FISHES OF THE MAINSTEM RIO GRANDE; BERNALILLO TO FORT CRAIG, NEW MEXICO

June 1999 through June 2001

With an emphasis on Rio Grande silvery minnow, *Hybognathus amarus* (Girard)

FINAL REPORT

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EXECUTIVE SUMMARY

Between June 1999 and June 2001, the Rio Grande, New Mexico was sampled between Bernalillo and Fort Craig. This represents the majority of the remaining range for the Rio Grande silvery minnow (*Hybognathus amarus*). A total of 116,605 fish were collected in 11,152 seine hauls that covered 251,110 m^2. The fish community was primarily associated with shallow depth and slow velocity. Fluvial and sensitive native fish species have mostly disappeared from the study area. Flathead chub and longnose dace are more typical of headwater streams and maintain limited presence while Rio Grande silvery minnow, the sole remaining representative of the mainstem Rio Grande fluvial fish community, is in steep decline. Otherwise, the fish community is homogenized, with a few widespread species having variable success, depending upon reach-specific habitat conditions.

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INTRODUCTION

This report includes data from a series of efforts to document Rio Grande silvery minnow (*Hybognathus amarus*) status. Rio Grande silvery minnow was listed as an endangered species in 1979 by the New Mexico Department of Game and Fish (Propst 1999), in 1994 by the U.S. Fish and Wildlife Service (1994), and in 1994 by the Republic of Mexico (SDS 1994). Historically, the species was known from the mainstem Rio Grande, Rio Chama, and Pecos River of New Mexico and Texas, U.S.A.; and Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas, Mexico (Bestgen and Platania 1991; Bestgen and Propst 1994; U.S. Fish and Wildlife Service 1999).

The current range of Rio Grande silvery minnow includes the mainstem Rio Grande between Cochiti Dam and the headwaters of Elephant Butte Reservoir, as well as the Rio Jemez below Jemez Canyon Dam, totaling about 290 km. The population is concentrated in three reaches that compose the central portion of the occupied area (Dudley and Platania 2001, 2002). Diversion dams separate and control the downstream flow regime of each reach (U.S. Fish and Wildlife Service 1999). The influence of irrigation return flow, tributary inflow, and riverside drains on river system stability in the Rio Grande also varies among reaches (Lagasse 1994). The upstream-most of the three central reaches is Angostura Reach, extending from Angostura Dam downstream to Isleta Dam. Next downstream is Isleta Reach, extending from Isleta Dam to San Acacia Dam. San Acacia Reach extends downstream from San Acacia Dam to the headwaters of Elephant Butte Reservoir. San Acacia Reach comprises the final Rio Grande Silvery minnow stronghold (Dudley and Platania 2001, 2002).

Analyses of recent Rio Grande silvery minnow distribution and abundance documents the continued decline of the species (Bestgen and Platania 1991; Platania 1991, 1993a, 1993b, 1995; Lang and Altenbach 1994; Dudley and Platania 1997, 1999, 2000; Smith and Hoagstrom 1997; Smith 1999). In general, these efforts indicated decreasing abundance in Angostura, Isleta, and San Acacia reaches, with most Rio Grande silvery minnow collections and highest abundance occurring in San Acacia Reach.

Few data are available regarding Rio Grande silvery minnow status outside of the three central reaches. Collections in Cochiti Reach (which extends from Cochiti Dam to Angostura Dam including Cochiti, San Felipe, and Santo Domingo pueblos) have not documented Rio Grande silvery minnow since 1994. Cochiti Reach collections in 1984 yielded Rio Grande silvery minnow at sites within Cochiti and San Felipe pueblos (Platania 1991), but surveys at the Cochiti Pueblo site in 1993 (Platania 1993a) and failed to produce the species. Surveys of sites within Santo Domingo and San Felipe pueblos in 1994 documented the presence of Rio Grande silvery minnow (Platania 1995), while surveys in Cochiti and San Felipe sites between 1995 and 1999 failed to produce Rio Grande silvery minnow. There have been no documented surveys in Cochiti Reach since 1999, therefore it must be assumed that the species could persist, albeit in low numbers. However, the Rio Grande downstream of Cochiti Dam continues to change in response to altered water and sediment flow regimes (Richard 2001) and effects of these changes on the Rio Grande silvery minnow population are unknown.

Rio Grande silvery minnow distribution and abundance within Elephant Butte Reservoir has not been documented, but a single collection in the inflow delta in 1998 produced a single adult (75mm) Rio Grande silvery minnow (Broderick 2000). The habitat was described as reservoir, lentic habitat with silt substrate. Other *Hybognathus* species described as a fluvial species, such as plains minnow, *Hybognathus placitus*, have shown persistence in a reservoir system after 50 years of impoundment, albeit in greatly reduced numbers (Lienesch et al. 2000). A single collection of one individual does not affirm the fact that Rio Grande silvery minnow can persist in Elephant Butte Reservoir, but it is possible that Rio Grande silvery minnow may periodically use the Elephant Butte delta.

