth et al. 1982 model.

<table>
<thead>
<tr>
<th></th>
<th>GEN</th>
<th>VA</th>
<th>AZ</th>
<th>OK</th>
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<tbody>
<tr>
<td>ADULT</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DEPTH</td>
<td>CHI²</td>
<td>5.59</td>
<td>3.46</td>
<td>3.12</td>
</tr>
<tr>
<td>D of F</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>VEL.</td>
<td>CHI²</td>
<td>0.68</td>
<td>1.89</td>
<td>13.65*</td>
</tr>
<tr>
<td>D of F</td>
<td>9</td>
<td>5</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>SUB.</td>
<td>CHI²</td>
<td>7.72*</td>
<td>10.22</td>
<td>2.56</td>
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<tr>
<td>D of F</td>
<td>2</td>
<td>7</td>
<td>6</td>
<td>3</td>
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<tr>
<td>JUV.</td>
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</tr>
<tr>
<td>DEPTH</td>
<td>CHI²</td>
<td>7.24</td>
<td>7.52</td>
<td>0.52</td>
</tr>
<tr>
<td>D of F</td>
<td>13</td>
<td>12</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>VEL.</td>
<td>CHI²</td>
<td>1.23</td>
<td>1.06</td>
<td>1.93</td>
</tr>
<tr>
<td>D of F</td>
<td>11</td>
<td>10</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>SUB.</td>
<td>CHI²</td>
<td>12.17*</td>
<td>3.38</td>
<td>2.81</td>
</tr>
<tr>
<td>D of F</td>
<td>2</td>
<td>7</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level.
smallmouth bass from all locations except Wet Beaver Creek. Sand had the highest preference value at that location.

Preference values for velocity were not significantly different for juvenile smallmouth bass from any of the areas. In all cases, slow velocities had the highest values (Figure 7).

Chi-square analysis (Table 1) indicated that the preference values for depth were significantly different for juvenile smallmouth bass from Oklahoma than for those from any other location. Most preference values peaked at depths of about 2.5 ft, but the Oklahoma values peaked at depths < 1 ft. After reaching a peak, most preference values declined with increasing depth. However, those based on data from Virginia and from the general curve did not decline as depth increased (Figure 8).

Preference values for substrate for juvenile smallmouth bass in Wet Beaver Creek were significantly different than those based on data from the general curve.

Juveniles in Wet Beaver Creek had the highest preference values for gravel. Data from Virginia showed the highest preference value for small boulders. The other data sets generally showed high preference values for substrates with
Figure 7. Curves of the suitability of different water velocity for juvenile smallmouth bass developed from 5 data sets. SUIT = suitability
Figure 8. Curves of the suitability of different water velocities for juvenile smallmouth bass developed from 5 data sets. SUIT = suitability.
large particle size (Figure 9).

**Roundtail Chub**

**Habitat use by roundtail chub in Wet Beaver Creek**

Estimates of habitat use and habitat preference were based on 85 observations of individual adult roundtail chub in Wet Beaver Creek. I made no quantitative estimates of population size, but I never saw more than 10 individuals during any one survey. Roundtail chub consistently used the deepest (depth > 6 ft), lowest velocity (velocities < 0.25 cfs) portions of the study area. The area most often occupied had a bedrock bottom and was adjacent to a large cliff. There was a deep crevice in the bedrock at the base of the cliff. When disturbed, the chub would swim into this crevice. They also congregated near large shadows and entered these shadows when disturbed.

**Interactions among species in Wet Beaver Creek**

Smallmouth bass used significantly shallower waters and substrates of smaller particle size than did roundtail chub. There were not significant differences in the velocities used.

Adult chub did not display aggressive behavior toward other
Figure 9. Histograms of the suitability of different substrates for juvenile smallmouth bass developed from 5 data sets. SUIT = suitability.
fish. They did not school (no coordinated swimming behaviors), but were consistently located near one another. Water temperature in Wet Beaver Creek ranged from 7 C in the winter to 19 C in the summer. I observed smallmouth bass and roundtail chub during the summer of 1989, but was unable to locate adults of either species the following winter. I did locate a few juvenile smallmouth bass. The following summer, I again found adults of both species at what appeared to be the same numbers as those observed in the summer of 1989.

Habitat preference values for roundtail chub in Wet Beaver Creek

Preference values were high at low velocities for adult roundtail chub from Wet Beaver Creek; velocities > 0.45 fps were not used (Figure 10). Depths of about 7 ft had the highest preference values; values declined rapidly at depths above and below 7 ft. Bedrock had the highest substrate preference value, and large boulders had an intermediate value. The highest preference value for cover was for instream cover.

