DEVELOPMENT AND EVALUATION OF HABITAT SUITABILITY CRITERIA FOR NATIVE FISHES AND ASSESSMENT OF THE RELATIONSHIP AMONG RIPARIAN AREAS AND STREAM MACROHABITAT TYPE AND FISH PRESENCE IN FOUR CENTRAL ARIZONA STREAMS

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As members of the Master's Committee, we certify that we have read the thesis prepared by **Zach Nemec**, titled **Development and Evaluation of Habitat Suitability Criteria for Native Fishes and Assessment of the Relationship Among Riparian Areas and Stream Macrohabitats Type and Fish Presence in Four Central Arizona Streams** and recommend that it be accepted as fulfilling the thesis requirement for the Master's Degree.

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TABLE OF CONTENTS

LIST OF TABLES

Chapter 1. Development and Evaluation of Habitat Suitability Criteria for Native Fishes in Four Arizona Streams

Chapter 2. Assessment of the Relationship Among Riparian Areas and Stream Macrohabitats Type and Fish Presence in Four Central Arizona Streams

LIST OF FIGURES

Chapter 1. Development and Evaluation of Habitat Suitability Criteria for Native Fishes in Four Arizona Streams

ABSTRACT

Habitat loss is an important reason for fish fauna declines in the southwestern U.S. Several studies have defined habitat conditions for selected native fish species in Arizona, yet habitat use can vary across streams due to a variety of biological and physical factors. In addition, previous studies have focused on effects of instream habitat characteristics and less on how riparian areas structure aquatic communities of the Southwest. Riparian areas affect aquatic communities in a variety of ways, including structuring instream habitat. Macrohabitat (riffle, run, pool) is an important determinant of fish use, and little is known about the effect of riparian vegetation and associated land use activities on the formation of macrohabitat. Therefore, the objectives of my study were to 1) evaluate suitable habitat for native Arizona species, and 2) to investigate the relationships among riparian vegetation and stream macrohabitats type and fish presence in four central Arizona streams. Fish and habitat data were collected in four streams along the Mogollon Rim in Arizona during the 2017 summer field season at base flow conditions. I used the National Hydrography Dataset (NHD) and National Agricultural Imagery Program (NAIP) aerial imagery to estimate the amount of vegetation cover within the riparian areas of each stream. I developed habitat suitability criteria for four native species in three streams. Most generalized criteria did not transfer among study streams, similar to finding from past studies suggesting that stream-specific criteria were more accurate. I found that Smallmouth Bass and Red Shiner had a negative relationship to canopy cover, possibly explained by high temperature tolerances of both species. Desert Sucker and Speckled Dace presence were positively related to presence of riffle habitat, as has been noted in previous habitat studies. Riffle habitat was positively related to increases in riparian vegetation cover. These results can inform researchers, agencies and stakeholders who study and manage Arizona’s riparian areas and instream habitat.

CHAPTER 1. Development and Evaluation of Habitat Suitability Criteria for Native Fishes in Four Arizona Streams

INTROUDUCTION

The endemic fishes of the southwest United States, specifically Arizona, have rapidly declined over the past several decades due to anthropogenic stressors such as water quality degradation, flow regime and other habitat manipulation, and introduction of non-native aquatic organisms (Miller et al. 1989; Minckley and Deacon 1991; Propst et al. 2008). To successfully manage these native populations, it is critical for agencies to distinguish habitat conditions these species are known to occupy and then manage or restore streams to promote these conditions. Studies have defined habitat conditions for several native fish species in Arizona, yet were evaluated on a broad macro/mesohabitat scale (i.e. pool, riffle, run) rather than specific quantitative measurements of specific habitat variables (Ivanyi 1989; Rinne 1991; Rinne 1992; Neary et al. 1996; Paroz et al. 2006; Rinne and Miller 2006). For some species, specific quantitative measurements of certain habitat variables have yet to be determined.

Specific quantitative measures of habitat conditions for native fishes can be derived through the development and evaluation of habitat suitability criteria (HSC). HSC are defined as the range of values for certain habitat variables utilized by a species (Bovee 1986). Habitat suitability criteria can be developed and evaluated for an individual stream (stream-specific HSC) or across multiple streams (generalized HSC). Stream-specific HSC are more effective in assessing fish habitat use than generalized HSC (Maki-Petays et al. 2002), although generalized HSC are more cost effective to develop compared to stream-specific HSC. This is because habitat occupancy for a certain fish species can vary among streams due many factors, including the presence of other fish species, lack of habitats being occupied at full carrying capacity, or physical differences between streams (Bozek and Rahel 1992). Therefore, it is critical to develop both types of HSC and evaluate their respective abilities to define which habitat conditions can be used to manage a particular species. Both types of HSC have been developed for several native Arizona fish species (Bonar et al. 2010; Petre and Bonar 2017) In addition, HSC have been applied in many instream flow studies across geographic areas (Barrett and Maughan 1995; Jowett 2002; Strakosh et al. 2003; Waddle and Bovee 2010).

The objectives of my study were to: (1) develop stream-specific and generalized HSC for select native Arizona fish species; (2) examine how habitat use varies with presence of other fishes; and (3) compare variability of HSC's for selected species among streams through measures of transferability.

METHODS

Study Sites

My study encompassed four streams (Blue River, Eagle Creek, Tonto Creek, and Verde River) located in central Arizona off the Mogollon Rim (Figure 1.1). Study streams were selected based on prioritization by professionals from the U.S. Fish and Wildlife Service (USFWS), U.S. Forest Service (USFS), Arizona Game and Fish Department (AZGFD), and University of Arizona's School of Natural Resources (UA SNRE).

The Blue River is an 81-km stream that starts outside of Alpine, Arizona at an elevation of 2000-m and flows south into San Francisco River. Average discharge in the Blue River ranges from 0.27 to 4.30 m^3/s (U.S. Bureau of Reclamation 2010). The riparian area of the Blue River comprises Narrowleaf Cottonwood *Populus angustifolia*, Fremont's Cottonwood *Populus fremontii*, Goodding's Willow *Salix gooddingii*, Arizona Sycamore *Platanus wrightii*, Walnut

Juglans spp., Arizona Alder *Alnus oblongifolia*, Willow *Salix* spp., Seepwillow *Baccharis salicifolia*, and Ponderosa Pine *Pinus ponderosa* (U.S. Bureau of Reclamation 2010). Native fish that have been captured in Blue River include Desert Sucker *Catostomus clarkii*, Sonora Sucker *Catostomus insignis*, Roundtail Chub *Gila robusta*, Loach Minnow *Rhinichthys cobitis*, Spikedace *Meda fulgida*, Speckled Dace *Rhinichthys osculus*, and Longfin Dace *Agosia chrysogaster* (U.S. Bureau of Reclamation 2010). Non-native fish that have been captured in the Blue River include Largemouth Bass *Micropterus salmoides*, Red Shiner *Cyprinella lutrensis*, Common Carp *Cyprinus carpio*, Flathead Catfish *Pylodictis olivaris*, Channel Catfish *Ictalurus punctatus*, Fathead Minnow *Pimephales promelas*, Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, Brook Trout *Salvelinus fontinalis*, Western Mosquitofish *Gambusia affinis*, and Green Sunfish *Lepomis cyanellus* (U.S. Bureau of Reclamation 2010).

Eagle Creek is an 84-km stream located in southeast Arizona (Marsh et al. 1991). Perennial reaches occur between the south slopes of the White Mountains in eastern Arizona at an elevation of 2800-m and the confluence of the Gila River. Average discharge in Eagle Creek is 0.94 m^3/s (Minckley and Sommer 1979). Riparian areas in the upper reaches of Eagle Creek support a mix of Fremont’s Cottonwood, Goodding’s Willow, Arizona Sycamore, and Walnut while lower reaches are dominated by Seepwillow and Burrobush *Hymenoclea monogy* (Marsh et al. 1991). Historically, the native fish of Eagle Creek has included Desert Sucker, Sonora Sucker, Razorback Sucker *Xyrauchen texanus*, Roundtail Chub, Loach Minnow, Spikedace, Speckled Dace, and Longfin Dace (Marsh et al. 1991). Several non-native species have been introduced such as Largemouth Bass, Smallmouth Bass *Micropterus dolomieu*, Yellow Bullhead *Ameiurus natalis*, Red Shiner, Common Carp, Flathead Catfish, Channel catfish, Fathead Minnow, Rainbow Trout, Western Mosquitofish, and Green Sunfish (Marsh et al. 1991).

Tonto Creek is a 117-km stream that starts outside of Payson, Arizona at an elevation of 1500-m and flows south into Roosevelt Lake, which is a reservoir of the Salt River system. Average discharge in Tonto Creek ranges from 0.57 to 3.13 m^3/s (Schumann and Thomsen 1972). The riparian vegetation varies from conifer to desert-scrub dominate due to changes in elevation (Robson and Banta 1995). Broadleaf trees such as Fremont's Cottonwood, Goodding's Willow, Arizona Sycamore, Saltcedar *Tamarix* spp., and Mesquite *Prosopis* spp. are common across the entire riparian area (Robson and Banta 1995). Tonto Creek contains both native and non-native fish species. Native fishes that have been found in Tonto Creek include Desert Sucker, Sonora Sucker, Roundtail Chub, Loach Minnow, Speckled Dace, and Longfin Dace (Leon 1993). Non-native fish have included Yellow Bullhead, Red Shiner, Common Carp, Channel catfish, Fathead Minnow, Rainbow Trout, Brown Trout, Brook Trout, Western Mosquitofish, and Green Sunfish (Leon 1993).

The Verde River is a 274-km perennial stream located in central Arizona. The stream starts near Prescott, Arizona at an elevation of 1300-m and flows into the Salt River. Average discharge ranged from 0.65 to 3.62 m^3/s (Neary and Rinne 1997), and native vegetation along the stream consisted of Fremont's Cottonwood and Goodding's Willow and non-native vegetation being Saltcedar and Giant Reed *Arundo donax* (Neary et al. 2012). The Verde River historically was rich with native fish diversity according to archeological records (Minckley and Alger 1968). Remnants of Desert Sucker, Sonora Sucker, Razorback Sucker, Roundtail Chub, and Colorado Pikeminnow *Ptychocheilus lucius* were found at archeological sites in Perkinsville (Minckley & Alger 1968). Other notable native species that were present and distributed throughout the Verde River were Gila Chub *Gila intermedia*, Flannelmouth Sucker *Catostomus latipinnis*, Loach Minnow, Spikedace, Speckled Dace, and Longfin Dace (Neary et al. 2012).

However, over the last several decades most of these species have declined or have been extirpated from the Verde River as the river has shifted to a non-native fish species dominated system including Largemouth Bass, Smallmouth Bass, Yellow Bullhead, Red Shiner, Common Carp, Flathead Catfish, and Green Sunfish (Rinne 2005).

Fish and Habitat Sampling

I sampled a total of 1,235 grids across 39 access points over the four study streams between May 15 and August 15, 2017. Access points were selected either randomly or in streams where access was limited, all access points were used. At each access point, I selected 30 or 60 sampling grids. A random starting location was chosen and I then moved upstream randomly selecting grids 15-40 m from the last grid and along a perpendicular axis to the stream. The number of sample grids varied among study streams (Table 1.1). All grids sampled during daylight hours during summer base flows.

Sampling was conducted using prepositioned areal electrofishing device (PAEDs, Bain et al. 1985). Arrays comprised of two, 1.5-m long by 1.3-cm diameter aluminum pipes, which were the electrodes, attached to a 3-m long extension cord. The electrodes were powered by a 2,500-watt generator that was hidden on shore. Electrodes were placed on the bottom of the streambed parallel to stream flow at a distance of 1 m apart providing a sample grid area of 1.5 m^2. After placement, electrodes were left undisturbed for a minimum of 11 minutes to allow fish to return to the previously disturbed area (Bain et al. 1985) before alternating current (AC) was delivered to the electrodes for 15 seconds by a hidden on-shore operator. While current was being applied to the electrodes, two crew members positioned downstream with dip nets moved upstream into the sample grid to capture all stunned fish. After the current was delivered, crew members continued collecting any fish that were trapped in substrate. Fish were identified to species and total length (TL mm) was measured. The PAEDs were used to collect fish to decrease the chance of fright bias and minor differences in capture efficiency related to size, species, and habitat sampled compared to other electrofishing techniques (Bain et al. 1985).

After fish were collected, several habitat variables were measured at each grid. Depth (cm) and velocity (m/s) were measured using a USGS Pygmy Current Meter (Rickly Hydrological Company, Columbus, Ohio) at each of the four corners of the PAEDs. All four measurements were averaged for an overall depth and velocity for each grid. Substrate size was classified using a modified Wentworth scale (Table 1.2; Bain and Stevenson 1999 and Bonar et al. 2010). A meter-long chain with ten equally-spaced segments was randomly placed in the 1.5 m^2 sample grid. Substrate size was measured at each segment and then averaged for an overall substrate value for a grid. Capture temperature (˚C) was measured at the surface of each grid using an ISO-calibrated thermometer. A convex spherical densitometer was used to estimate percent canopy cover above each grid. Spherical densiometer measurements followed the procedures of Lemmon (1956). The total number of unoccupied imaginary dots within the cells was counted. Then the measurement was multiplied by 1.04 and subtracted from 100 to calculate percent canopy cover. Measurements were taken in all four cardinal directions and averaged.