Rio Grande silvery minnow are sometimes collected from irrigation canals and drains (Painter 1979; Lang and Altenbach 1994; Smith and Hoagstrom 1997). Painter (1979) sampled the Middle Rio Grande Conservancy District (MRGCD), off-channel ponds, the Low Flow Conveyance Channel (LFCC), along with the Rio Grande in August through October, 1978. Most of his samples from the river were within abandoned pools or short stretches of flowing water because flows in the Rio Grande were low (Painter 1979). Overall, Rio Grande silvery minnow was the third most abundant species he collected, representing 11.0% of the total catch. Painter (1979) took more than three times as many samples from canals, drains, ponds, and the LFCC as from the Rio Grande, but half of the Rio Grande silvery minnow collections were from the Rio Grande. Rio Grande silvery minnow were found in 81.8% (18 of 22) of his Rio Grande samples, but only in 41.2% (28 of 68) of his canal, drain, pond, and LFCC samples (Painter 1979).

Lang and Altenbach (1994) surveyed MRGCD canals and drains in 1993, collecting a total of 114 young-of-the-year Rio Grande silvery minnow. Of these, 106 were captured within Belen Division (= Isleta Reach) (Lang and Altenbach 1994). Smith and Hoagstrom (1997) surveyed the LFCC between 1995 and 1997 prior to and immediately following the experimental re-operation (diversion of Rio Grande flow into the LFCC in April through July 1997) of this facility. Prior to re-operation, Rio Grande silvery minnow were rare (August 1995 through April 1997 electrofishing catch rate = 0.10 fish / hour), but the survey immediately following re-operation indicated the species was abundant in the LFCC (August 1997 electrofishing catch rate = 129.85 fish / hour). The catch rate for Rio Grande silvery minnow declined on a monthly basis thereafter. Low Rio Grande silvery minnow frequency of occurrence in canals and drains (Painter 1979; Lang and Altenbach 1994), predominance of young-of-the-year when present (Lang and Altenbach 1994), and dramatic abundance increase following LFCC operation (Smith and Hoagstrom 1997) suggest Rio Grande silvery minnow drains and canal populations are ephemeral, representing individuals displaced from the Rio Grande.

Rio Grande silvery minnow is the sole remaining species of the native fluvial minnow guild including five species that occupied main channel habitats of the Rio Grande and its largest tributaries in New Mexico. Fluvial fishes (including minnows) extirpated from the Rio Grande, New Mexico include Rio Grande speckled chub (*Macrhybopsis aestivalis aestivalis*), Rio Grande shiner (*Notropis jemezanus*), phantom shiner (*Notropis orca*), Rio Grande bluntnose shiner (*Notropis simus simus*), and freshwater drum (*Aplodinotus grunniens*) (Bestgen and Platania 1991). Each of these species likely belonged to a reproductive guild of pelagic spawners (Platania and Altenbach 1998) known as pelagophils (Balon 1975), which broadcast buoyant (freshwater drum) or semi-buoyant eggs (i.e., no nest is prepared and eggs do not adhere to substrate) (Page and Burr 1991). In some cases, eggs develop rapidly, hatch in less than 48 hours, and develop their swim bladder and fins to the point that allows directional swimming within 72 hours (Moore 1944; Bottrell 1962; Bottrell et al. 1964; Sliger 1967; Platania and Altenbach 1998). Thus, eggs and early proto-larvae of pelagophils are susceptible to downstream displacement (Moore 1944), which may partly account for their decline from the diversion dam- and reservoir-dissected reaches of the Rio Grande, New Mexico (Bestgen and Platania 1990; Fausch and Bestgen 1996; Platania and Altenbach 1998). This factor becomes most important in the face of dramatic changes to river geomorphology and flow regime (Lagasse 1981, 1994; Richard 2001). However, other obligate or facultative fluvial fishes that are not pelagophils, such as longnose gar (*Lepisosteus osseus*), American eel (*Anguilla rostrata*) [Note: the American eel is a saltwater pelagophil and was believed extirpated from New Mexico, with recent collections in the Rio Grande likely the result of emigration from privately stocked ponds in Colorado (Sublette et al. 1990)], shovelnose sturgeon (*Scaphirhynchus platorhynchus*), blue sucker (*Cycleptus elongatus*), and gray redhorse (*Moxostoma congestum*) have also disappeared from the Rio Grande, New Mexico (Gehlbach and Miller 1961; Sublette et al. 1990). Therefore, other factors such as loss of ecological function and natural fluvial conditions are likely significant factors in the extirpation of these fishes as well as the decline of pelagophils including Rio Grande silvery minnow.