Habitat use of roundtail chub in Fossil Creek

Estimates of habitat use and habitat preference values for roundtail chub on Fossil Creek were based on 529 observations
Figure 10. Preference of adult roundtail chub for selected environmental conditions in Wet Beaver Creek, AZ. Category III curves. SUIT = suitability.
of individual fish. Fossil Creek contained no smallmouth bass, but did contain several age classes of roundtail chub. Water temperatures in Fossil Creek were 19 C during all seasons, and fish of all size classes were observed throughout the year.

Univariate F tests indicated that adult roundtail chub utilized different depths, velocities and substrates in the two creeks. Adult roundtail chub did not use riffles and shallow areas in Wet Beaver Creek but they did in Fossil Creek. Adult chub in Fossil Creek generally used deep (depth > 6 ft), slow (velocity < 0.33 cfs) waters, but they also occasionally used shallow (depth < 3 feet) and swift (velocity > 1.5 cfs) waters. As in Wet Beaver Creek, chub congregated near shadows and moved into them when disturbed. Univariate F tests indicated that there were significant differences in the occurrence of juveniles and adults across depth, velocity and substrate. These differences were related to the fact that juveniles used riffles more than adults did.

**Interactions among species in Fossil Creek**

I observed no interspecific interactions between the chub and other fish in the stream. Roundtail chub co-occurred with razorback suckers but razorback suckers generally lay on the bottom in deep, slow areas whereas, roundtail chub occupied
mid-water areas in the water column.

Habitat preference values for roundtail chub in Fossil Creek

I combined data for all age classes of roundtail chub in Fossil Creek, and found high preference values for velocities < 1.5 fps and low preference values for those > 1.5 fps (Figure 11). Preference values for depth peaked at 3.2 ft and remained > 0.8 until the depth reached 8.5 ft. They declined at depths > 8.5 ft. Preference values were highest for sand and small boulders but were also relatively high for all substrates except bedrock. All types of cover had high preference values.

Preference values for adult roundtail chub (176 observations) in Fossil Creek were highest at 0.75 fps and then declined gradually until they reached zero at velocities of 3.15 fps (Figure 12). Preference values for depth appeared to be bimodal, with a lesser peak between 3 and 4 ft and the highest values at depths between 7 and 10 ft. The highest preference values for substrate were for small boulders and gravel. Adults had high preference values for any cover but areas adjacent to large instream objects had the highest value.

Subadult roundtail chub in Fossil Creek (350 observations) had high preference values for velocities near 0.5 fps and low
Figure 11. Preference of total roundtail chub for selected environmental conditions in Fossil Creek, AZ. Category III curves. SUIT = suitability.
Figure 12. Preference of adult roundtail chub for selected environmental conditions in Fossil Creek, AZ. Category III curves. SUIT = suitability.
preference values for velocities > 2.0 fps (Figure 13). Preference values were high for depths between 3 and 5 ft, but low for depths > 7 ft. Preference values were high for sand but also relatively high for all substrates except bedrock and large boulders. They were also high for all types of cover.
Figure 13. Preferences of subadult roundtail chub for selected environmental conditions in Fossil Creek, AZ. Category III curves. SUIT = suitability.
DISCUSSION

Comparison of habitats used by smallmouth bass and roundtail chub

Adult roundtail chub used different habitats in Wet Beaver Creek than they did in Fossil Creek. It is possible that these differences are the result of the presence of smallmouth bass in Wet Beaver Creek. Minckley (1973) has hypothesized that smallmouth bass displace roundtail chub in areas of co-occurrence. I can neither verify nor reject this hypothesis. I saw no direct indications that smallmouth bass displace adult roundtail chub; only one interaction was observed.

However, I did see indirect indication of such interactions. Adult roundtail chub in Fossil Creek had high preference values for shallow areas but had low preference values for these same depths in Wet Beaver Creek; shallow depths in Wet Beaver Creek were occupied by smallmouth bass. I was also unable to verify recruitment of juvenile roundtail chub in that portion of Wet Beaver Creek where smallmouth bass and roundtail chub co-occurred. However, juvenile roundtail chub do occur in Wet Beaver Creek above the reaches occupied by smallmouth bass.
There are two possible ways to demonstrate whether interspecific interactions result in differences in habitat use. First, one could remove one species from the stream and then evaluate the habitat used by the remaining species. However, it might be difficult or impossible to remove a species without disturbing the remaining biological components.

The second approach (the one attempted in my study) is to compare habitat preference values for roundtail chub in streams that differ only in species composition. If preference values vary in streams where the only difference is the complement of associated species, it would offer evidence that biological interactions are taking place. Alternatively, if habitat preference values remain the same despite the complement of associated species, it would indicate that biological interactions are not taking place. Although, this approach appears intuitively logical, it is impossible to find streams that differ only in species composition. Wet Beaver Creek and Fossil Creek were in the same drainage and had many of the same of physical features. However, Fossil Creek had constant temperature over all seasons, whereas Wet Beaver Creek experienced the typical temperature variations of the region. Although, these physical differences preclude the conclusion that the presence of smallmouth bass affects habitat preference values for roundtail chub, the differences
in habitat preferences observed do lend credence to the possibility of such interactions.