Data Analysis

Development of Stream-Specific and Generalized Habitat Suitability Criteria.— HSC were developed for five variables: depth, velocity, substrate class, capture temperature, and percent canopy cover. Habitat suitability criteria, was developed by starting with the central 50% frequency of occupied grids and expanding it to produce a significant ($\alpha \leq 0.05$) t-statistic using a one-sided chi-square test to assess if the species were non-randomly selecting a type of habitat (Thomas and Bovee 1993; Waddle and Bovee 2010). A table was used to cross-categorize sample grids from each study stream as occupied-central 50%, occupied-not-central 50%, unoccupied-central 50%, and unoccupied-not–central 50% using the central 50% occupied grids. Then a *t*-value was calculated and tested for significance (Conover 1980).

$$t = [N^{0.5}\,(ad\text{-}bc)] \;/\; [(a+b)(c+d)(a+c)(b+d)]^{0.5}$$

Where a = number of occupied grids within the central 50%, b = number of occupied grids outside the central 50%, c = number of unoccupied grids within the central 50%, d = number of unoccupied grids outside the central 50%, and N = total number of grids. The null hypothesis was that central 50% grids would be occupied in the same proportion as grids outside the central 50% (Thomas and Bovee 1993). If the null hypothesis was accepted then the frequency was expanded by 10% each time until a significant ($\alpha \leq 0.05$) *t*-statistic was produced.

I developed stream-specific HSC for individual species and two size groups within species - small and large. The size groups were defined as < (small) or ≥ (large) the median total length of all captured individuals of that species.

The minimum and maximum values of each stream-specific habitat suitable criteria were averaged to create generalized HSC for each species (Mäki-Petäys et al. 2002). A second set was also developed averaging minimum and maximum values of each stream-specific habitat suitable criteria from my data and HSCs from two previous studies (Rinne 1992; Bonar et al. 2010). These studies were included due to similar methodology.

Transferability of Generalized Habitat Suitability Criteria.— To test whether HSC reflected that observed in each stream, a one-sided chi-square test was used to analyze the transferability of the generalized HSC as described above for non-random selection (Thomas and Bovee 1993).

Effects of Multiple Interacting Habitat Variables.— Individual variables are important for developing HSC, but these variables can interact. I used multivariate statistical analyses to evaluate effects of interacting habitat variables on habitat selection (Mäki-Petäys et al. 2002). Explanatory variables were tested for multicollinearity using a correlation matrix (Petre and Bonar 2017). If explanatory variables had significant associations ($r > 0.5$) with other explanatory variables, they were removed from further analyses. A logistic regression model was suitable due to the binary response of species presence or absence and the numerous environmental variables that describe the habitat (Manly et al. 2002). Presence was defined as if a certain species was detected in the sample grid when absence was defined as if a certain species was not detected in the sample grid. Mean depth, mean velocity, mean substrate, capture temperature, and overhead cover were modeled as continuous variables. The presence/absence of non-native fishes was included as a categorical variable within the model. The model was refitted using backwards elimination, which removed any variables based on estimated chi square probabilities ($P > 0.05$) and effect likelihood ratio tests ($P > 0.05$). Likelihood-ratio tests were done to compare the goodness of fit between models. A McFadden's R^2 was calculated for each model, which is defined as:

$$1 - ln(LM_1)/ln(LM_0)$$

The value $ln(LM_1)$ is the log likelihood value for the fitted model and $ln(LM_0)$ is the log likelihood for the null model with only an intercept as a predictor. The measure ranges from 0 to 1, with values closer to zero indicating that the model has no predictive power.

To assess the classification performance of each model a confusion matrix was used (Ramsey and Schafer 2012). A confusion matrix is a 2 × 2 table with "False" and "True" columns and “0” and “1” rows. The columns represent whether the models predicted the species to be absent or present. The rows represent whether species were actually absent or present. A true positive, which is in the bottom-right quadrant of the table, indicates the models predicted the species to be present and the species was present. A true negative, which is in the top-left quadrant of the table, indicates the models predicted the species to be absent and the species were absent. A false positive, which is in the top-right quadrant of the table, indicates the models predicted the species to be present, but the species was actually absent (Type 1 error). A false negative, which is in the bottom- left quadrant of the table, indicates the models predicted the species to be absent, but the species was actually present (Type II error). The estimated models predicted values using a training data set, which was a 60% randomly-chosen subset of the whole data set.

Overall accuracy of the models was reported as the area under the receiver operator curve (AUC, Fielding and Bell 1997). Values greater than 0.9 indicated a high accuracy model, values between 0.7-0.9 were deemed useful, and values lower than 0.7 were considered low accuracy (Manel et al. 2001). Data analysis was conducted in R/Rstudio Version 1.1.456 using the Hmisc, magrittr, and ROCR packages (Sing et al. 2005; Bache and Wickham 2014; R Core Team 2016; RStudio Team 2016; Harrell 2018).

RESULTS

Habitat Suitability Criteria.— Stream-specific and generalized habitat suitability criteria were developed for Desert Sucker, Longfin Dace, Speckled Dace, and Sonora Sucker. Because of the low number of grids containing native fishes, stream-specific criteria could not be developed for the Verde River for all species, Eagle Creek for Sonora Sucker, and Tonto Creek for Speckled Dace. There were not enough grids occupied by Spikedace, Roundtail Chub, and Loach Minnow in any of the study streams to develop stream-specific or generalized HSC.

Desert Suckers were typically found at depths of 6-82 cm, velocities of 0.00-0.77 m/s, and across all substrates with the exception of silt and clay. Desert Suckers were captured in grids with temperatures ranging from 9.0-28.0˚C and canopy cover of 0-100%. Desert Suckers were selecting depths of 15-54 cm at velocities of 0.18-0.66 m/s over gravel-pebble substrate at temperatures of 15.0-24.0˚C (Table 1.3).

Longfin Dace typically were found at depths of 6-89 cm, velocities of 0.00-0.69 m/s, and over all substrates. Longfin Dace were captured in grids with temperatures of 11.0-29.5˚C and canopy cover of 0-100%. Longfin Dace selected depths of 9-57 cm, velocities of 0.16-0.37 m/s, gravel-pebble substrates, temperatures of 16.0-25.0˚C, and a wide range of canopy cover from 2-88% (Table 1.4).

Speckled Dace were captured primarily at depths of 8-51 cm, velocities of 0.00-0.74 m/s, and were found over all substrates with the exception of boulders. Speckled Dace were captured in grids with temperatures of 9.5- 26.0˚C and canopy cover of 0-100%. Speckled Dace were selecting depths of 14-24 cm at velocities of 0.17-0.43 m/s over gravel-pebble substrate at temperatures of 15.0-21.0˚C with canopy cover of 16-57% (Table 1.5).

Generally, Sonora Suckers were found at depths of 6-89 cm, velocities of 0.00-0.71 m/s, and were found over all substrates. Sonora Suckers were captured in grids with temperatures of 9.5- 28.0˚C and canopy cover of 0-80%. Sonora Suckers were selecting depths of 21-51 cm at velocities of 0.00-0.21 m/s over gravel substrate at temperatures of 17.0-26.0˚C with canopy cover of 0-7% (Table 1.6).

Transferability.— Overall, 33% of the generalized criteria developed for Desert Sucker and 18% of the generalized criteria incorporating previous studies (Rinne 1992 and Bonar et al. 2010) were transferable across three study streams (Table 1.7 & 1.8). The amount of generalized criteria and generalized criteria incorporating previous studies that were able to transfer was similar across all size groups.

Of the generalized criteria developed for Longfin Dace, 33% were transferrable while 33% of the generalized criteria incorporating previous studies transferrable across the three study streams (Table 1.7 & 1.8). The amount of generalized criteria and generalized criteria incorporating previous studies that were able to transfer was greater for the large size group (≥ 40 mm) than for all sizes and for the small size group (< 40 mm).

Overall, 50% of the generalized criteria developed for Speckled Dace were transferable and 53% of the generalized criteria incorporating previous studies were transferable across two study streams (Table 1.7 & 1.8). The amount of generalized criteria that were transferable was greater for the large size group (≥ 47 mm) than for all sizes and for the small size group (< 47 mm). The amount of generalized criteria incorporating previous studies that were transferable was greater for all sizes than large size groups (≥ 47 mm) and small size groups (< 47 mm).

Of the generalized criteria developed for Sonora Sucker, 20% were transferable while 13% of the generalized criteria incorporating previous studies were transferable across two study streams (Table 1.7 & 1.8). The amount of generalized criteria that were able to transfer was similar across all size classes. The amount of generalized criteria incorporating previous studies that were transferable was greater in the large size group (≥ 60 mm) than for the small size group (< 60 mm) or all sizes considered together as one group.

Logistic Regression Analysis.— There was no multicollinearity among the explanatory variables tested, therefore no significant interactions between explanatory variables. Depth, substrate, capture temperature, and presence of non-native fishes were significant variables in explaining the presence or absence of Desert Suckers (Table 1.9). The likelihood ratio test found the observed difference in model fit was significantly different and the residual deviance was significantly reduced between the full model and empty model containing just the intercept. The likelihood ratio test found the observed difference in model fit was not significantly different and the residual deviance was not significantly reduced between the full model and the revised model excluding velocity and canopy cover variables. Both models had McFadden's R^2 of 0.08. Both of the models had 78% of the predicted observations as true negatives and 22% false negatives. The AUC for both models was 0.69.

Depth, velocity, and presence of non-native fishes were significant variables in regards to the presence or absence of Longfin Dace (Table 1.10). The likelihood ratio test showed the observed difference in model fit was significantly different and the residual deviance was significantly reduced between the full model and empty model containing just the intercept. The likelihood ratio test showed the observed difference in model fit was not significantly different and the residual deviance was not significantly reduced between the full model and the revised model excluding substrate, capture temperature, and canopy cover variables. Both models had McFadden's R^2 of 0.07. Both of the models had 72% of the predicted observations as true negatives, 1% true positives, 26% false negatives, and 1% true negatives. The AUC for both models was 0.68.

Depth, velocity, substrate, and capture temperature were significant variables in regards to the presence or absence of Speckled Dace (Table 1.11). The likelihood ratio test showed the observed difference in model fit was significantly different and the residual deviance was significantly reduced between the full model and empty model containing just the intercept. The likelihood ratio test showed the observed difference in model fit was not significantly different and the residual deviance was not significantly reduced between the full model and the revised model excluding canopy cover and presence of non-native fishes. Both models had McFadden's R^2 of 0.12. Both of the models had 56% of the predicted observations as true negatives, 16% true positives, 17% false negatives, and 11% true negatives. The AUC for both models was 0.72.

Capture temperature and canopy cover were significant variables in regards to the presence or absence of Sonora Sucker (Table 1.12). The likelihood ratio test showed the observed difference in model fit was significantly different and the residual deviance was significantly reduced between the full model and empty model containing just the intercept. The likelihood ratio test showed the observed difference in model fit was not significantly different and the residual deviance was not significantly reduced between the full model and the revised model excluding depth, velocity, substrate, and presence of non-native fishes. Both models had McFadden's R^2 of 0.06. Both of the models had 92% of the predicted observations as true negatives and 8% false negatives. The AUC for both models was 0.75. A summary of logistic regression model results for all four native fish species can be seen in Table 1.13

DISCUSSION

It is important to know the habitat preference of these species in order to manage their habitat accordingly, especially if anthropogenic stressors are reducing the availability of this defined habitat (Minckley and Deacon 1991). Habitat selection of Desert Sucker, Longfin Dace, and Speckled Dace in Eagle Creek and Blue River and Sonora Sucker in Tonto Creek were similar to the habitat use documented in previous studies (Rinne 1992; Paroz et al. 2006).

Despite this similarly to previous studies at Tonto Creek, habitat occupancy varied across the four study streams for several species. Desert Sucker, Longfin Dace, and Sonora Sucker used slower, deeper water in Tonto Creek than in Blue River and Eagle Creek. A possible explanation is that pool macrohabitats were dominant at Tonto Creek (>50%) compared to Blue River and Eagle Creek (<19%), so all fish had fewer choices at Tonto Creek. Habitat availability is a factor to consider when assessing habitat preference for species, since habitat that is preferred by a given species may be limited in a given stream. Habitat occupancy also varied within streams for several species. Specifically, Longfin Dace was shown to use a wide range of habitat variables within streams they occupied. Longfin Dace are considered to be habitat generalists occupying a wide range of habitats (Minckley and Marsh 2009). Although my study agrees with past literature about Longfin Dace habitat use, I saw that the species selected specified ranges of certain habitat variables. Habitat selection differs from use by it being an active process of behaviors that are learned or inherent (Hutto 1985). These behaviors are driven by different aspect of a species life cycle such as reproduction and growth (Krausman 1999). Even though habitat occupancy differed across and within streams for several species I was able to establish habitat preference among several native fishes.