Native fish species diversity in the Rio Grande, New Mexico has declined (Dudley and Platania 1997), similar to rivers throughout the U.S.A. (Rahel 2000, Scott and Helfman 2001). Within the U.S.A., rivers of southwestern states contain the most altered fish faunas [i.e., the faunas are dominated by tolerant fishes such as red shiner (*Cyprinella lutrensis lutrensis*), common carp (*Cyprinus carpio*), and channel catfish (*Ictalurus punctatus*)], largely because of the success of introduced fishes (Rahel 2000). Fish introductions can negatively impact native fish communities (Minckley 1995), but changes within the composition of the native community (i.e., reduced species diversity) may also indicate negative impacts to a river system (McCormick et al. 2001). Ascension of tolerant native and non-native fishes within a community is often related to changes to the riverine environmental variables such as water temperature, sediment supply, and/or nutrient supply (Cross et al. 1985). In the southwestern U.S.A., a species that has benefited both from introduction into non-native waters and riverine alterations in native streams is the red shiner (Anderson et al. 1983; Cross et al. 1985; Matthews and Gelwick 1990; Gido et al. 1997; Wilde and Ostrand 1999; Bonner and Wilde 2000; Winemiller et al. 2000). Red shiner, a tolerant, native species to the Rio Grande, has become an increasingly dominant species in recent Rio Grande collections while other native species such as Rio Grande silvery minnow have declined (Bestgen and Platania 1991; Platania 1991, 1993a, 1993b, 1995; Lang and Altenbach 1994; Dudley and Platania 1997, 1999, 2000; Smith and Hoagstrom 1997; Smith 1999).

The fish community downstream of Cochiti Dam may still be adjusting to the current flow/sediment regime since storage began in the reservoir in 1973 (Lagasse 1994; Richard 2001). Many studies have documented the effects of dams on downstream fish communities. For example, reservoirs may serve as a source for periodic downstream invasions of inhabitant fishes (Walburg 1971; Walburg et al. 1971). Fish communities below impoundments typically have lower species diversity than pre-dam communities because of reduced habitat diversity and stability (Richards 1976; Anderson et al. 1983; Patton and Hubert 1993; Kinsolving and Bain 1993; Martinez et al. 1994; Travnichek and Maceina 1994; Travnichek et al. 1995; Van Steeter and Pitlick 1998). But, if hypolimnetic dam release reduces river temperature, fishes adapted to cooler waters may become established via introduction or invasion, and the net increase in diversity due to additions of cold-tolerant species may mask the loss of some native species adapted to more natural conditions (Vanicek et al. 1970; Edwards 1978).

Factors other than large dams that reduce Rio Grande flow and subsequently favor tolerant fishes include river diversion, land use change, dispersal barriers and pollution (Dudley and Platania 1997). Large diversion dams in the study area both impound and divert Rio Grande water and may be barriers to upstream dispersal of fishes (Platania 1991). Other factors that may also reduce Rio Grande flow include seepage losses from the river via groundwater pumping (Kelly 1982) and seepage to riverside drains (Theis and Taylor 1939). Increasing urbanization has likely affected runoff patterns (Kelly 1982) and could also increase water pollution (McQuillan 1982). Combinations of these many impacts have likely impacted the fish community of the Rio Grande, New Mexico via changes in flow and water chemistry.

Goals

The historical decline of Rio Grande silvery minnow distribution and abundance coupled with ongoing changes to the Rio Grande where Rio Grande silvery minnow persist has caused concern over the continued survival of the species (Bestgen and Platania 1991; Platania 1991, 1993b; Dudley and Platania 1997, 2002; Smith and Hoagstrom 1997; Smith 1999). Recent declines in abundance within Angostura and Isleta reaches raised this concern to a higher level and were the primary motivation for studies described below. This report is a combination of three separate studies, and is complemented by an account of mesohabitat features associated with Rio Grande silvery minnow collections (Watts et al. 2002). Data collection methods were consistent between the three studies and results are combined here. This report also intends to evaluate the fish community of the three reaches where Rio Grande silvery minnow are best known, with an emphasis on Rio Grande silvery minnow within each fish community.

The primary goal of each study and this entire report was to document Rio Grande silvery minnow distribution and abundance at specific times and within certain river reaches. This report is separated into two chapters. Chapter 1 summarizes the distribution and abundance of all fishes collected including general habitat association of the fish community as a whole. Chapter 2 summarizes species-specific mesohabitat associations and co-occurrence of fish species, including how these associations affect Rio Grande silvery minnow.

METHODS AND MATERIALS

Study Area

Three reaches (Angostura, Isleta, and San Acacia) of the mainstem Rio Grande were surveyed (Figure 1). These reaches represent the core area of Rio Grande silvery minnow distribution. Other waters within the known distribution of Rio Grande silvery minnow not included in this study include Cochiti Reach, Rio Jemez below Jemez Canyon Dam, off-channel canals and drains, and Elephant Butte Reservoir. Cochiti Reach and Rio Jemez were not sampled during this study because of inaccessibility. The canals and drains were not surveyed because they do not sustain persistent Rio Grande silvery minnow populations. Future monitoring of these areas as well as Elephant Butte Reservoir could increase knowledge about distribution and abundance of Rio Grande silvery minnow.