I do not know where adult smallmouth bass and roundtail chub in Wet Beaver Creek go in the winter. Stream obstructions make it unlikely that they leave the stream. O. E. Maughan (personal communication) has observed aggregations of smallmouth bass in deep pools under organic debris during cold weather. Further investigation of winter habitat selection is needed.

Comparability of smallmouth bass curves

Curves of preference for depth by adult smallmouth bass

All the depth preference values for adult smallmouth bass were generally the same. However, there were differences at the upper limits of these values. The preference values for depth for adult smallmouth bass from Wet Beaver Creek peaked more quickly and dropped off more sharply than did the values from other areas. Smallmouth bass had access to deep water in Wet Beaver Creek, but were rarely observed there. The preference values for depth for adult smallmouth bass from Oklahoma (Orth et al. 1982), also peaked at shallow depths then dropped off sharply at depths > 4 ft. Deep pools were impossible to sample effectively with the gear used in this study (O. E.
Maughan, personal communication). Therefore, the rapid decline in preference values for depth in the Oklahoma data may reflect sampling bias.

The depth preference values from other geographic areas did not drop off as depth increased. The preference values for deeper areas were based on data in the Virginia study, but in most of the other studies the authors simply extrapolated the general form of the curve to depths for which they had limited data (i.e., deep water areas).

In summary, the preference values for depth for adult smallmouth bass appear to be generally similar among the sites analyzed. However, the values given for depths > 4 ft are not entirely substantiated by data.

Preference values for velocity for adult smallmouth bass

In general, the preference values for velocity for adult smallmouth bass were similar among streams. However, the preference values for velocity from the Verde River, Arizona were significantly different from any others. The uniqueness of the preference values from the Verde River may be attributable to the fact that most fish were captured with gill and trammel nets in this study, whereas other studies relied on electroshockers and underwater observations to
obtain data. Trammel and gill nets capture fish by passive interception, and preference values based on these data may reflect movement through rather than preference for a particular habitat condition.

Another possibility is that the size and the flow periodicity of the Verde River are responsible for the uniqueness of the curves from that area. The Verde is a large river and Leonard and Orth (1988) and Bain et al. (1988) have suggested that habitat preference values can not be transferred between large and small streams. However, this explanation is not entirely adequate to explain the differences, because the Virginia preference values, which were similar to values from other areas, were also obtained by sampling a large river.

Bain et al. (1988) have suggested that differences in flow periodicity may also preclude the application of preference values across geographic areas. Differences in flow periodicity might explain the variation between preference values from Wet Beaver Creek and the Verde River (except for snow melt, Wet Beaver Creek has a fairly constant flow of about 7 cfs, whereas the Verde River has much greater flow variation).

In spite of the differences discussed, all of the preference values for velocity had the same general pattern; high at low
velocity, dropping off sharply as velocity increases. I believe that the differences between the preference values from the Verde River and those from other areas are largely a function of sampling technique. I would suggest that the most reliable values are those based on underwater observation, the next most reliable are those based on active capture techniques, and the least reliable are those based on passive capture techniques.

Preference values for substrate for adult smallmouth bass

The lack of congruence in the substrate categories among the various studies limited my ability to compare preference values for substrate among sites. However, there are several reason to question the transferability of preference values for substrate among areas. Several authors, including those that produced the general preference values, suggested that sand provides unsuitable substrate for adult smallmouth bass. However, smallmouth bass had a high preference value for sand in Wet Beaver Creek. This high preference value for sand in Wet Beaver Creek, may be a function of local geology. Wet Beaver Creek flows through sandstone and sand is the predominant substrate. In addition, my underwater observations indicated that fish were responding to depth, velocity, and cover rather than substrate. For example, fish that I disturbed, ultimately returned to that site, even if I
altered the substrate.

Preference values for depth for juvenile smallmouth bass

The preference values for depth for juvenile smallmouth bass varied only slightly. Preference values from Virginia and the general study were higher at greater depth than they were in Wet Beaver Creek or Oklahoma. It is possible that the failure to sample deep waters biased the preference values at depths > 4 ft in the Oklahoma data. Differences in preference values between Oklahoma and Wet Beaver Creek may result from the curve smoothing techniques used in each study and the limitations of Chi-square analysis. The data used for Wet Beaver Creek were the midpoints of habitat use categories. These midpoints were obtained by subjecting the raw data to the Sturges method and subsequently smoothing the curve as discussed earlier. Depth categories were combined to allow the incorporation of depths designated as unsuitable in the Oklahoma curves. Consequently, the chi-square analysis of depth preferences for juvenile smallmouth bass in Wet Beaver Creek and Oklahoma, only had 4 degrees of freedom. The degrees of freedom ranged from 6 to 13 for the other comparisons.