Generalized habitat suitability criteria did not transfer well across the four study streams. My results agree with past studies that criteria are better to be developed for the stream of interest rather than a broad area (Moyle and Baltz 1985; Heggenes 1990; Bozek and Rahel 1992; Mäki-Petäys et al. 2002; Guay et al. 2003). Guay et al. (2003) saw differences in substrate size to be a possible cause for criteria not being able to transfer from one river to another. Additional reasons for lack of transferability include differences in habitat availability, thermal regimes, and fish communities, or food resources in each stream (Moyle and Baltz 1990). For example, we observed dissimilarities among thermal regimes and fish communities in our four study streams. Capture temperatures in the Blue River ranged from 9 to 27˚C and from 12 to 24˚C in Eagle Creek, while Tonto Creek ranged from 15.5 to 29.5˚C and the Verde River from 15 to 29˚C. Although these temperatures were simply instantaneous measurements taken during daylight hours between the months of May through August, they suggest possible differences in thermal regime between streams. The percentage of non-native fish also varied dramatically between study streams, with non-native fish dominating in the Verde River and Tonto Creek (>59%) but relatively uncommon in the Blue River and Eagle Creek (<18%). Although I did not estimate population parameters (e.g. total abundance, density), these relative abundance measures suggest that there may be differences in fish community composition across the four study streams. Thus, generalized criteria failed to transfer into the study streams potentially due to the differences in physical habitat and biological communities.

Nonnative fish presence was negatively related to the presence of Desert Sucker and Longfin Dace. This result is in agreement with past studies that nonnative fishes negatively impact native fishes through competition and predation (Miller 1961; Minckley and Deacon 1968; Moyle et al. 1986). Criteria were developed for these two species in the Blue River, Eagle Creek, and Tonto Creek. My sampling of the Blue River and Eagle Creek were dominated by native fishes when Tonto Creek was dominated by nonnative fishes. Desert Sucker and Longfin Dace may have occupied not preferred habitat in Tonto Creek than in the Blue River and Eagle Creek due to predator avoidance or competition of nonnative fishes.

CONCLUSION

Development and use of stream-specific HSC provided a more accurate representation of habitat use of fishes in these Arizona streams. If lack of resources prohibits the development of stream-specific habitat suitability criteria for a certain stream, a viable option is to use developed stream-specific HSC for a stream that is similar to the stream of interest in both large-scale physical factors and biological factors. Generalized criteria can give broad insight to what native fish species are, but are less suited for individual streams Overall, the development of habitat suitability criteria is a powerful tool in order to manage and conserve species of interest.

TABLES

Table 1.1– Number of grids for each native species in respective study stream.

	Blue River	Eagle Creek	Tonto Creek	Verde River	Total
Number of grids	300	240	305	390	1235
Desert Sucker	73	82	19	3	177
Sonora Sucker	20	4	35	5	64
Longfin Dace	91	75	50	0	216
Speckled Dace	111	96	0	1	208
Roundtail Chub	0	0	3	3	6
Spikedace	8	0	0	0	8
Loach Minnow	0	0	0	0	0

Table 1.2– Wentworth scale for the classification of instream substrate types (from Bain and Stevenson 1999, taken from Bonar et al. 2010).

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

Table 1.3– Desert Sucker stream-specific habitat suitability criteria ranges with critical *t* from chi-square analysis (TL = total length; $P \leq 0.05$*, $P \leq 0.01$**, $P \leq 0.001$***).

Criteria Set	Velocity (m/s)	*T*	Depth (cm)	*T*	Substrate Class	*T*	Temperature (˚C)	*T*	Canopy Cover (%)	*T*
Blue River- All	0.18- 0.66	2.43**	9.0-45.0	1.24	2.2 - 4.0	0.56	17.0 - 24.0	2.06*	0 - 90	1.53
TL < 83 mm	0.17-0.64	2.14*	12.75-24.0	1.43	1.6- 3.9	1.11	17.0 - 25.0	1.46	2 - 68	1.64*
TL ≥ 83 mm	0.31-0.50	1.99*	19.5-31.3	1.83*	2.2 - 4.2	1.64*	17.0 - 24.5	1.80*	2 - 80	1.03
Eagle Creek-All	0.17- 0.36	3.06**	15.3-23.0	4.35**	2.3 - 3.9	2.42**	15.0 - 21.0	2.74**	34 - 85	1.69*
TL < 83 mm	0.17 - 0.32	3.28**	14.5-22.0	3.84**	2.2 - 3.9	2.04*	15.0 - 21.0	2.74**	34 - 85	1.69*
TL ≥ 83 mm	0.21 - 0.42	2.98**	16.3-25.0	3.73**	3.1 - 3.7	3.28**	15.0 - 21.0	2.63**	0 - 99	0.59
Tonto Creek-All	0.00 -0.47	0.87	28.0-54.0	2.88**	2.5 - 3.7	2.16*	19.0 - 28.0	1.37	0 - 20	0.81
TL < 83 mm	0.00 -0.43	0.90	28.0-65.8	1.85*	2.5 - 3.6	1.95*	20.0 - 28.0	1.34	0 - 26	2.06**
TL ≥ 83 mm	0.03 - 0.47	2.44**	26.5-47.0	1.66*	3.5 - 4.1	2.13*	19.0 - 25.5	1.61	24 -84	2.04*

Table 1.4– Longfin Dace stream-specific habitat suitability criteria ranges with critical *t* from chi-square analysis (TL = total length; $P \leq 0.05$*, $P \leq 0.01$**, $P \leq 0.001$***).

Criteria Set	Velocity (m/s)	*T*	Depth (cm)	*T*	Substrate Class	*T*	Temperature (˚C)	*T*	Canopy Cover (%)	*T*
Blue River- All	0.19 - 0.37	2.79**	9.0 - 52.5	0.32	1.0 - 3.7	1.56	16.0 -25.0	1.89*	9 - 63	2.19**
TL < 40 mm	0.18 - 0.34	3.45**	13.5 - 22.8	1.55	1.7 - 2.9	2.25*	16.0 - 26.0	1.78*	11 - 63	1.79*
TL ≥ 40 mm	0.08 - 0.62	2.29*	9.0 - 41.0	0.88	1.0 - 3.7	2.06*	18.0 - 22.0	1.76*	9 - 63	1.58
Eagle Creek-All	0.16 - 0.29	4.14**	14.3 - 23.0	2.84**	2.3 - 3.7	2.45**	15.0 - 21.0	2.20*	43 - 84	1.99*
TL < 40 mm	0.15 - 0.25	3.66**	13.3-27.0	1.70*	2.4 - 3.6	1.75*	16.0 - 20.0	2.58**	47 - 83	2.08*
TL ≥ 40 mm	0.16 - 0.29	4.12**	13.3-22.0	3.62**	2.3 - 3.6	2.46**	15.0 - 21.0	1.92*	43 - 86	1.94*
Tonto Creek-All	0.00 - 0.31	1.32	9.3 - 57.3	2.75**	1.8 - 3.1	2.27*	21.5 - 28.0	1.60	2 - 22	2.51**
TL < 40 mm	0.00 - 0.08	2.16*	9.0 - 58.0	2.16*	1.7 - 3.0	2.41**	18.0 - 29.5	1.42	2 - 25	1.68*
TL ≥ 40 mm	0.00 - 0.31	0.39	10.8 - 28.0	3.29**	1.7 - 3.5	3.04**	22.0 - 28.0	2.59**	1 - 26	2.71**

Table 1.5– Speckled Dace stream-specific habitat suitability criteria ranges with critical *t* from chi-square analysis (TL = total length; $P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

Criteria Set	Velocity (m/s)	*T*	Depth (cm)	*T*	Substrate Class	*T*	Temperature (˚C)	*T*	Canopy Cover (%)	*T*
Blue River- All	0.24 - 0.43	1.99*	14.8 - 24.0	2.15*	0.5 - 4.5	0.46	17.0 - 21.5	2.55**	16 - 57	1.85*
TL < 47 mm	0.15 - 0.41	1.17	9.5 - 38.5	1.68*	0.9 - 3.9	2.06*	17.0 - 21.0	1.75*	21 - 58	2.39**
TL ≥ 47 mm	0.28 - 0.44	3.18**	15.3 - 24.0	2.35**	2.1 - 3.9	0.26	17.0 - 22.0	1.67*	14 - 52	1.87*
Eagle Creek-All	0.17 - 0.32	3.95**	14.0 - 22.5	3.69**	2.3 - 3.8	2.71**	15.0 - 21.0	1.67*	0 - 98	1.63*
TL < 47 mm	0.17 - 0.29	3.73**	14.0 - 23.5	2.27*	2.3 - 3.8	2.18*	15.0 - 20.0	1.97*	0 - 98	1.36
TL ≥ 47 mm	0.18 - 0.32	3.83**	14.3 - 22.5	3.16**	2.9 - 3.7	2.39**	14.0 - 21.0	2.65**	28 - 95	1.78*

Table 1.6– Sonora Sucker stream-specific habitat suitability criteria ranges with critical *t* from chi-square analysis (TL = total length; $P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

Criteria Set	Velocity (m/s)	*T*	Depth (cm)	*T*	Substrate Class	*T*	Temperature (˚C)	*T*	Canopy Cover (%)	*T*
Blue River- All	0.30 - 0.44	1.22	13.3 - 25.8	1.34	2.2 - 2.7	3.16**	17.0 - 25.0	1.83*	0 - 80	1.46
TL < 60 mm	0.31- 0.35	4.98**	14.0 - 33.0	1.79*	1.7 - 2.6	2.29*	9.5 - 21.5	1.56	0 - 80	0.84
TL ≥ 60 mm	0.12 - 0.71	0.42	6.0 - 28.5	1.69*	2.3 - 3.3	2.42**	17.0 - 25.0	2.03*	10 - 50	1.67*
Tonto Creek-All	0.00 - 0.21	1.67*	21.3 - 51.3	1.66*	2.3 - 3.7	1.40	24.5 - 26.0	2.34**	0 - 7	2.30*
TL < 60 mm	0.00 - 0.09	1.71*	22.3 - 41.8	2.48**	1.6 - 4.1	1.35	23.0 - 28.0	2.94**	0 - 7	2.49**
TL ≥ 60 mm	0.00 - 0.30	0.77	18.8 - 32.5	2.62**	2.7 - 3.5	2.75**	24.5 - 27.0	2.43**	0 - 35	1.17

Table 1.7– Generalized habitat suitability criteria using stream-specific criteria from this study for Desert Sucker (CACL), Longfin Dace (AGCH), Sonora Sucker (CAIN), and Speckled Dace (RHOS) with critical *t*-scores from transferability chi-square analysis (TL = total length; $P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