Angostura Reach (61 km) extends from Angostura Diversion Dam to Isleta Diversion Dam, including portions of San Felipe, Santa Ana, Sandia, and Isleta Pueblos, along with the cities of Bernalillo, Corrales, and Albuquerque within Sandoval and Bernalillo counties. Major tributaries confluent with the Rio Grande in Angostura Reach include Rio Jemez, Galisteo Creek, Arroyo de la Barranca, Arroyo de las Lomatas Negras, Albuquerque Metropolitan Area Flood Control Authority (AMAFCA) North Diversion Channel, Arroyo de Calabacillas, and Tijeras Arroyo/AMAFCA South Diversion Channel. Major irrigation and drain returns include Upper Corrales Riverside Drain, La Orilla Drain, Atrisco Riverside Drain, and Albuquerque Riverside Drain. Bridge crossings in this reach include U.S. Highway 550, New Mexico

Highway 528 (Alameda Boulevard), Paseo del Norte, Montaño Road, U.S. Interstate 40, Central Avenue, Bridge Boulevard (Barelas bridge), New Mexico Highway 500 (Rio Bravo Boulevard), U.S. Interstate 25, and Atchison Topeka and Santa Fe (AT&SF) Railroad (on Isleta Pueblo).

A sand-gravel bed dominates Angostura Reach, with the abundance of sand or gravel being variable (Lagasse 1981). Gravel armor is locally common, particularly upstream of Albuquerque where the river channel is degrading. Average bed elevation reduction between Angostura Dam and U.S. Highway 550 bridge was 2.2 m for the period 1971 to 1995 (Baird 2001). This degradation was primarily due to sediment capture by Cochiti and Jemez Canyon dams (Lagasse 1994). Water temperature in this reach is relatively low compared to downstream reaches (Ortiz et al. 2000).

Isleta Reach (90 km) extends from Isleta Diversion Dam to San Acacia Diversion Dam. This reach includes the southern portion of Isleta Pueblo, cities of Bosque Farms, Valencia, Los Lunas, Belen, and smaller villages such as La Joya, and Bernardo, along with Sevilleta National Wildlife Refuge, all within Bernalillo, Valencia, and Socorro counties. Major tributaries confluent with the Rio Grande in this reach include Abo Arroyo, Rio Puerco, Salas Arroyo, Arroyo Los Alamos, Bernardo Arroyo, Cañada Ancha, Canoncito Colorado, Arroyo Rosa de Castillo, and Rio Salado. However, all tributaries (except Abo Arroyo) enter the Rio Grande within the downstream-most 18 km (20.0%) of the reach. Major irrigation returns include Isleta Conveyance Return, Calle del Rio Wasteway, Peralta Riverside Drain, San Juan Heading, Feeder Ditch 3, Lower San Juan Riverside Drain, and Rio Puerco confluence. Bridge crossings include Isleta Dam, New Mexico Highway 49 (Los Lunas), New Mexico Highway 6 (Belen), AT&SF Railroad (below Belen), New Mexico Highway 109 (Jarales), and U.S. Highway 60 (Bernardo).

The Rio Grande in Isleta Reach has a sand-bed (Lagasse 1981). Surface flow is sometimes intermittent (Ortiz et al. 2000). Irrigation return flow comprises a large proportion of base-flow (U.S. Fish and Wildlife Service 1999) because much of the Rio Grande is diverted at Isleta dam (Ortiz et al. 2000). Sediment loads near the downstream end of the Isleta Reach are higher than upstream because of inputs from the lower tributaries (U.S. Fish and Wildlife Service 1999). The channel in most of the reach is stable and channel mobility is decreasing downstream from the Rio Puerco confluence (Baird 2001).

The San Acacia Reach (roughly 76 km) extends from San Acacia Diversion Dam to the headwaters of Elephant Butte Reservoir (the exact location of the lower boundary varies depending upon reservoir water-surface elevation). This reach is relatively remote, including only the city of Socorro and villages of San Acacia, Lemitar, Escondida, and San Antonio along with Bosque del Apache National Wildlife Refuge, all within Socorro County. Major tributaries confluent with the Rio Grande in this reach include Arroyo Alamillo, Arroyo de la Parida, North Socorro Diversion Channel, Arroyo de los Pinos, Arroyo de Tio Bartolo, Arroyo de la Presilla, Arroyo del Tajo, and Arroyo de las Canas. Most tributaries that reach the Rio Grande in this reach enter from the east (except North Socorro Diversion Canal and Brown Arroyo) because western inflows are captured and/or diverted into the LFCC. Major irrigation drain returns include the Low Flow Conveyance Channel 9-mile Outfall and Brown Arroyo. Bridge crossings include Escondida, U.S. Highway 380 (San Antonio), and AT&SF (San Marcial).

The Rio Grande in San Acacia Reach has a sand-gravel, sand, and silt-armored bed that is locally variable. Surface flow is often intermittent within San Acacia reach, particularly during spring, late summer, and fall (Ortiz et al. 2000). The river channel upstream from Escondida bridge is degrading with an average bed lowering of 2.9 m for the period 1962 to 1999 (Baird 2001). Downstream from U.S. Highway 380 bridge, the river channel is aggrading (Baird 2001).

Data Collection

Fishes were collected using a 3.2 mm mesh seine, 3.0 m wide x 1.2 m deep with a double lead-line (every 15 cm). Sampling sites were selected to represent each river reach (Tables 1-3). Angostura Reach was divided into sections and each section was sampled by day-long raft trips, so long as flow was adequate for rafting. At low flow, specific sample sites were accessed by vehicle. When sections were sampled by raft, sampling was conducted at different locations throughout each section. For analysis, all Angostura Reach data were grouped into the day-float sections. Isleta and San Acacia reach sites were sampled entirely by vehicle access and each site was evaluated individually.