Preference values for velocity for juvenile smallmouth bass
Preference values for velocity for juvenile bass were very consistent among geographic areas, and are probably applicable among locations. Since juvenile fish are generally more restrictive in their habitat preferences than adults, these data would tend to support Layher and Maughan (1987b) who concluded that preference values for habitat specialists have more general applicability than do those for habitat generalists.

Preference values for substrate for juvenile smallmouth bass

The preference values for substrate for juvenile smallmouth bass showed little consistency over space. Therefore, I do not recommend the general application of these values. Underwater observations in Wet Beaver Creek consistently indicated juvenile bass sought refuge in the interstitial spaces between gravel particles. These observations contrasted with those from other studies which showed either high preference values for larger substrates or no substrate preferences.

This discrepancy in preferences values for substrate could result from a combination of factors that were unique to Wet Beaver Creek. Deep water in Wet Beaver Creek usually had a substrate of fractured bedrock and boulders imbedded in sand. Shallow water had either a silt or a gravel substrate over
sand. Juvenile smallmouth bass seeking shallow, low velocity water were restricted in their choices. When given the choice between larger refuges in deep, high velocity pools and smaller refuges in shallow, low velocity habitats, smallmouth bass chose the latter.

Comparability of preference values for roundtail chub

Preference values for depth for adult roundtail chub

Adult roundtail chub utilized shallower water in Fossil Creek than in Wet Beaver Creek. It is possible the difference in the physical conditions between the two creeks were responsible for differences in the habitat selected. Wet Beaver Creek had a constant discharge of 7 cfs while Fossil Creek’s discharge was 43 cfs. Water temperature in Fossil Creek was 19 C year round whereas temperatures in Wet Beaver Creek varied seasonally, approaching the temperature seen in Fossil Creek only during the summer. Neither adult smallmouth bass or roundtail chub could be located during the winter when water temperatures were 7 C in Wet Beaver Creek, whereas chub were visible year round in Fossil Creek.

Another possibility is that the two populations actually have different habitat preferences. At the initiation of this study, these populations were considered to be different
subspecies (Lee et al. 1980). Subspecies sometimes differ in the habitats that are selected. However, this possibility now seems remote. Recent investigation of the systematics of the Gila complex has led W.L. Minckley (unpublished data) to conclude that both populations belong to the same undescribed Gila species.

**Preference values for velocity for adult roundtail chub**

Adult roundtail chub in Fossil Creek preferred swifter water than they did in Wet Beaver Creek. The explanations given above for difference in depth selection may also explain the difference in preference values for velocity.

**Preference values for substrate for adult roundtail chub**

In Wet Beaver Creek, adult roundtail chub preferred bedrock over all other substrates, whereas in Fossil Creek they preferred small boulders. These differences could be a function of the limited quantity of bedrock substrate in Fossil Creek. There were high preference values for instream overhead cover in Wet Beaver Creek, whereas preference values were high for all types of cover in Fossil Creek. I have no explanation for the differences in habitat preference values between the two streams.
Biological constraints to the use of preference values for adult roundtail chub

The absence of recruitment to the roundtail chub population in Wet Beaver Creek indicates that the population is not doing well and that the preference values obtained may be suspect. Absence of recruitment could be due either to habitat loss, competition with other species, or predation. Minckley (1973, 1983) has suggested that habitat alteration, in conjunction with the introduction of non-native species, is a major cause of the loss of native southwestern fishes. Habitat alterations usually are the direct result of the manipulation of water discharge through diversions or impoundments, but they can also be the result of changes within the terrestrial portion of the ecosystem with secondary effects on the aquatic aspects through changes in water quality and increased infiltration of precipitation (Dunn and Leopold 1978).

Flow reduction can reduce the habitat necessary to sustain a fish population (Tyus 1990). Similarly, increased flows can reduce some habitats (e.g., slackwaters). Velocity changes of any type can, in combination with local geology, alter the substrate and thus affect foraging and spawning success. Even if mean or median flows remain unchanged, the loss of annual flooding events or other variations in flow regime can affect spawning and recruitment of fishes (Tyus 1990, Grossman et al.
Most of the flow alterations mentioned above are the result of diversions or regulated flows released from impoundments. Both the Wet Beaver and Fossil Creek study sites were selected because they were above all diversions. Furthermore, both sites were within federally designated wilderness areas that precluded extensive resource development within the watersheds.

There are physical differences between the sites, notably, geology, annual water temperature extremes, and flow regimes. However, the fact that healthy roundtail chub populations have existed in both streams in the past indicates that these differences do not preclude Wet Beaver Creek from maintaining a roundtail chub population. The relative isolation of the areas and the lack of water regulating structures upstream from my study sites lead me to conclude that physical habitat loss in Wet Beaver Creek cannot explain the failure of roundtail chub recruitment.