Criteria Set	Velocity (m/s)	*T*	Depth (cm)	*T*	Substrate Class	*T*	Temperature (˚C)	*T*	Canopy Cover (%)	*T*
CACL- All Sizes	0.12 - 0.50		17.4 - 40.7		2.3 - 3.9	-	17.0 - 24.3		11 - 65	
Blue		2.63**		0.38		0.13		2.06*		0.67
Eagle		4.32**		1.08		2.07*		-1.69		0.25
Tonto		0.83		1.48		1.68*		0.58		1.71*
TL < 83 mm	0.11 - 0.46		18.4- 37.3		2.1 - 3.8		17.3 - 24.7		12 - 59	
Blue		0.91		-1.69		-0.52		0.47		1.02
Eagle		4.35**		-0.03		1.92*		-0.68		1.65*
Tonto		0.42		1.43		1.16		-0.33		1.53
TL ≥ 83 mm	0.18 - 0.46		20.8 - 34.4		2.9 - 4.0		17.0 - 23.7		9 - 88	
Blue		1.69*		1.14		1.91*		1.77*		-1.11
Eagle		2.47**		-0.01		3.74**		-1.00		-0.71
Tonto		0.16		0.85		-0.08		0.30		1.86*
AGCH- All Sizes	0.12 - 0.32		10.9 - 44.3		1.7 - 3.5		17.5 - 24.7		18 - 56	
Blue		4.66**		-0.81		-0.06		1.33		0.33
Eagle		5.30**		1.39		1.63		-2.26		0.96
Tonto		0.56		0.01		2.48**		-0.75		1.38
TL < 40 mm	0.11 - 0.22		11.9 -35.9		1.9 - 3.2		16.7 - 25.2		20 - 57	
Blue		2.89**		0.27		2.29**		-0.06		-0.44
Eagle		3.06**		1.61		1.02		-2.17		0.78
Tonto		-1.50		-0.15		0.74		-0.65		-0.09
TL ≥ 40 mm	0.08 - 0.41		11.0- 30.3		1.7 - 3.6		18.3 - 23.7		18 - 58	
Blue		2.63**		-0.46		0.65		1.74*		0.74
Eagle		5.51**		3.22**		2.53**		-0.27		0.12
Tonto		1.69*		1.84*		2.70**		-1.17		2.17*
CAIN- All Sizes	0.15 - 0.33		17.3 - 38.6		2.3 - 3.2		20.8 - 25.5		0 - 44	
Blue		1.40		0.81		0.85		1.45		0.44
Tonto		-0.35		2.43**		0.81		-0.65		3.37**
TL < 60 mm	0.06 - 0.40		14.2 - 35.2		2.0 - 3.7		20.0 - 26.5		5 - 29	
Blue		1.79*		1.02		-1.47		0.19		-0.78
Tonto		-0.69		2.15*		0.38		-0.06		0.01
TL ≥ 60 mm	0.06 - 0.51		12.4 - 30.5		2.5 - 3.4		20.8 - 26.0		5 - 43	
Blue		-0.17		0.35		0.54		1.02		1.35
Tonto		1.30		1.67*		1.81*		0.04		-0.01
RHOS- All Sizes	0.21 - 0.38		14.4 - 23.3		1.4 - 4.2		16.0 - 21.3		8 - 78	
Blue		2.17*		1.85*		1.00		1.28		2.32**
Eagle		3.80**		3.42**		4.01**		0.60		-0.37
TL < 47 mm	0.16 - 0.35		11.8 - 31.0		1.6 - 3.9		16.0 - 20.5		11 - 78	
Blue		1.46		-0.58		1.39		1.06		2.98**
Eagle		3.66**		1.60		2.39**		1.32		0.50
TL ≥ 47 mm	0.23 - 0.38		14.8 - 23.3		2.5 - 3.8		15.5 - 21.5		21 - 74	
Blue		2.96**		1.90*		0.42		1.86*		1.25
Eagle		3.97**		2.53**		2.50**		-0.17		0.48

Table 1.8– Generalized habitat suitability criteria using stream-specific criteria from this study and two previous studies (Rinne 1992; Bonar et al. 2010) for Desert Sucker (CACL), Longfin Dace (AGCH), Sonora Sucker (CAIN), and Speckled Dace (RHOS) with critical *t*-scores from transferability chi-square analysis (TL = total length; $P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

Criteria Set	Velocity (m/s)	*T*	Depth (cm)	*T*	Substrate Class	*T*	Temperature (˚C)	*T*
CACL- All	0.15- 0.41		17.6 - 40.5		2.7 - 4.0		15.5 - 23.5	
Blue		1.61		0.23		0.27		1.37
Eagle		4.08**		0.36		2.63**		-1.17
Tonto		-0.70		1.52		0.07		0.47
TL < 83 mm	0.15 - 0.39		18.2 -38.5		2.5 - 4.0		15.8 - 23.8	
Blue		2.21*		-1.55		-0.48		-0.48
Eagle		5.10**		-0.30		1.16		-0.68
Tonto		-0.75		1.34		1.07		1.34
TL ≥ 83 mm	0.19 – 0.40		19.6 – 36.8		3.0 – 4.1		15.5 – 23	
Blue		0.94		1.95*		2.76**		1.67
Eagle		2.42**		0.41		4.38**		-0.43
Tonto		0.38		1.49		0.30		0.20
AGCH- All	0.14 - 0.30		11.4 - 40.9		1.6 - 3.5		16.9 - 24.8	
Blue		4.31**		-0.15		-0.06		1.19
Eagle		5.12**		2.17*		1.63		-2.26
Tonto		0.47		0.10		2.48**		-0.90
TL < 40 mm	0.14 - 0.24		12.1 - 35.9		1.8 - 3.3		16.3 - 25.1	
Blue		3.90**		0.21		1.22		0.16
Eagle		3.17**		1.71*		0.59		-2.17
Tonto		-1.17		0.06		0.85		-0.70
TL ≥ 40 mm	0.12 - 0.35		11.5 - 32.5		1.6 - 3.6		17.5 - 24.0	
Blue		2.53**		-0.24		0.16		2.19*
Eagle		4.63**		2.77**		2.12*		-1.16
Tonto		3.00**		1.80*		3.05**		-2.01
CAIN- All	0.14 - 0.29		19.5 - 41.9		2.1 - 3.5		20.5 - 26.3	
Blue		0.12		-0.47		1.28		0.69
Tonto		-0.46		1.96*		-0.08		0.26
TL < 60 mm	0.10 - 0.33		18.0 - 40.2		1.9 - 3.8		20.0 - 27.0	
Blue		0.58		0.94		-1.51		0.06
Tonto		-0.89		1.89*		0.69		-0.10
TL ≥ 60 mm	0.10 - 0.38		17.1 - 37.9		2.2 - 3.6		20.5 - 26.7	
Blue		-0.01		-0.11		2.50**		0.74
Tonto		1.58		1.58		1.96*		-0.05
RHOS- All	0.21 - 0.35		13.4 - 23.0		2.1 - 4.2		14.3 - 21.2	
Blue		1.55		1.76*		1.78*		1.67*
Eagle		3.56**		3.70**		4.32**		1.67*
TL < 47 mm	0.18 - 0.34		12.0 - 26.9		2.2 - 4.1		14.3 - 20.7	
Blue		1.01		-0.43		1.07		0.79
Eagle		2.92**		2.91**		2.97**		1.97*
TL ≥ 47 mm	0.22 - 0.36		13.6 - 23.0		2.6 - 4.0		14.0 - 21.3	
Blue		2.37**		1.58		0.50		0.84
Eagle		3.33**		4.10**		4.17**		2.65**

Table 1.9 – Parameter estimates and associated values for explanatory variables in logistic regression analysis for Desert Sucker in Blue River, Eagle Creek, and Tonto Creek ($P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	-0.96	0.57	-1.68	0.0926
Depth (cm)	-0.01	0.01	-2.57	0.0101*
Velocity (m/s)	-0.09	0.49	-0.20	0.8408
Substrate (Wentworth)	0.46	0.10	4.79	<0.0001***
Temperature (˚C)	-0.05	0.02	-2.07	0.0386*
Canopy Cover (%)	-0.01	0.02	-0.65	0.5153
Nonnative (presence)	-1.28	0.33	-3.89	<0.0001***
Revised				
Intercept	-1.12	0.51	-2.20	0.0279*
Depth (cm)	-0.02	0.01	-2.64	0.0084**
Substrate (Wentworth)	0.44	0.09	4.97	<0.0001***
Temperature (˚C)	-0.05	0.02	-1.97	0.0492*
Nonnative (presence)	-1.23	0.32	-3.91	<0.0001***

Table 1.10 – Parameter estimates and associated values for explanatory variables in logistic regression analysis for Longfin Dace presence in Blue River, Eagle Creek, and Tonto Creek ($P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	0.57	0.55	1.04	0.2996
Depth (cm)	-0.04	0.01	-6.19	$<0.0001^{***}$
Velocity (m/s)	-2.40	0.52	-4.62	$<0.0001^{***}$
Substrate (Wentworth)	0.03	0.08	0.32	0.7478
Temperature (˚C)	0.01	0.02	0.27	0.7881
Canopy Cover (%)	-0.01	0.01	-0.78	0.4337
Nonnative (presence)	-0.92	0.25	-3.67	0.0002^{***}
Revised				
Intercept	0.65	0.24	2.67	0.0076^{**}
Depth (cm)	-0.04	0.01	-6.16	$<0.0001^{****}$
Velocity (m/s)	-2.40	0.49	-4.91	$<0.0001^{***}$
Nonnative (presence)	-0.83	0.23	-3.68	0.0002^{***}

Table 1.11 – Parameter estimates and associated values for explanatory variables in logistic regression analysis for Speckled Dace presence in Blue River and Eagle Creek (*P* ≤ 0.05*, *P* ≤ 0.01, *P* ≤ 0.001***).**

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	0.55	0.60	0.93	0.3547
Depth (cm)	-0.04	0.01	-4.25	<0.0001***
Velocity (m/s)	-3.42	0.61	-5.62	<0.0001***
Substrate (Wentworth)	0.75	0.11	6.65	<0.0001***
Temperature (˚C)	-0.05	0.03	-1.97	0.0492*
Canopy Cover (%)	-0.01	0.01	-0.64	0.5235
Nonnative (presence)	-1.65	1.12	-1.47	0.1405
Revised				
Intercept	0.44	0.57	0.78	0.4377
Depth (cm)	-0.04	0.01	-4.32	<0.0001***
Velocity (m/s)	-3.39	0.61	-5.59	<0.0001***
Substrate (Wentworth)	0.74	0.11	6.63	<0.0001***
Temperature (˚C)	-0.05	0.03	-1.93	0.0537
Nonnative (presence)	-1.60	1.12	-1.43	0.1522

Table 1.12 – Parameter estimates and associated values for explanatory variables in logistic regression analysis for Sonora sucker presence in Blue River and Tonto Creek. Asterisk (*P* ≤ 0.05*, *P* ≤ 0.01, *P* ≤ 0.001***).**

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	**-2.87**	**1.14**	**-2.53**	**0.0115****
Depth (cm)	**-0.06**	**0.01**	**-0.77**	**0.4401**
Velocity (m/s)	**-1.64**	**1.00**	**-1.63**	**0.1034**
Substrate (Wentworth)	**0.11**	**0.14**	**0.80**	**0.4262**
Temperature (˚C)	**0.06**	**0.04**	**1.26**	**0.2076**
Canopy Cover (%)	**-0.02**	**0.01**	**-2.64**	**0.0084****
Nonnative (presence)	**-0.08**	**0.34**	**-0.24**	**0.8107**
Revised				
Intercept	**-3.64**	**0.95**	**-3.84**	**0.0001*****
Temperature (˚C)	**0.08**	**0.04**	**2.07**	**0.0381****
Canopy Cover (%)	**-0.02**	**0.01**	**-3.04**	**0.0023****

Table 1.13– Summary of logistic regression models for each species (+ = significant positive coefficient, - = significant negative coefficient, and N.S. = non –significant coefficient, significance ≤ 0.05)

	Velocity (m/s)	Depth (cm)	Substrate Class	Temperature (˚C)	Canopy Cover (%)	Presence of Nonnative Fish
Desert Sucker	N.S.	-	+	-	N.S.	-
Longfin Dace	-	-	N.S.	N.S.	N.S.	-
Speckled Dace	-	-	+	-	N.S.	N.S.
Sonora Sucker	N.S.	N.S.	N.S.	+	-	N.S.