Sampling was initiated in June 1999 and terminated in June 2001. Between June and August 1999, the majority of fish were identified and enumerated in the field and immediately returned to the river, but exceptionally large fish collections were preserved to serve as voucher specimens and allow accurate identification in the laboratory. From September 1999 to April 2000, all fish collected were preserved for voucher specimens and catalogued into the fish division of the Museum of Southwestern Biology, Department of Biology, at the University of New Mexico. Fish were preserved in the field with 10% formalin, later transferred to 70% ethyl alcohol, and subsequently identified. Beginning in May 2000 and continuing through the end of the study, all fish collected were identified and enumerated in the field and immediately released.

Distance seined was measured to the nearest 0.1 m for each seine haul. Seine haul width was assumed to be 3.0 m (width of the seine). All available mesohabitat types (e.g., run, pool, backwater, riffle, plunge, isolated pool, bank, embayment, confluence, and forewater) were sampled and qualitative habitat descriptions were recorded for each seine haul. Mesohabitat categories were derived from subjective observations and did not represent quantifiable habitat divisions. Each of the mesohabitat types is described in greater detail in Appendix A.

Qualitative habitat information (dominant substrate type, relative depth, and relative current velocity) was recorded for each seine haul. Qualitative descriptions of dominant substrate type (silt, sand, or gravel), relative depth ("low" less than 0.3 m, "medium" 0.3 to 0.6 m, "deep" greater than 0.6 m), and relative current speed ("slackwater" 0 m / s, "slow" less than 0.3 m / s, "medium" 0.3 to 0.6 m / s, "fast" greater than 0.6 m / s) were recorded for each seine haul. Presence of debris and shoreline within each seine haul was noted.

Analyses

Summary statistics including seining effort, density, percent occurrence, and number of species captured were calculated using seine haul data. Effort (m^2) was calculated as the length (m) multiplied by the width (m) measured for each seine haul. Density (fish / m^2) was calculated as the number of fish captured per m^2. Percent occurrence was calculated as the number of seine hauls containing a particular species divided by all seine hauls.

Summary statistics were pooled by site or section (depending on reach) and reach to summarize differences in fish species composition, with special attention to Rio Grande silvery minnow. Trends in intra-reach differences (by site or section) in fish density were summarized by identifying where the highest densities of fish occurred within a particular reach.

A summary of the flow regime during the sampling period was conducted by comparing observations of fish community structure with flow conditions to assess flow-related community stability. Streamflow data was obtained for the three gages within each reach during the study period as well as recent historical data for the years 1974 through 2000 (Ortiz et al. 2000). These dates represent recent data available since the closure of Cochiti Dam. Streamflows during the study period were reported and compared as a percentage of the mean monthly streamflow for the years 1974 through 2000. Mean monthly streamflow values from June 1999 to September 2000 were obtained from published reports (Ortiz et al. 2000), while mean monthly streamflow values from October 2000 through June 2001 were obtained from provisional recent daily streamflow values available on the United States Geological Survey National Water Information System Web (NWISWeb) data for New Mexico internet site (http://waterdata.usgs.gov/nm/nwis/nwis). Mean monthly streamflow values obtained from provisional recent daily streamflow values were calculated by averaging all reported mean daily streamflow values reported from a particular month.

Hill's diversity numbers (Hill 1973) and *J* of Pielou (Pielou 1966) were used to examine fish species diversity between reaches throughout the study period. Hill's diversity numbers represent the effective number of species present in a sample and incorporate other diversity indices such as Shannon's diversity index (Shannon and Weaver 1971; Smith and Powell 1971) and Simpson's diversity index (Simpson 1949). These numbers represent the total number of species (N0 = species richness), the number of abundant species (N1 = inverse natural log of Shannon's index), and the number of very abundant species (N2 = reciprocal of Simpson's index) present in a collection (Hill 1973). *J* of Pielou utilizes two of Hill's diversity numbers and is calculated by dividing the natural log (ln) of N1 by the natural log (ln) of N0 (Pielou 1966). This statistic computes the maximum possible Shannon's index value that would result if each species comprised an equal proportion of the total sample (Pielou 1966). The more species present and the more even their distribution, the higher the index value. The resulting index is therefore a measure of species evenness.

Spatial (all collections combined by reach and all pair-wise comparisons) and temporal (intra-reach monthly and all monthly pair-wise) reach fish community stability and similarity based on relative abundance were compared using Morisita's (Morisita 1959) index. Morisita's index (I_m) is preferred to assess fish communities because it is independent of sample size or species diversity (Wolda 1981; Smith and Zaret 1982) and has been used widely (Ross et al. 1985; Matthews 1986, 1990; Matthews et al. 1988; Meador and Matthews 1992; Gido et al. 1997). Morisita's index values range from 0.0 (no similarity) to slightly above 1.0 (high similarity). Morisita's index values were calculated for each sample (by reach) and averaged to obtain a mean Morisita's index value for each reach (Gido et al. 1997). Initial observation of inter-reach similarity with Bartlett's homogeneity of variance test revealed unequal variances ($p < 0.0001$) in mean Morisita's index values calculated to determine similarity between reaches (Gido et al. 1997; Zar 1999). The repeated-measures analysis of variance (ANOVA) procedure was therefore used to test for differences in inter-reach mean Morisita's index (Zar 1999).