Coexisting species in each stream may have caused shifts in preference values of adult fish. Smallmouth bass in Wet Beaver Creek may utilize some of the same resources as roundtail chub. If these resources are in limited supply, such interaction could lead to displacement of one species by
the other in some environments. There is evidence to support
the idea of interactions between these two species; Minckley
(1973) observed a decline in the roundtail chub population in
the Salt River drainage following the introduction of
smallmouth bass. However, in other areas, (e.g., the upper
Verde River, Arizona) smallmouth bass apparently co-exist with
native species (P. Barrett, unpublished data).

Many mechanisms have been suggested to explain how introduced
fishes reduce the numbers of natives fishes. Crowder et al.
(1981) demonstrated that following the establishment of
alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus
mordax*) in Lake Michigan, only those native fishes with little
dietary overlap with the introduced species remained common.
McComas et al. (1982) contended that dietary overlap alone
explained why the introduced inland silverside (*Menidia
beryllina*) replaced the brook silverside (*Labidesthes
sicculus*) in Lake Texoma, Oklahoma. Gatz et al. (1987)
compared habitat use by rainbow trout (*Oncorhynchus mykiss*) in
the presence and absence of brown trout (*Salmo trutta*) and
contended that there was strong evidence of competition
between the species. Despite the general acceptance of
competition as an influence of habitat utilization, there have
been few, if any, controlled experiments demonstrating
competition between fishes native to the Southwest.
Diamond (1978; 1983) argues that three experimental approaches yield evidence of competition: laboratory experiments, field experiments and natural experiments. He believes that none of the three experimental types is superior to the others and each should complement the other.

Laboratory experiments are the most controllable and the least like natural conditions, because they allow researchers to modify a single factor. This approach may offer the most statistically valid evidence of competition, but such experiments usually exclude many of the factors that may limit a species. Furthermore, it may be difficult to maintain laboratory populations for the number of generations necessary to obtain evidence of competition.

Field experiments (i.e., the manipulation of populations) are more natural than laboratory experiments. However, the outcome may vary with year, season or location, depending on the local and temporal variables such as weather or resource abundance. Experiments may not continue for enough generations to test for the influence of temporal variation which may be critical in allowing a small number of individuals of one species to gain a foothold in a new area. Species interactions other than those studied also may result in community changes which further influence resource abundance. Finally, populations of federally listed
threatened or endangered species are protected from many of these proposed manipulations.

Diamond (1983) contends that natural experiments (i.e., the study and comparison of changes in local communities) have some inherent advantages. He argues that they allow data to be gathered far more quickly than is possible by field experiments. He also believes that natural experiments permit researchers to examine situations which would be impossible to manipulate with field experiments (e.g., it is difficult to remove an entire rodent species from a mountain range, but a suspected competitor could be introduced or colonize a mountain range which lacks the former species). Finally, natural experiments reveal the end result of ecological and evolutionary processes operating over long time periods.

Although objections have been raised to interpreting niche shifts as evidence of competition (Connell 1975), Diamond (1983) states:

"In science, one can never rule out the possibility that a phenomenon is due to some unspecified factor rather than to an observed correlation: the best one can do is to strengthen the observed correlation and weaken likely alternatives."
My observations with smallmouth bass and roundtail chub are a mixture of natural and field experiments as defined by Diamond (1983). Although I did not manipulate the populations in the field, smallmouth bass have been in Wet Beaver Creek for about 20-30 years (R. Clarkson, AGFD, personal communication). This is a long period by experimental standards, yet short by ecological and evolutionary measures.

Based on the circumstantial evidence obtained in my study, and the observations by others that the introduction of smallmouth bass is often associated with a concurrent decline in roundtail chub populations, I conclude that the presence of smallmouth bass may cause shifts in the habitat used by roundtail chub. An exact mechanism cannot be presented for this suspected interaction, but laboratory experiments such as those suggested by Diamond (1978, 1983) and Moyle and Balts (1985) might identify the mechanism.

In addition, Maughan (personal communication) has suggested using presence or density of potential predators/competitors as a habitat factor. Now seems the time to incorporate such factors into studies of habitat preference values.

Preference values for depth for juvenile roundtail chub

The absence of juvenile roundtail chub in Wet Beaver Creek
precluded any comparisons of habitat preference values for juveniles. However, it was possible to compare preference values for juveniles in Fossil Creek with adults in both streams. Juvenile roundtail chub in Fossil Creek had higher preference values for shallow water than did adults in either stream. The tendency for juveniles to occupy shallower water than conspecific adults has been documented for many species. Such differences in adult and juvenile preferences may limit either competition or conspecific predation.

Preference values for velocity for juvenile roundtail chub
Juveniles in Fossil Creek had higher preference values for low velocity than did adults from either stream. The explanations made earlier to explain differences in depth selection between juveniles and adults has equal validity here.