FIGURES

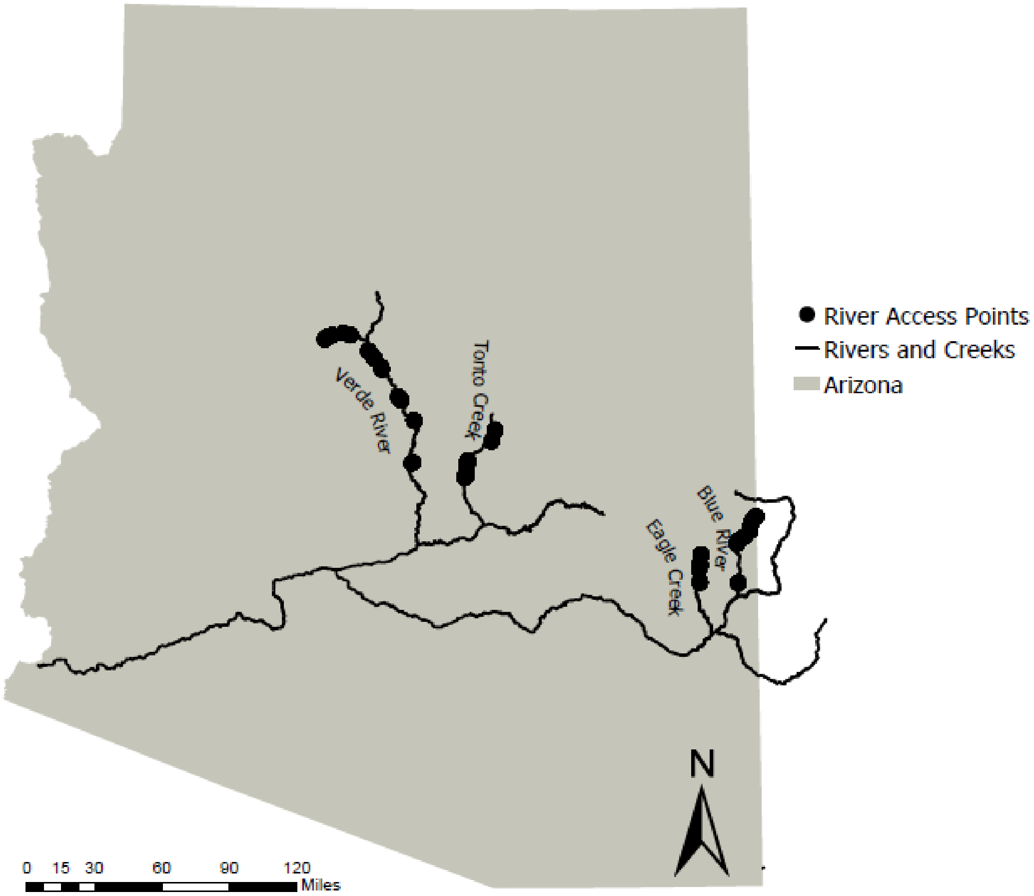

Figure 1.1—Map of study sites

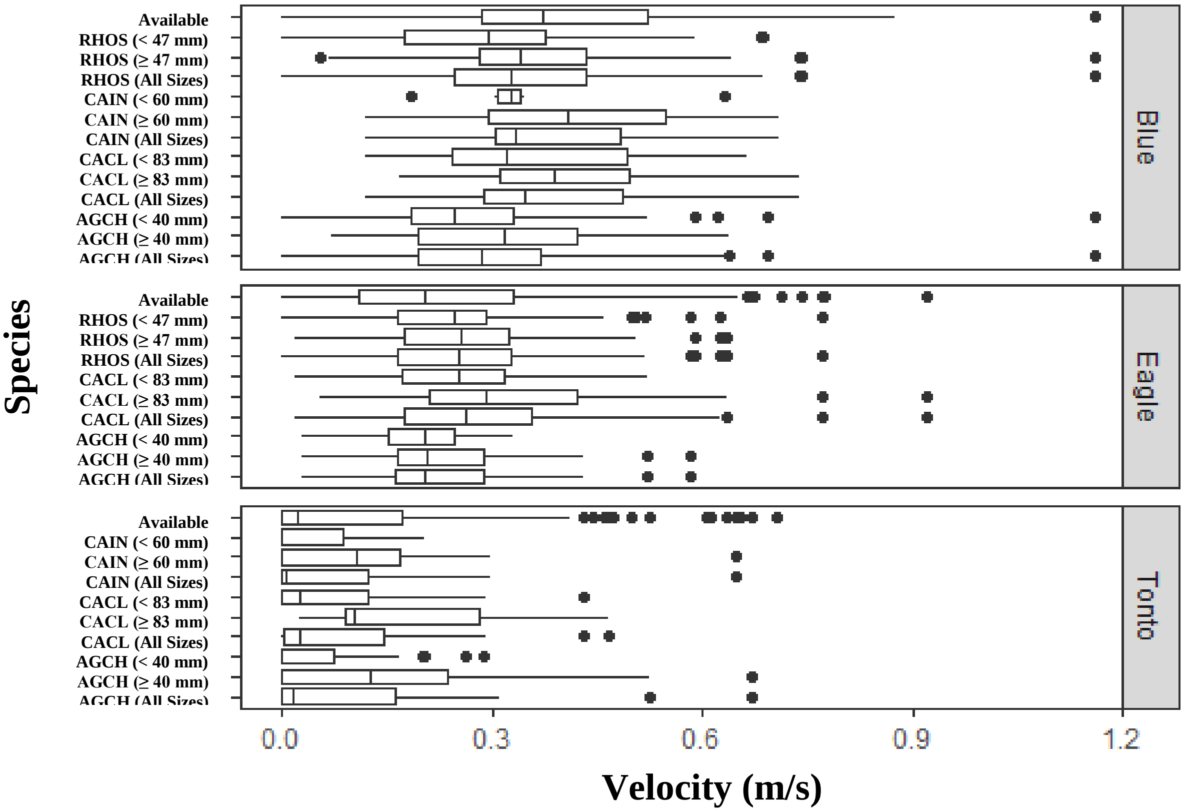

Figure 1.2— Distribution of available and occupied grid by Speckled Dace (RHOS), Sonora Sucker (CAIN), Desert Sucker (CACL), and Longfin Dace (AGCH) for velocity in Blue River, Eagle Creek, and Tonto Creek. Size groups were designated as small (<) or large (≥) median total length of captured fish of that species. The box dimensions represent the middle 50%, and the lines in the boxes represent the means. The rightmost whisker represents the 95th percentile; the leftmost whisker represents the 5th percentile.

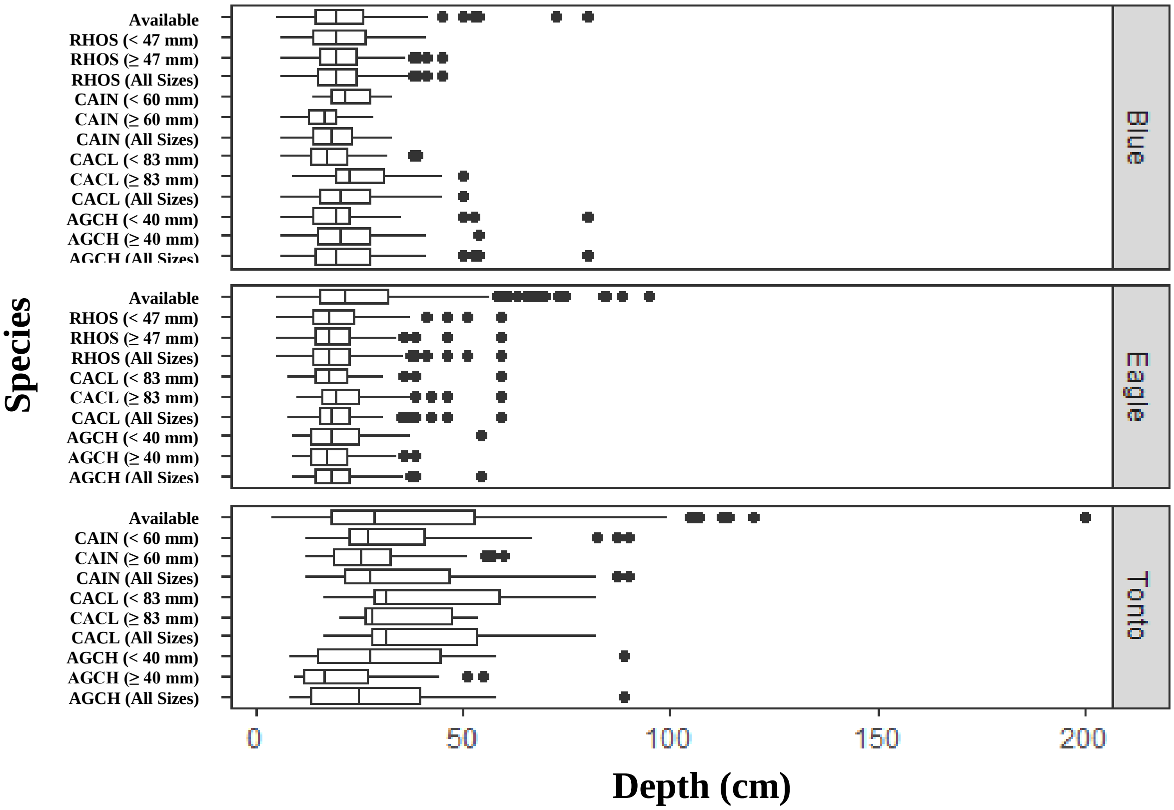

Figure 1.3— Distribution of available and occupied grid by Speckled Dace (RHOS), Sonora Sucker (CAIN), Desert Sucker (CACL), and Longfin Dace (AGCH) for depth in Blue River, Eagle Creek, and Tonto Creek. Size groups were designated as small (<) or large (≥) median total length of captured fish of that species. The box dimensions represent the middle 50%, and the lines in the boxes represent the means. The rightmost whisker represents the 95th percentile; the leftmost whisker represents the 5th percentile.

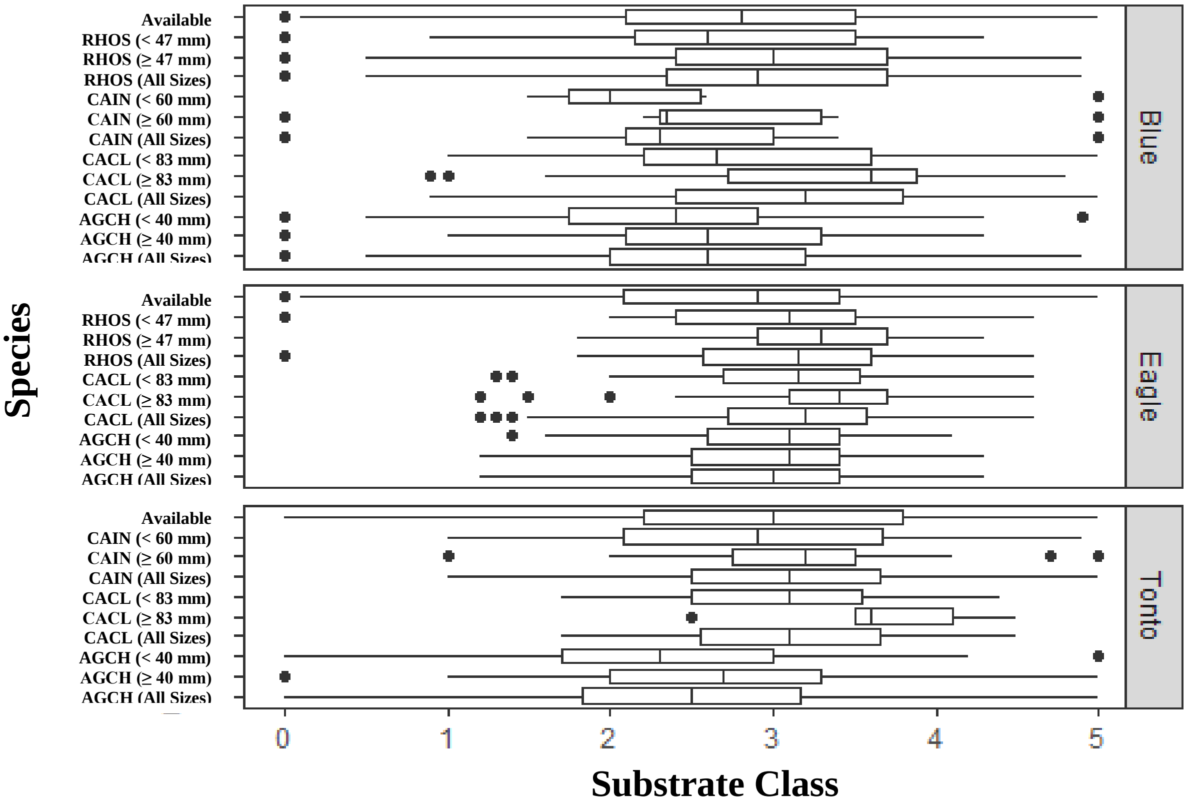

Figure 1.4— Distribution of available and occupied grid by Speckled Dace (RHOS), Sonora Sucker (CAIN), Desert Sucker (CACL), and Longfin Dace (AGCH) for substrate class (seen in Table 1.2) in Blue River, Eagle Creek, and Tonto Creek. Size groups were designated as small (<) or large (≥) median total length of captured fish of that species. The box dimensions represent the middle 50%, and the lines in the boxes represent the means. The rightmost whisker represents the 95th percentile; the leftmost whisker represents the 5th percentile.