To assess spatial and temporal assemblage similarity based on species presence/absence, we used Jaccard's coefficient of community (CC) (Hauer and Lamberti 1996). This index is the proportion of unique species captured in two samples that occur in both and ranges from 0.0 indicating no shared species to 1.0 for identical species composition (Lohr and Fausch 1997). Values less than 0.6 are thought to indicate substantial differences in species presence / absence (Rahel 1990). A one-way analysis of variance (ANOVA) model followed by Tukey's mean comparison test (if applicable) was used to test for differences in mean Jaccard's index values calculated to determine similarity between reaches (Zar 1999).

Density (# fish / m^2) was used to compare overall fish habitat use. Seine hauls were classified as either containing fishes or not containing fishes and subsequently analyzed for habitat use. Seine hauls were grouped by reach to identify inter-reach differences in habitat use. Occurrence within each classification was used to identify which habitat category fishes "used" more frequently than expected ($p < 0.05$) (Neu et al. 1974). The overall table significance was • • ═•0.05, with individual test significance values (0.00167) calculated using the Bonferroni simultaneous correction (• • / N), where N = 15 (total number of tests, Neu et al. 1974). Samples were grouped by reach and analyses were based on these classifications. For variables with multiple categories, overall significance was calculated with a chi-square goodness-of-fit test. If overall test was significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). If fishes occurred significantly less than expected within a habitat category ($p < 0.00167$), it was denoted with a minus (-) sign. If fishes occurred significantly more than expected within a habitat category ($p < 0.00167$), it was denoted with a plus (+) sign. Both the plus (+) and minus (-) signs indicate fishes did not follow the "expected" pattern defined by all available seine hauls. If fishes did not occur significantly more or less than expected within a habitat category ($p \geq 0.00167$), it was denoted with an equal (=) sign, indicating fishes followed the "expected" pattern as defined by all available seine hauls.

RESULTS

A total of 116,605 fish were collected in 11,152 seine hauls that covered 251,110 m^2 (Table 4). The average seine haul was 7.5 m in length, covering 22.5 m^2. Ninety-one percent of all seine hauls were completed in Angostura and Isleta reaches, and sampling in these reaches was conducted throughout the study period (Tables 1,2). In San Acacia Reach, sampling was concentrated in 1999 and 2001 and sites were visited a total 69 times for a total of 1,008 seine hauls covering 24,407.6 m^2 (Table 3). A total of 22 fish species (8 native, 14 non-native) representing 9 families and 20 genera were collected (Table 4). Fish density and percent occurrence increased by reach from Angostura downstream (Tables 5 to 7). Low Angostura Reach density (0.267 fish / m^2) and percent occurrence (36.9%), contrasted with higher values in Isleta (0.648 fish / m^2, 60.2%) and San Acacia (0.743 fish / m^2, 69.5%) reaches, respectively.

There were 10,907 Rio Grande silvery minnow collected representing 9.4% of all fish collected, but the majority (96.1%) were collected in San Acacia Reach (Table 7). Thus, Rio Grande silvery minnow composed a small percentage (< 1.0%) of Angostura and Isleta Reach collections. A total of 195 were collected in Angostura and Isleta reaches, representing less than 0.3% of all fish collected (Tables 5,6). In contrast, Rio Grande silvery minnow was the most abundant species collected in the San Acacia Reach, comprising 59.0% of all fish collected (Table 7) and San Acacia Reach density (0.439 fish/m^2) was higher than either Angostura Reach (0.001 fish / m^2) or Isleta Reach (0.001 fish / m^2) (Tables 1-3).

Intra-reach differences (by site or section) indicated several spatial trends in fish density. Highest intra-reach fish densities were found immediately below diversion dams (Angostura and San Acacia) and in upstream sections of each reach (Isleta Reach, Tomé site). Lowest fish densities were found at downstream-most sites in Angostura and Isleta reaches, while lowest density in San Acacia Reach was at Ft. Craig, the next to the downstream-most site (this site is represented by only 3 seine hauls). Within Angostura Reach, fish density decreased from upstream to downstream. In Isleta and San Acacia reaches, fish density trends were variable.

For the most part, this study was conducted under relatively low flow conditions. Mean monthly streamflows were generally lower than normal for the recent period (1974 through 2000, Rio Grande at Albuquerque gage, station 08330000). Spring streamflow (i.e., snowmelt runoff) was average to above average previous to the study, but by July 1999, streamflow dipped to 61.8%, below normal for the recent period (1974 through 2000, Rio Grande at Albuquerque gage, station 08330000). Streamflow was also below average from fall 1999 through summer 2000 (monthly mean streamflow in May through July 2000 was 27.5% to 56.2% of the average).