Biological constraints to the use of preference curves for juvenile roundtail chub

The preference values for juvenile roundtail chub were based on data from a single population. Furthermore, the data indicated that preference values differed for adults of the same species in the two streams. The limited nature of these data and the fact that there was no consistency in habitat preference values for adults indicates that the preference values obtained on Fossil Creek must be applied cautiously.
outside of that stream.

General considerations concerning preference value comparisons between areas

Habitat preference values are very difficult to compare with existing methodologies. Subjective visual comparisons and Chi-square tests were the primary tools I used to compare curves. Chi-square assumes a frequency distribution is being tested. This assumption is violated when preference data (use data divided by availability data) are used. In addition, the limited number of degrees of freedom in my data make it difficult to draw rigorous statistical conclusions. However, the results do give a general indication of similarities or differences between depth and velocity curves.

Another problem is created by the subjectivity involved in reclassifying substrate data between studies and combining categories to eliminate division by zero. Chi-square analysis was not appropriate for comparing substrate histograms.

These problems have been long recognized by biologists and statisticians. John Kittleson (Consulting Statistician, University of Arizona, personal communication) is developing new approaches for comparing suitability curves. Such techniques are needed if we are to understand the degree of
applicability to new geographic areas of these curves.

Despite the difficulties I encountered, my data indicated that preference values for depth and velocity for adult smallmouth bass were applicable between areas, but that those for other variables were not. Conversely, in the two streams I studied, preference values for roundtail chub were not applicable to streams other than those from which they were developed. These data could be interpreted to mean that habitat preference values are little affected by the occurrence of other species in a species rich environment, but can be greatly affected in a species poor environment. If such an interpretation is true, it would allow preference values for species from species rich areas to be applied more confidently outside the area for which they were developed.

The data for this study can also be interpreted to support the contention of Layher and Maughan (1987b) that the preference values for habitat specialists are more applicable across large geographic areas than are those for habitat generalists. Smallmouth bass, although they are widely distributed, are generally considered to be somewhat restricted in their habitat tolerances. Roundtail chub, although they are geographically restricted in distribution, are habitat generalists. Data collected in this study indicate that the degree of habitat specificity of a species, as well as the
level of species diversity of the area in which an organism lives must be considered in determining the applicability of habitat preference values.
Preference values for velocity developed for juvenile smallmouth bass seem readily applicable among different geographic areas. Juvenile smallmouth have more restrictive velocity requirements than do adults. Layher and Maughan (1987b) have previously concluded that the preference values for stenohabitat species are more likely to be generally applicable to areas other than those from which they were developed, than are preference values for euryhabitat species.

Preference values for depth for juvenile smallmouth are generally applicable to areas other than those from which they were developed, but the upper limits need better definition. The Virginia preference values have no upper depth limit, whereas the general values suggest occupation of depths up to 6 ft. Preference values from the Wet Beaver and Verde Rivers suggest an upper limit of about 4 ft and those from Oklahoma suggest no upper limit.

The preference values for substrate for juvenile bass appear to be site specific and should probably not be used outside of the area for which they were calculated.
In general, the preference values for depth and velocity for adult smallmouth bass are applicable to areas other than those from which they were developed. However, the Wet Beaver Creek data are the only data which I feel accurately quantifies the upper limit of depth preference by adult smallmouth bass. Before the Wet Beaver preference values are applied to large rivers, further investigation is needed.

Roundtail chub preferences differed between the two sites studied and values should not be applied to areas other than those from which they were developed. Although evidence implied that smallmouth bass caused the changes in roundtail preferences, laboratory studies would be required to verify this hypothesis.
APPENDIX A. ADULT AND JUVENILE SMALLMOUTH BASS CURVES DEVELOPED FROM PREVIOUS STUDIES.
Figure A1. Preferences of adult smallmouth bass for selected environmental conditions. Data are from Barrett et al. 1988. Category III curves. SUIT = suitability.
Figure A2. Preferences of juvenile smallmouth bass for selected environmental conditions. Data are from Barrett et al. 1988. Category III curves. SUIT = suitability.

![Graph 1: Depth vs. Suitability](image)

![Graph 2: Velocity vs. Suitability](image)