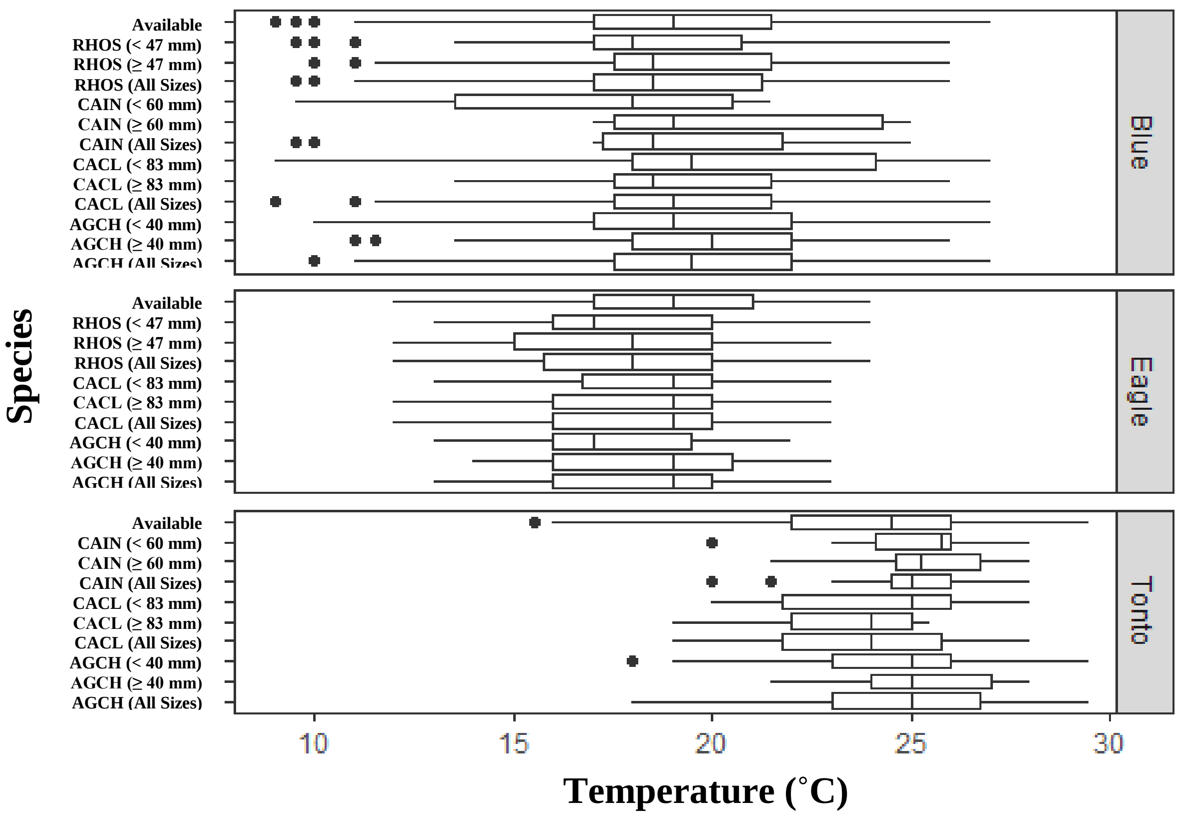

Figure 1.5— Distribution of available and occupied grid by Speckled Dace (RHOS), Sonora Sucker (CAIN), Desert Sucker (CACL), and Longfin Dace (AGCH) for capture temperature in Blue River, Eagle Creek, and Tonto Creek. Size groups were designated as small (<) or large (≥) median total length of captured fish of that species. The box dimensions represent the middle 50%, and the lines in the boxes represent the means. The rightmost whisker represents the 95th percentile; the leftmost whisker represents the 5th percentile.

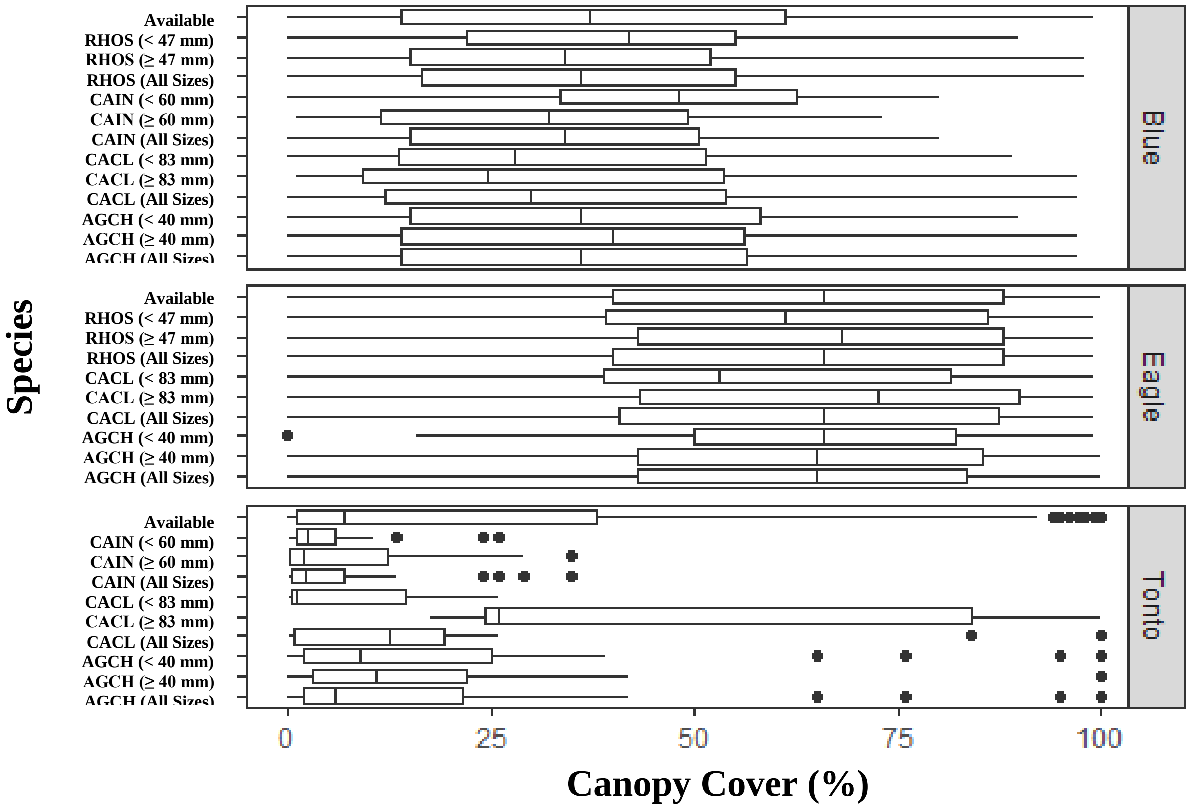

Figure 1.6— Distribution of available and occupied grid by Speckled Dace (RHOS), Sonora Sucker (CAIN), Desert Sucker (CACL), and Longfin Dace (AGCH) for canopy cover in Blue River, Eagle Creek, and Tonto Creek. Size groups were designated as small (<) or large (≥) median total length of captured fish of that species. The box dimensions represent the middle 50%, and the lines in the boxes represent the means. The rightmost whisker represents the 95th percentile; the leftmost whisker represents the 5th percentile.

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CHAPTER 2. Assessment of the Relationship Among Riparian Aras, Stream Macrohabitat Types, and Fish Presence in Four Central Arizona Streams

INTRODUCTION

Riparian areas are the transitional zones between stream and upland ecosystems (Zaimes 2007). Though there are many biological and physical characteristics that can define this type of land depending on the specific academic discipline, agency, organization, and or scientific publication (Zaimes 2007). Comparable to wetlands, riparian areas have soil, hydrology, and vegetation characteristics that are used to distinguish them from both the aquatic and terrestrial ecosystems (Ffolliott et al. 2004). In this study, I will be using the associated vegetation to define the extent of the riparian areas. This land type comprises less than 2% of the land area yet supports over 70% of all vertebrate species in the arid, Southwestern United States (Johnson et al. 1989). These zones contribute to numerous ecosystem processes such as habitat creation, nutrient cycling, and energy transfer to both the aquatic and terrestrial communities (Naiman et al. 1993). Yet there is still a lack of information regarding the role of riparian vegetation in structuring specifically the fish community and the formation of the stream macrohabitat (i.e. pools, riffles, runs) in this region of the United States. In addition, it is still unclear how some human land use activities such as grazing can impact riparian areas (Rinne 1999) when other human land use activities such as flow modification have been shown to alter the riparian plant communities (Merritt and Cooper 2000; Obedzinski et al. 2001; Stromberg et al. 2003; Stromberg and Tellman 2009). It is important to know the relationship of riparian vegetation condition and human land use of grazing to fish populations of the arid southwestern United States to better manage riparian areas accordingly. Therefore, the objective of my study was to examine the relationship riparian vegetation condition human land use activity of grazing has in structuring stream macrohabitat and fish presence.

METHODS

Study Sites

My study encompassed four streams (Blue River, Eagle Creek, Tonto Creek, and Verde River) located in central Arizona off the Mogollon Rim (Figure 1.1). Study streams were selected based on prioritization by professionals from the U.S. Fish and Wildlife Service (USFWS), U.S. Forest Service (USFS), Arizona Game and Fish Department (AZGFD), and University of Arizona's School of Natural Resources (UA SNRE).

The Blue River is an 81-km stream that starts outside of Alpine, Arizona at an elevation of 2000-m and flows south into San Francisco River. Average discharge in the Blue River ranges from 0.27 to 4.30 m^3/s (U.S. Bureau of Reclamation 2010). The riparian area of the Blue River comprises Narrowleaf Cottonwood *Populus angustifolia*, Fremont's Cottonwood, Goodding's Willow *Salix*, Arizona Sycamore *Platanus wrightii*, Walnut *Juglans* spp., Arizona Alder *Alnus oblongifolia*, Willow *Salix* spp., Seepwillow *Baccharis salicifolia*, and Ponderosa Pine *Pinus ponderosa* (U.S. Bureau of Reclamation 2010). Native fish that have been captured in Blue River include Desert Sucker *Catostomus clarkii*, Sonora Sucker *Catostomus insignis*, Roundtail Chub *Gila robusta*, Loach Minnow *Rhinichthys cobitis*, Spikedace *Meda fulgida*, Speckled Dace *Rhinichthys osculus*, and Longfin Dace *Agosia chrysogaster* (U.S. Bureau of Reclamation 2010). Non-native fish that have been captured in the Blue River include Largemouth Bass *Micropterus salmoides*, Red Shiner *Cyprinella lutrensis*, Common Carp *Cyprinus carpio*, Flathead Catfish *Pylodictis olivaris*, Channel Catfish *Ictalurus punctatus*, Fathead Minnow *Pimephales promelas*, Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, Brook Trout *Salvelinus* *fontinalis,* Western Mosquitofish *Gambusia affinis,* and Green Sunfish *Lepomis cyanellus* (U.S. Bureau of Reclamation 2010).

Eagle Creek is an 84-km stream located in southeast Arizona (Marsh et al. 1991). A perennial reach, which started on the south slopes of the White Mountains in eastern Arizona at an elevation of 2800-m, flowed to the confluence of the Gila River. Average discharge in Eagle Creek was 0.94 m^3/s (Minckley and Sommer 1979). Riparian areas in the upper reaches of Eagle Creek contained a mix of Fremont's Cottonwood, Goodding's Willow, Arizona Sycamore, and Walnut while lower reaches were dominated by Seepwillow and Burrobush *Hymenoclea monogy* (Marsh et al. 1991). Historically, the native fish assemblage of Eagle Creek has included Desert Sucker, Sonora Sucker, Razorback Sucker *Xyrauchen texanus,* Roundtail Chub, Loach Minnow, Spikedace, Speckled Dace, and Longfin Dace (Marsh et al. 1991). Several non-native species have been introduced such as Largemouth Bass, Smallmouth Bass *Micropterus dolomieu,* Yellow Bullhead *Ameiurus natalis,* Red Shiner, Common Carp, Flathead Catfish, Channel catfish, Fathead Minnow, Rainbow Trout, Western Mosquitofish, and Green Sunfish (Marsh et al. 1991).

Tonto Creek is a 117-km stream that starts outside of Payson, Arizona at an elevation of 1500-m and flows south into Roosevelt Lake, which is a reservoir of the Salt River system. Average discharge in Tonto Creek ranged from 0.57 to 3.13 m^3/s (Schumann and Thomsen 1972). The riparian vegetation varied, from conifer to desert-scrub dominated, throughout Tonto Creek due to changes in elevation (Robson and Banta 1995). Broadleaf trees such as Fremont's Cottonwood, Goodding's Willow, Arizona Sycamore, Saltcedar, and Mesquite were common across the entire riparian area (Robson and Banta 1995). Tonto Creek contained both native and non-native fish species. Native fishes that have been found in Tonto Creek include Desert

Sucker, Sonora Sucker, Roundtail Chub, Loach Minnow, Speckled Dace, and Longfin Dace (Leon 1993). Non-native fish have included Yellow Bullhead, Red Shiner, Common Carp, Channel catfish, Fathead Minnow, Rainbow Trout, Brown Trout, Brook Trout, Western Mosquitofish, and Green Sunfish (Leon 1993).

The Verde River is a 274-km perennial stream located in central Arizona. The stream starts near Prescott, Arizona at an elevation of 1300-m and flows east of Phoenix, Arizona into the Salt River. Average discharge ranged from 0.65 to 3.62 m^3/s (Neary and Rinne 1997), and native vegetation along the stream included Fremont's Cottonwood and Goodding's Willow and non-native vegetation included Saltcedar and Giant Reed (Neary et al. 2012). The Verde River historically had high native fish diversity according to archeological records (Minckley and Alger 1968). Remnants of Desert Sucker, Sonora Sucker, Razorback Sucker, Roundtail Chub, and Colorado Pikeminnow *Ptychocheilus lucius* were located in Perkinsville (Minckley and Alger 1968). Other notable native species that were historically present and distributed throughout the Verde River were Gila Chub *Gila intermedia*, Flannelmouth Sucker *Catostomus latipinnis*, Loach Minnow, Spikedace, Speckled Dace, and Longfin Dace (Neary et al. 2012). However, over the last several decades most of these species have declined or have been extirpated from the Verde River as the river has shifted to a non-native fish species dominated system that includes Largemouth Bass, Smallmouth Bass, Yellow Bullhead, Red Shiner, Common Carp, Flathead Catfish, and Green Sunfish (Rinne 2005).