There was a noticeable difference in streamflows between irrigation (March through November) and non-irrigation (December through February) during the study period. During irrigation season, Angostura Reach typically had highest streamflow. Diversions at Isleta and San Acacia dams reduced streamflows 20% to 90%. The only month this wasn't the case was August 1999 when summer rainstorms produced monthly mean streamflow of 65.7 m^3 / s in San Acacia Reach (Rio Grande floodway at San Acacia, station 08358400), while Angostura and Isleta reaches had 11.7% to 17.0% less streamflow (Figure 2a). During non-irrigation season, streamflows were similar in all three reaches (20.5 m^3 / s to 26.2 m^3 / s) with San Acacia recording highest streamflow overall.

Fish species diversity as measured with Hill's diversity numbers (Hill 1973) and J of Pielou (Pielou 1966) indicated decreasing diversity from upstream to downstream (Table 8, Figure 2b). Angostura Reach had highest species richness (N0 = 20), most abundant species (N1 = 4.53), most very abundant species (N2 = 3.46), and highest species evenness (J of Pielou = 0.50). Isleta Reach had fewest very abundant species (N2 = 2.42), while San Acacia Reach had lowest species richness (N0 = 18), fewest abundant species (N1 = 2.77), and lowest species evenness (J of Pielou = 0.50). While these numbers indicate decreasing diversity from upstream to downstream, they do not indicate absolute reductions in the species present. For example, some species such as brown trout *Salmo trutta* (Angostura Reach) and smallmouth buffalo *Ictiobus bubalus* (San Acacia Reach) were collected in only one reach. Also, the most abundant species were not consistent in all three reaches. The three most abundant species in Angostura Reach were red shiner, white sucker, and western mosquitofish. In Isleta Reach, river carpsucker (*Carpiodes carpio elongatus*) replaced white sucker as one of the three most abundant species. In San Acacia Reach, Rio Grande silvery minnow replaced river carpsucker as one of the three most abundant species. Nonetheless, red shiner and western mosquitofish remained abundant in all three reaches.

According to Morisita's (I_m) index (based on fish species relative abundance), the three reaches contained distinct fish communities (Table 9). But, when comparing Jaccard's (CC) index (based on fish species presence/absence), the three reaches were similar (CC = 0.73 to 0.86). Highest inter-reach mean similarity based on Morisita's index ($I_m = 0.60$) was between Angostura and Isleta reaches, but indicated only moderate similarity, while the San Acacia community was dissimilar from either of the other two reaches (Gido et al. 1997).

Morisita's and Jaccard's index revealed similar results for intra-reach spatial fish community stability when comparing all pair-wise samples (Figures 3a, 3b). Comparisons of mean Morisita's index revealed differences in intra-reach fish community stability (Figure 3a; $p < 0.0001$). Overall, intra-reach mean similarity was relatively high ($I_m > 0.6$) for all reaches, indicating that intra-reach fish communities were stable, but Isleta Reach had significantly higher intra-reach mean similarity than either Angostura ($p < 0.0001$) or San Acacia ($p = 0.0006$) reaches. Angostura and San Acacia reaches were not significantly different in intra-reach mean similarity ($p = 0.9192$), indicating similar fish community stability (although the fish communities themselves were different). Jaccard's index values indicated high intra-reach fish community stability based on presence/absence for Angostura and San Acacia reaches (CC =

0.63, 0.64 respectively) , with Isleta reach slightly less similar (CC = 0.59) although when all three reaches were compared, no significant difference was found ($p > 0.05$) (Figure 3b).

Temporal changes as analyzed by all monthly pair-wise collections indicated inter-reach similarity calculated from Morisita's index was lowest (< 0.6) in early summer and winter (July 1999, December 1999, May to July 2000; Figure 4a). Low inter-reach similarity between Angostura and Isleta reaches in December 1999 (San Acacia Reach was not sampled during this period) resulted from high red shiner and fathead minnow densities in Isleta Reach contrasted with high western mosquitofish density in Angostura Reach. The differences in the fish communities of these reaches were most evident during June and July collections in 1999 and 2000, when Morisita's index values were between 0.08 and 0.22 (Figure 4a). These low Morisita's index values coincided with high catch rates of Rio Grande silvery minnow in San Acacia Reach, white sucker in Angostura Reach, and red shiner in Isleta Reach. Similar analysis of inter-reach similarity calculated from presence / absence data using Jaccard's index revealed variable fish communities (CC = 0.41 to 0.85) (Figure 4b).

Intra-reach Morisita's and Jaccard's index values revealed variable (i.e., unstable) fish communities (Figures 5a, 5b) when comparing samples within reaches with the next previous sample in that reach. Intra-reach Morisita's index variability in Angostura Reach could be attributed to white sucker abundance variability. The lowest intra-reach Morisita's index value calculated for Angostura Reach ($I_m = 0.09$, Figure 5a) was in May of 2000, following an increase of white sucker. Intra-reach Morisita's index values for Isleta and San Acacia Reach were relatively higher. In Isleta Reach, the lowest Morisita's index value ($I_m = 0.50$, Figure 5a) was also calculated in May of 2000, following an increase of red shiner. In San Acacia Reach, the lowest Morisita's index value ($I_m = 0.60$, Figure 5a) was calculated in September of 1999, following a decrease in Rio Grande silvery minnow abundance. Jaccard's index values for intra-reach similarity based on species presence/absence were variable, ranging from 0.30 in Isleta Reach for November 1999, to 1.00 in San Acacia Reach for January 2000 (Figure 5b). Jaccard's index values increased throughout all reaches between June 1999 and November through February 2001, indicating relatively high intra-reach fish community stability based on species presence/absence. Decreasing Jaccard's index values were noted from November through February 2001 until the end of the study, although values remained relatively high (CC > 0.60).