![Bar Graph: Dominant Substrate vs. Suitability](image)
Figure A3. Preferences of adult smallmouth bass for selected environmental conditions. Data are from Leonard et al. 1986. Category III curves. SUIT = suitability.
Figure A4. Preferences of juvenile smallmouth bass for selected environmental conditions. Data are from Leonard et al. 1986. Category III curves. SUIT = suitability.
Figure A5. Preferences of adult smallmouth bass for selected environmental conditions. Data are from Edwards et al. 1983. Category III curves. SUIT = suitability.
Figure A6. Preferences of juvenile smallmouth bass for selected environmental conditions. Data are from Edwards et al. 1983. Category III curves. SUIT = suitability.
Figure A7. Preferences of adult smallmouth bass for selected environmental conditions. Data are from Orth et al. 1981. Category III curves. SUIT = suitability.
Figure A8. Preference of juvenile smallmouth bass for selected environmental conditions. Data are from Leonard et al. 1981. Category III curves. SUIT = suitability.
APPENDIX B: SPATIAL PREFERENCE AND POPULATION STRUCTURE OF THE
RAZORBACK SUCKER (XYRAUCHEN TEXANUS) POPULATION OF FOSSIL
CREEK, ARIZONA.
The razorback sucker (*Xyrauchen texanus*) was once common throughout the lower Colorado River basin, but its populations have declined dramatically during the last century (Minckley 1973). Although the reasons for this decline are not known, Minckley (1983) has speculated that a combination of habitat destruction and the introduction of exotic fishes has contributed to the problem.

In 1981, biologists agreed that the razorback sucker was in danger of extinction, but agencies and interest groups agreed to a 10-year delay in listing under the Endangered Species Act (G. Divine, USFWS, personal communication). The moratorium was enacted to allow propagation and repatriation of the fish without the bureaucracy encountered during attempts to reestablish other listed fishes. It was hoped that the 10-year period would be sufficient to demonstrate the initial recovery of the species and that listing the fish would not be necessary. The species is currently artificially propagated and has been introduced within portions of the Salt and Gila River drainages (D. Hendrickson, AGFD, personal communication). Successfully reproducing populations have yet to be established in the wild.
The moratorium is about to expire and the razorback sucker was proposed for listing as endangered in the Federal Register on May 22, 1990 (CFC vol. 55, no. 99).

Although Fossil Creek has been studied since at least 1904 (Chamberlain 1904), razorback suckers were not found in the stream until this study in 1989. Previously only three species, *Pantosteus clarki*, *Rhinichthys osculus* and roundtail chub were reported in this headwater area (Neve 1976; C. Minckley, personal communication).

It is possible that razorback sucker are native to the area and represent a reproducing population, but it is more probable that these fish are the product of recent stockings. Arizona Game and Fish Department has stocked razorback suckers in Fossil Creek, but the exact location (i.e., whether above or below the impoundment) is unclear (Dean Hendrickson, personal communication).

Two points make the study of this population important. First, even if introduced as fingerlings by the Arizona Game and Fish Department, the size of the fish indicates that the creek is suitable for adult survival and growth. Second, when the species is listed as threatened or endangered, the Fossil Creek population will receive full protection under the
Endangered Species Act.

MATERIALS AND METHODS

Techniques identical to those used for the analysis of habitat use of the smallmouth bass and roundtail chub populations on Wet Beaver and Fossil Creeks were used to gather data and produce preference curves for the razorback sucker population.

Habitat use data (31 observations) for razorback suckers were taken during the Spring of 1990. Capture depletion methods were used to make population estimates for razorback sucker. The length of stream above the dam is limited and contains only one large pool. On 17 and 18 September, 1990, upper Fossil Creek was sampled using a trammel net and a backpack shockers. A 60-ft trammel net was set and run at 4-hour intervals for 24 hours. Fish removed from the net were weighed and measured, but we were unable to sex them in the field. Captured fish were held in floating live cars within the stream.

Backpack shockers were used to sample the riffle areas for smaller razorback suckers. I reasoned that the presence of juvenile razorback suckers would be indicative of reproduction.
RESULTS

Before I set the net, I swam an underwater transect in pool and adjacent run and riffle. I counted 73 roundtail chub, 11 Gila mountain-suckers (*Pantosteus clarki*), and one razorback sucker. We caught 13 razorback suckers in the trammel net over a 24-hour period (Figure B1, Table B1). We caught more razorback sucker than any other species; five roundtail chub and 12 Gila mountain-suckers were captured. The depletion estimate of population size was 16 razorback suckers; the $r^2$ for this regression was 0.37. All netted fish appeared healthy, with no obvious physical problems (e.g., lesions, disease, lordosis). Razorback suckers were measured and weighed in an effort to discern age classes (Figures B2 and B3).

Electroshocking the riffles and other shallow areas produced no juvenile razorbacks, although juvenile chub, mountain suckers and adult speckled dace were captured.

The sample size for the velocity data for razorback sucker was sufficiently large that I was 95% confident that the true mean value of the velocity preference for a given interval was within the interval range. The sample size for depth data was sufficiently large that I was 80% confident
Figure B1. Razorback sucker depletion sampling effort.
Four hour net intervals, September 17 - 19, 1990, Fossil Creek, AZ.

r-squared = 0.37
X intercept = 15.5
Table B1. Depletion sampling data for fish captured with trammel nets from Fossil Creek, AZ, September 17 - 18, 1990.