Fish and Habitat Sampling

I sampled a total of 1,235 grids across 39 access points over the four study streams between May 15 and August 15, 2017. Access points were selected either randomly or in streams where access was limited, all access points were used. At each access point, I selected 30 or 60 sampling grids. A random starting location was chosen and I then moved upstream randomly selecting grids 15-40 m from the last grid and along a perpendicular axis to the stream. The number of sample grids varied among study streams (Table 1.1). All grids were sampled during daylight hours during summer base flows.

Sampling of Fish and Related Variables.— Fish sampling was conducted using a prepositioned areal electrofishing device (PAEDs, Bain et al. 1985). Arrays comprised of two, 1.5-m long by 1.3-cm diameter aluminum pipes, which were the electrodes, attached to a 3-m long extension cord. The electrodes were powered by a 2,500-watt generator that was hidden on shore. Electrodes were placed on the bottom of the streambed parallel to stream flow at a distance of 1 m apart providing a sample grid area of 1.5 m^2. After placement, electrodes were left undisturbed for a minimum of 11 minutes to allow fish to recolonize the previously disturbed area (Bain et al. 1985) before alternating current (AC) was delivered to the electrodes for 15 seconds by a hidden on-shore operator. While current was being applied to the electrodes, two crew members positioned downstream with dip nets moved upstream into the sample grid to capture all stunned fish. After the current was delivered, crew members continued collecting any fish that were trapped in substrate. Fish were identified to species and total length (TL mm) was measured. The PAEDs were used to collect fish to decrease the chance of fright bias and minimize differences in capture efficiency related to size, species, and habitat sampled compared to other electrofishing techniques (Bain et al. 1985).

After fish were collected, several habitat variables were measured at each grid. Depth (cm) and velocity (m/s) were measured using a USGS Pygmy Current Meter (Rickly Hydrological Company, Columbus, Ohio) at each of the four corners of the PAEDs. All four measurements were averaged for an overall mean depth and mean velocity for each grid. Substrate size was classified using a modified Wentworth scale (Table 2.1; Bain and Stevenson 1999 and Bonar et al. 2010). A meter-long chain with ten equally-spaced segments was randomly placed in the 1.5 m^2 sample grid. Substrate size was measured at each segment and then averaged for a mean substrate value for a grid. Capture temperature (˚C) was measured at the surface of each grid using an ISO-calibrated thermometer. A convex spherical densitometer was used to estimate percent canopy cover above each grid. Spherical densiometer measurements followed the procedures of Lemmon (1956). The total number of unoccupied imaginary dots within the cells was counted. Then the measurement was multiplied by 1.04 and subtracted from 100 to calculate percent canopy cover. Measurements were taken in all four cardinal directions and averaged. Macrohabitat was classified as pool, riffle, or run according to Arend (1999). Detectable grazing was noted visually in the field at the immediate banks adjacent of each grid by the presence of ungulate tracks, grazed vegetation, or manure. Land cover type (non-forested or forested) was categorized on both sides of the banks immediately adjacent to each grid in the field. “Non-forested” consisted of land that was grass, bare ground, or rock and forested consisted of shrubs, tree, or mix of both. Grids were georeferenced using ArcGIS Desktop (Esri, Redlands, California) on Latitude 12 Rugged Tablet (Dell Computer Company, Round Rock, Texas).

Sampling of Macrohabitat and Related Variables.— Both additional variables and variables above were used to see how they were related to macrohabitat measured at each grid. I used the classification of macrohabitat and the measurements of velocity, depth, substrate, percent canopy cover, detectable grazing and derived stream gradient from the summer 2017 field season and percent vegetation cover in buffers around all access points was obtained using

GIS methods and aerial imagery. Using ArcGIS Pro (Esri, Redlands, California), I digitalized centerlines along the thalweg in a stream segment from National Agricultural Imagery Program (NAIP) aerial imagery (U.S. Department of Agriculture 2018). The 2017 NAIP was used due to its high resolution, 60-cm, and that it was developed at the same time sampling occurred. The centerline started at the most downstream grid at each stream segment and extended upstream to include all grids within that stream segment. The upstream boundary of the reach was extended until the estimated mean velocity was greater than 1.00 m/s from the National Hydrological Dataset Plus Version 2 (USEPA and USGS 2018). Differences in estimated mean velocities were used as the upstream boundary of center lines due to macrohabitat types having different velocities and high stream velocities could possibly restrict upstream movement of certain fish species (Arend 1999; Ward et al. 2003). After centerlines were digitalized, 20-m buffers were created around the centerlines. Buffer width was determined based on literature stating the minimum width to maintain stream temperature was 10-m from each stream bank (Barton et al. 1985). Buffer width was expanded to 50-m for the Verde River to account for wide sections of river (~30-m). I classified forested land cover type within each buffer using the 2017 NAIP imagery. The percentage of forested land cover type for each buffer was extracted and used as continuous variables in multinomial logistic regression for macrohabitat type. Gradient was also extracted and used in the models (National Hydrological Dataset Plus Version 2). I used in-field measurements of land cover type and cross categorized with the predicted land cover type to see how well the classification performed. Predicted land cover type was determined by seeing what cover type was predicted that was adjacent to each sample grid on both sides of the banks plotted in ArcGIS.

Data Analysis

I used multivariate statistical analyses to evaluate effects of interacting habitat and riparian variables on fish and macrohabitat presence. Explanatory variables were tested for multicollinearity using a correlation matrix (Petre and Bonar 2017). If explanatory variables had significant associations ($r > 0.5$) between other explanatory variables they were further removed from the analysis.

Sampling of Fish and Related Variables.— I used binomial logistic regression to model the presence of certain fish species due to the binary response of presence or absence and the numerous environmental variables that describe the habitat and the extent of the riparian area (Manly et al. 2002). Presence was defined as if a certain species was detected in the sample grid when absence was defined as if a certain species was not detected in the sample grid. Mean depth, mean velocity, mean substrate, capture temperature, and percent canopy cover were modeled as continuous variables, while presence/absence of native and non-native fishes, detectable grazing (observed ungulate tracks, grazed vegetation, or manure at the immediate banks adjacent of each grid), and macrohabitat type were included as categorical variables. The models were refitted using backwards elimination, which removed any variables based on estimated chi square probabilities ($P > 0.05$) and effect likelihood ratio tests ($P > 0.05$). Likelihood-ratio tests were done to compare the goodness of fit between models. A McFadden's R^2 was calculated for each model, which is defined as:

$$1 - ln(LM_1)/ln(LM_0)$$

The value $ln(LM_1)$ is the log likelihood value for the fitted model and $ln(LM_0)$ is the log likelihood for the null model with only an intercept as a predictor. The measure ranges from 0 to 1, with values closer to zero indicating that the model has no predictive power.

To assess the classification performance of each model a confusion matrix was used (Ramsey and Schafer 2012). A confusion matrix is a 2 × 2 table with “False” and “True” columns and “0” and “1” rows. The columns represent whether the models predicted the species to be absent or present. The rows represent whether species were actually absent or present. A true positive, which is in the bottom-right quadrant of the table, indicates the models predicted the species to be present and the species was present. A true negative, which is in the top-left quadrant of the table, indicates the models predicted the species to be absent and the species were absent. A false positive, which is in the top-right quadrant of the table, indicates the models predicted the species to be present, but the species was actually absent (Type 1 error). A false negative, which is in the bottom- left quadrant of the table, indicates the models predicted the species to be absent, but the species was actually present (Type II error). The estimated models predicted values using a training data set, which was a 60% randomly-chosen subset of the whole data set.

Overall accuracy of the models was reported as area under the receiver operator curve (AUC, Fielding and Bell 1997). Values greater than 0.9 indicated a high accuracy model, values between 0.7-0.9 were deemed useful, while values lower than 0.7 were considered low accuracy (Manel et al. 2001).

Data analysis was conducted in R/Rstudio Version 1.1.456 using the following packages Hmisc, magrittr, and ROCR (Sing et al. 2005; Bache and Wickham 2014; R Core Team 2016; RStudio Team 2016; Harrell 2018).

Sampling of Macrohabitat and Related Variables.— I used a multinomial logistic regression model to examine relationships between presence of a specific macrohabitat type and other habitat variables because the response variable (macrohabitat type) had more than two levels of a nominal response. The model estimates individual logistic regressions for each response variable. The separate models express the effect predictor variables have on the probability of success of that specific response variable in comparison to a reference category. Riffle macrohabitat was set as the reference category. Mean depth, mean velocity, mean substrate, percent canopy cover, percentage of forested and stream gradient were modeled as continuous variables while detectable grazing was included as a categorical variable. The model was refitted using Akaike information criteria (AIC; Ramsey and Schafer 2002). If the ΔAIC between two models was ≥ 2 than the model was refitted until ΔAIC was < 2 and the model with the lower AIC was selected. A McFadden's R^2 and confusion matrix was calculated for the multinomial logistic regression model.

RESULTS

Sampling of Fish and Related Variables.— I found no multicollinearity among the explanatory variables tested; therefore, no significant interactions between explanatory variables. I developed logistic regression models for Desert Sucker, Longfin Dace, Speckled Dace, Smallmouth Bass, and Red Shiner due to their presence in several study streams. The models had a significantly greater fit than empty models just including the intercept. There was no significant difference in fit between the full and revised models. My models predicted over 75% species absence and presence correct and had AUCs over 0.70. Substrate type was positively related and presence of non-native fishes and pool macrohabitat were negatively related to presence of Desert Suckers (Table 2.2). The model had McFadden's R^2 of 0.08.

The variable of undetectable grazing was positively related and the variables of velocity, depth, and presence of non-native fishes were negatively related to the presence of Longfin Dace (Table 2.3). The model had McFadden's R^2 of 0.11.

The variables of substrate and undetectable grazing was positively related and the variables of velocity, depth, capture temperature, run macrohabitat, and pool macrohabitat were negatively related to the presence of Speckled Dace (Table 2.4). The model had McFadden's R^2 of 0.24.

The variables of velocity, depth, substrate, capture temperature, canopy cover, and presence of native fishes were negatively related to the presence of Smallmouth Bass (Table 2.5). The model had McFadden's R^2 of 0.10.

The variables of velocity, capture temperature, and presence of native fishes were positively related and the variables of depth and canopy cover were negatively related to the presence of Red Shiner (Table 2.6). The model had McFadden's R^2 of 0.24.

Sampling of Macrohabitat and Related Variables.— Velocity, depth, substrate, stream gradient, and percent forested were significant variables in regards to distinguishing macrohabitat type in the multinomial regression (Table 2.7). with forested areas being more associated with riffle and run habitat than pool habitat, and higher gradient areas associated more with riffles than runs or pools. The negative log likelihood was 579.97 with residual deviance of 1159.94. The McFadden's R^2 was 0.52 and AIC of 1191.94. My model predicted 79% of macrohabitat type correct.

DISCUSSION

The presence of Desert Sucker and Speckled Dace was negatively related to presence of pool macrohabitat coincides with past studies that these species prefer more riffle habitat (Rinne 1992). Macrohabitat type was not significantly related to Longfin Dace presence agreeing with others who consider the fish a habitat generalist (Minckley and Marsh 2009).

Longfin Dace and Specked Dace were more likely to occupy grids in reaches that didn’t appear to be grazed. The other fish species I examined (Desert Sucker, Smallmouth Bass, Red Shiner) showed no relationship with grazing. Studies have shown fish communities respond negatively to cattle grazing (Behnke and Zarn 1976; Lyons et al. 2000). Specifically, grazing can cause indirect negative effects on fish via increased nutrient loading and degrading streambanks, which leads to increase in-stream sedimentation (Wohl and Carline 1996; Sovell et al. 2000). Although undetectable grazing was found to be significantly related to the presence of two native fish species my study does not account for density, severity, seasonality, or type of grazer. My study indicates that grazing should be further investigated as a concern. More detailed studies of effects of the type and amount of riparian grazing, and if overlying factors may be responsible for the relationships are warranted.

Presence of Longfin Dace and Desert Sucker was negatively related to presence of nonnative fishes. My findings support studies that have shown that nonnative fish negatively impact the native fish community of the southwest U.S. (Minckley and Deacon 1991). Presence of nonnative fishes was not significantly related to the presence of Speckled Dace, likely because streams inhabited by Speckled Dace, Blue River and Eagle Creek, had few nonnative fishes. The Blue River had one grid with one nonnative fish out of a total of three hundred grids. Eagle Creek had six grids with nine nonnative fish out of a total of two hundred and forty grids. Presence of native fishes was a significant positive coefficient for the presence of Smallmouth

Bass and Red Shiner. Nonnative fishes have been shown to prey upon or displace native fishes in Arizona (Minckley and Deacon 1991; Rinne 1991); therefore presence of these particular species of native fish benefits and does not hamper the presence of nonnative fishes.