<table>
<thead>
<tr>
<th>Hours set</th>
<th><em>X. taraxus</em></th>
<th><em>P. clarki</em></th>
<th><em>G. robusta</em></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>-</td>
<td>5</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
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<td>9</td>
</tr>
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<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
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<tr>
<td>20</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>24</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Total fish captured = 30
Figure B2. Razorback sucker length data from Fossil Creek, AZ.
Figure B3. Razorback sucker weight data from Fosail Creek, AZ.
that the true mean value of the depth preference for a given interval was within the interval range. Velocities < 1.0 fps had relatively high preference values and 0.5 fps had the highest value (Figure B4). Depths between 5 and 9 ft had relatively high preference values, and 6.6 ft had the highest value. Fines had the highest preference value for substrates, but both small and large boulders and bedrock had relatively high values. Sand and gravel were not utilized. Razorbacks suckers tended to position themselves adjacent to large, instream cover and instream overhead cover. Therefore, preference values for cover were high for these types of structure. All other types of cover also had relatively high preference values.

DISCUSSION

The disparity between visual counts of razorback suckers (1) and trammel net captures (13) is a result of the tendency of the suckers to position themselves under rooted aquatic vegetation. This behavior makes them difficult to see.

Juvenile razorback suckers were not taken from upper Fossil Creek. Razorback suckers begin reproduction when they reach approximately 350 mm total length (W.L. Minckley, personal communication). The largest adults collected in Fossil Creek were only 280 mm. Either the fish have not reached
Figure B4. Preferences of razorback sucker for selected environmental conditions in Fossil Creek, AZ. Category III curves. SUIT = suitability.
sufficient size/age for spawning, or suitable spawning habitat does not exist in Fossil Creek, or all young fish are lost subsequent to the adult spawn. Future studies of this population will be needed to determine if razorback suckers will be able to successfully recruit juveniles to the population.

There were no discernable length categories of razorback sucker (Figure B2), but there were two distinct weight classes (Figure B3), fish < 130 g and fish > 210 g. In the absence of any evidence of recruitment, it is probable that either two different age classes were stocked, or individuals within the Fossil Creek population of razorback suckers have differential growth rates.

The preference values I developed for razorback suckers are the only ones for lower Colorado River populations. However, they should be used cautiously because they are based on limited data and are probably from an introduced population. Minckley (1983) suggests that a combination of habitat alteration and competition with exotic species has led to the disappearance of razorback sucker from many locations. No exotics were present in Fossil Creek so that these preference may serve as a baseline for areas with populations of native fishes. In areas where there are exotic predators and competitors, the applicability of these preference would be
questionable. Should preference values developed at other lower basin sites verify the relationships shown here, the likelihood that the preference values have predictive value for other sites would be enhanced.

CONCLUSION

Subadult razorback suckers survive in Fossil Creek but our inability to locate any juveniles and the virtual absence of size classes leads me to conclude that razorback suckers have not successfully reproduced there, or young razorback suckers were lost before they were recruited to the population.

The preference values developed for razorback suckers within the Fossil Creek study area are important because they represent the only habitat information from the lower basin. However, until more information is available it is impossible to generalize the applicability of these values. Therefore, the use of these curves beyond Fossil Creek should be done cautiously.
APPENDIX C. SUBSTRATE CLASSIFICATIONS.
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<thead>
<tr>
<th>Code</th>
<th>Substrate</th>
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<tr>
<td>1</td>
<td>Fines (silt, detritus)</td>
</tr>
<tr>
<td>2</td>
<td>Sand</td>
</tr>
<tr>
<td>3</td>
<td>Small gravel (4-25 mm)</td>
</tr>
<tr>
<td>4</td>
<td>Large gravel (25-75 mm)</td>
</tr>
<tr>
<td>5</td>
<td>Cobble (75-200 mm)</td>
</tr>
<tr>
<td>6</td>
<td>Small boulder (200-600 mm)</td>
</tr>
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<td>7</td>
<td>Large boulder (&gt; 600 mm)</td>
</tr>
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<td>8</td>
<td>Bedrock</td>
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APPENDIX D. COVER CLASSIFICATIONS.
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</thead>
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<td>No cover</td>
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<tr>
<td>Instream overhead cover</td>
<td>Y/N</td>
</tr>
<tr>
<td>Offstream overhead cover</td>
<td>Y/N</td>
</tr>
<tr>
<td>Adjacent to small (&lt; 150 mm) instream cover</td>
<td>Y/N</td>
</tr>
<tr>
<td>Adjacent to large (&gt;150 mm) instream cover</td>
<td>Y/N</td>
</tr>
<tr>
<td>Under surface turbulence</td>
<td>Y/N</td>
</tr>
</tbody>
</table>
LITERATURE CITED


Orth, D.J. and O.E. Maughan. 1982. Evaluation of the incremental methodology for recommending instream flows