Percent canopy cover was not a significant factor in predicting the presence of all three native fish species, suggesting that other habitat, biological, and land-use variables are more influential in determining their distributions. However, percent canopy cover was inversely related to presence of Smallmouth Bass and Red Shiner. Yu and Peters (2002) saw no positive relationship between cover and Red Shiner presence. Studies have shown that Smallmouth Bass prefer instream cover over open water (Probst et al. 1984; Todd and Rabeni 1989). Instream cover may include boulders, logjams, and rootwads. Reason that canopy cover was negatively related to Smallmouth Bass presence is possibly due to the lack in availability of these cover types. High temperature tolerance limits of both species could be another factor. Clancey (1980) saw that adult Smallmouth Bass have a preferred summer temperature range of 21-27˚C. Also, several studies have shown adult Smallmouth Bass grow faster with increased summer temperatures (Doan 1941; Brown 1961; Forney 1972). Red Shiner has been shown to tolerate and even prefer warm temperatures in several studies (Matthews and Hill 1977; Carveth et al. 2006; and Bonar et al. 2010).

My models were better at predicting species absence than presence. This can be due to the unequal amount of presence and absence data which can affect the coefficients estimates and legitimacy of models (Hosmer and Lemeshow 2000). Petre and Bonar (2016) saw that more absence than presence data resulted in a model that predicted a species absence better than presence. My models are still insightful on what habitat variables are important in regarding species presence and powerful at predicting species absence.

Stream macrohabitat is the dynamic relationship between slope, sediment supply, and discharge (Allan and Castillo 2007). This is indicative in my study because gradient was a significant coefficient in both models. As gradient increased the more likely the habitat was to be a pool and run rather than a riffle. On a larger scale, percentage of vegetation cover was seen as a significant coefficient showing riparian area relates to macrohabitat in streams. I found significant relationship between land cover types and stream macrohabitat, with forested areas being more associated with riffle and run habitat than pool habitat.

I was only able to classify land cover type into broad categories even when using high resolution aerial imagery. Vegetation type is an important consideration due to the differences in shading and bank stabilization (Simon and Collison 2002). More specific vegetation types were noted in the field but not quantified making it difficult to analyze. The supervised classification predicted about 70% of the land cover type correct. Errors in the supervised classification may have been due to differences in seasonality of when the aerial imagery was taken and ground truth of bank vegetation. Even though the geospatial analysis did not account for vegetation type it still was able to show that land cover type within riparian areas was significantly related to macrohabitat type.

CONCLUSION

Riparian areas are an essential ecosystem to the flora and fauna of the southwestern United States but the relationships between riparian vegetation and the Southwestern fish communities and macrohabitat presence are less understood. Here I studied relationships among riparian area vegetation and fish species presence and macrohabitat type. I saw that two nonnative species, Smallmouth Bass and Red Shiner, were inversely related to increase of canopy cover. This may be explained by the lack of preferred cover types, seasonal or daily use of cover types including no cover, or preferred stream temperatures. Also, cover was not significantly related to the presence of Desert Sucker, Longfin Dace, and Speckled Dace. Undetectable grazing was significantly related to presence of Longfin Dace and Speckled Dace. Grazing may alter the amount of nutrients, sediments, or thermal regime of streams therefore negatively impacting these two species. This work should be considered an initial step in identifying that relationships between cover and grazing and presence of native Arizona fishes exist. Further studies with before/after/treatment/control (BACI) or other experimental designs are required to definitively state that grazing and other human activities within riparian areas causes absence of the fish species I examined.

Macrohabitat was related to gradient and the amount of forested land cover type within the immediate area of the study streams. Stream gradient was more associated with pool and run habitat than riffle habitat type. Forested land was more associated with riffle and run than pool habitat type. Again, now that relationships have been identified, experimental designs such as BACI could be used to test cause and effect relationships.

TABLES

Table 2.1– Wentworth scale for the classification of instream substrate types (from Bain and Stevenson 1999, taken from Bonar et al. 2010).

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

Table 2.2– Parameter estimates and associated values for explanatory variables in logistic regression analysis for Desert Sucker in Blue River, Eagle Creek, and Tonto Creek ($P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	-0.86	0.65	-1.33	0.1842
Depth (cm)	0.00	0.00	0.02	0.9861
Velocity (m/s)	-0.89	0.59	-1.49	0.1358
Substrate (Wentworth)	0.40	0.10	3.84	<0.0001***
Temperature (˚C)	-0.04	0.03	-1.60	0.1089
Canopy Cover (%)	0.00	0.00	-1.18	0.2396
Nonnative (presence)	-1.34	0.36	-3.74	<0.0001***
Undetectable Grazing	0.22	0.20	1.09	0.2774
Macrohabitat:Run	-0.33	0.23	-1.47	0.1419
Macrohabitat:Pool	-1.38	0.49	-2.81	0.005**
Revised				
Intercept	-1.86	0.37	-5.03	<0.0001***
Substrate (Wentworth)	0.35	0.10	3.53	0.0004***
Nonnative (presence)	-1.31	0.32	-4.03	<0.0001***
Macrohabitat:Run	-0.23	0.21	-1.12	0.2627
Macrohabitat:Pool	-1.12	0.33	-3.42	0.0006***

Table 2.3– Parameter estimates and associated values for explanatory variables in logistic regression analysis for Longfin Dace in Blue River, Eagle Creek, and Tonto Creek ($P \leq 0.05$*, $P \leq 0.01$**, $P \leq 0.001$***).

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	0.11	0.64	0.17	0.8642
Depth (cm)	-0.03	0.01	-3.56	0.0003***
Velocity (m/s)	-3.51	0.66	-5.32	<0.0001***
Substrate (Wentworth)	0.07	0.09	0.76	0.4489
Temperature (˚C)	0.01	0.02	0.34	0.7739
Canopy Cover (%)	0.00	0.00	-0.43	0.6678
Nonnative (presence)	-1.74	0.33	-5.26	<0.0001***
Undetectable Grazing	0.52	0.20	2.58	0.0091**
Macrohabitat:Run	0.13	0.23	0.58	0.5629
Macrohabitat:Pool	-0.78	0.44	-1.79	0.0729
Revised				
Intercept	0.38	0.36	1.05	0.2937
Depth (cm)	-0.03	0.01	-3.52	0.0004***
Velocity (m/s)	-3.47	0.66	-5.29	<0.0001***
Nonnative (presence)	-1.64	0.31	-5.32	<0.0001***
Undetectable Grazing	0.54	0.20	2.70	0.0070**
Macrohabitat:Run	0.10	0.22	0.45	0.6525
Macrohabitat:Pool	-0.82	0.41	-1.98	0.0481*

Table 2.4– Parameter estimates and associated values for explanatory variables in logistic regression analysis for Speckled Dace in Blue River, Eagle Creek, and Tonto Creek ($P \leq 0.05{*}$, $P \leq 0.01{**}$, $P \leq 0.001{***}$).

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	**1.84**	**0.65**	**2.81**	**0.0050^{**}**
Depth (cm)	**-0.03**	**0.01**	**-3.19**	**0.0014^{**}**
Velocity (m/s)	**-2.95**	**0.62**	**-4.76**	**$<0.0001^{***}$**
Substrate (Wentworth)	**0.39**	**0.11**	**3.70**	**0.0002^{***}**
Temperature (˚C)	**-0.09**	**0.03**	**-3.79**	**0.0001^{***}**
Canopy Cover (%)	**0.00**	**0.00**	**-0.34**	**0.7314**
Nonnative (presence)	**-17.75**	**491.99**	**-0.04**	**0.9712**
Undetectable Grazing	**0.42**	**0.21**	**2.02**	**0.0434^{*}**
Macrohabitat:Run	**-0.48**	**0.23**	**-2.05**	**0.0400^{*}**
Macrohabitat:Pool	**-1.75**	**0.53**	**-3.32**	**0.0009^{***}**
Revised				
Intercept	**1.76**	**0.61**	**2.87**	**0.0041^{**}**
Depth (cm)	**-0.03**	**0.01**	**-3.21**	**0.0013^{**}**
Velocity (m/s)	**-2.94**	**0.62**	**-4.74**	**$<0.0001^{***}$**
Substrate (Wentworth)	**0.39**	**0.10**	**3.69**	**0.0002^{***}**
Temperature (˚C)	**-0.09**	**0.03**	**-3.78**	**0.0001^{***}**
Nonnative (presence)	**-17.73**	**491.90**	**-0.04**	**0.9712**
Undetectable Grazing	**0.43**	**0.21**	**2.04**	**0.0412^{*}**
Macrohabitat:Run	**-0.47**	**0.23**	**-2.03**	**0.0425^{*}**
Macrohabitat:Pool	**-1.73**	**0.53**	**-3.31**	**0.0009^{***}**

Table 2.5– Parameter estimates and associated values for explanatory variables in logistic regression analysis for Smallmouth Bass in Tonto Creek and Verde River ($P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	2.31	0.99	2.34	0.0191*
Depth (cm)	-0.02	0.01	-4.60	<0.0001***
Velocity (m/s)	-1.47	0.65	-2.26	0.0237*
Substrate (Wentworth)	-0.22	0.09	-2.49	0.0129*
Temperature (˚C)	-0.04	0.04	-1.10	0.2722
Canopy Cover (%)	-0.01	0.00	-2.52	0.0119*
Native (presence)	-1.36	0.39	-3.46	0.0006***
Undetectable Grazing	-0.15	0.23	-0.66	0.5126
Macrohabitat:Run	0.27	0.32	0.83	0.4061
Macrohabitat:Pool	-0.49	0.43	-1.14	0.2340
Revised				
Intercept	1.23	0.46	2.66	0.0078**
Depth (cm)	-0.02	0.01	-4.66	<0.0001***
Velocity (m/s)	-1.38	0.64	-2.15	0.0317*
Substrate (Wentworth)	-0.22	0.09	-2.59	0.0097**
Canopy Cover (%)	-0.01	0.00	-2.46	0.0137*
Native (presence)	-1.39	0.39	-3.55	0.0004***
Macrohabitat:Run	0.30	0.32	0.93	0.3503
Macrohabitat:Pool	-0.46	0.43	-1.08	0.2793

Table 2.6– Parameter estimates and associated values for explanatory variables in logistic regression analysis for Red Shiner in Tonto Creek and Verde River ($P \leq 0.05$*, $P \leq 0.01$, $P \leq 0.001$***).**

	Parameter Estimate	SE	*Z*	*P*
Full				
Intercept	-3.51	1.48	-2.37	0.0178*
Depth (cm)	-0.05	0.01	-5.46	<0.0001***
Velocity (m/s)	2.38	0.72	3.33	0.0009***
Substrate (Wentworth)	-0.09	0.13	-0.72	0.4706
Temperature (˚C)	0.14	0.06	2.50	0.0123*
Canopy Cover (%)	-0.01	0.01	-2.53	0.0114*
Native (presence)	1.08	0.33	3.29	0.0010***
Undetectable Grazing	0.03	0.31	0.11	0.9149
Macrohabitat:Run	-0.33	0.37	-0.87	0.3856
Macrohabitat:Pool	0.33	0.52	0.63	0.5288
Revised				
Intercept	-3.93	1.39	-2.83	0.0047**
Depth (cm)	-0.05	0.01	-5.80	<0.0001***
Velocity (m/s)	2.03	0.55	3.73	0.0001***
Temperature (˚C)	0.15	0.05	2.78	0.0053**
Canopy Cover (%)	-0.02	0.01	-2.95	0.0032**
Native (presence)	1.05	0.32	3.25	0.0011**

Table 2.7– Parameter estimates and associated values for explanatory variables in full logistic regression analysis for macrohabitat type in all four study streams ($P \le 0.05^{*}$, $P \le 0.01^{**}$, $P \le 0.001^{***}$).

	Parameter Estimate	SE	*Z*	*P*
Intercept				
Run	3.28	0.52	6.37	$<0.0001^{***}$
Pool	4.35	0.69	6.32	$<0.0001^{***}$
Depth (cm)				
Run	0.08	0.01	8.70	$<0.0001^{***}$
Pool	0.14	0.01	12.85	$<0.0001^{***}$
Velocity (m/s)				
Run	-5.27	0.53	-9.91	$<0.0001^{***}$
Pool	-24.07	1.71	-14.08	$<0.0001^{***}$
Substrate (Wentworth)				
Run	-0.96	0.11	-8.61	$<0.0001^{***}$
Pool	-1.22	0.15	-8.38	$<0.0001^{***}$
Canopy Cover (%)				
Run	0.00	0.00	-1.42	0.1569
Pool	0.00	0.01	0.23	0.8177
Undetectable Grazing				
Run	-0.19	0.21	-0.91	0.3644
Pool	-0.56	0.33	-1.71	0.0868
Gradient (m/km)				
Run	36.87	0.01	5943.54	$<0.0001^{***}$
Pool	37.23	0.01	5934.42	$<0.0001^{***}$
Forested (%)				
Run	0.01	0.01	0.66	0.5113
Pool	-0.03	0.01	-2.42	0.0153^{*}

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