When all fishes were combined, fish were significantly associated with shoreline, slackwater and/or slow velocity, and silt substrate. In Angostura Reach fishes were significantly associated with debris and shallow depth (Table 20). Additionally, fishes were collected more than expected in slackwater. They were found more than expected in slow velocity in Isleta Reach, and in slackwater and slow velocity in San Acacia Reach. Thus, the fish community was primarily associated with shallow depth and slow velocity.

DISCUSSION

Fish Community

Fish community composition somewhat changed from that reported in previous studies. More species of non-natives were observed (N = 14; Table 4) than in 1984 (N = 10; Platania 1991) or 1987 through 1992 (N = 12; Platania 1993b) surveys. Recent surveys (Dudley and Platania 2002) indicate similar levels of non-native persistence (N = 14). Native Rio Grande chub (*Gila pandora*), present in Angostura Reach in 1984 (Platania 1991), was not captured in a 1987 through 1992 survey (Platania 1993b) nor during this study, but absence from Angostura

Reach is not particularly surprising because large numbers were rarely present (Platania 1993b). Recent collections in 2001 indicate the continued low-level persistence of Rio Grande chub (Dudley and Platania 2003). Spotted bass (*Micropterus punctulatus*), had not been reported in previous collections from the study area. The origin of this species is most likely the result of sport fish stockings.

Red shiner appears to have increased in abundance in the last 30 years. Painter (1979) did not report numbers of specimens collected between the Rio Grande and the associated canals and drains, but he found red shiner to represent 3.8% of his collections, while that species composed 45.7% of collections in this study (Table 4). Red shiner was the most abundant species in 1984 collections in Isleta Reach (Platania 1991) and represented 55% of 1987 through 1988 collections between Bernalillo and Elephant Butte Reservoir (Platania 1993b). Thus, it appears that red shiner have numerically dominated the fish community since 1984. Red shiner have increased in other rivers via dominance within tailwaters below dams (Edwards 1978; Anderson et al. 1983; Martinez et al. 1994) and dominance within dewatered rivers where fluvial conditions decline (Summerfelt and Minckley 1969; Cross et al. 1985). Both of these impacts prevail within the study area.

Rio Grande silvery minnow composed 11.0% of fishes collected from the Rio Grande and adjacent canals in 1978 (Painter 1979) and 18.0% of the total catch between 1987 and 1992 (Platania 1993b). The majority (99.9%) of Rio Grande silvery minnow collected in the latter study occurred within the first two years of the study (1987, 1988) and only three were sampled in the last three years (1989 through 1992) (Platania 1993b). Between 1992 and 1997, Rio Grande silvery minnow remained common in Angostura Reach (Dudley and Platania 1997, 1999). However, a density decline was observed between 1997 and 1999 (Dudley and Platania 2000). Prior to that, Rio Grande silvery minnow density declined in Isleta Reach (1987 through 1992) (Platania 1993b), and density has remained low since (Dudley and Platania 1997, 1999, 2000; Smith 1999). San Acacia Reach produced the majority of Rio Grande silvery minnow between 1996 and 1999 (Dudley and Platania 1997, 1999, 2000) and this study indicates this trend continues (Tables 5 through 7).

Angostura Reach

Angostura Reach had low fish community and moderate flow regime stability (Figures 2, 3). Increased channel instability and channel immobilization has likely facilitated Angostura Reach fish community instability. Of the three study reaches, Angostura Reach is closest to Cochiti, Galisteo, and Jemez Canyon dams. Galisteo and Jemez Canyon dams have primarily acted to reduce sediment supply and storm runoff while Cochiti Dam not only captures sediment, but operations control Rio Grande streamflow (Richard 2001). Tail-water conditions prevail immediately below Cochiti Dam and continue to extend downstream into Angostura Reach, creating a relatively narrow, armored river channel (Lagasse 1994; Richard 2001). Cochiti Dam outflow has relatively low temperature, which may both increase sediment entrainment and affect the fish community (Vanicek et al. 1970). Proximity to Cochiti Dam makes Angostura Reach flow fluctuations more pronounced than Isleta Reach and more regulated than San Acacia Reach. Thus native fishes have declined from Angostura Reach and the fish community is largely comprised of cool water species (e.g., white sucker), along with several reservoir species (e.g., bluegill and white crappie).

Increased flow fluctuation may impact fluvial fishes and/or species inhabiting flow-dependent habitats such as riffles and shorelines (Richards 1976; Bain et al. 1988; Leonard and

Orth 1988; Lobb and Orth 1991; Aadland 1993; Kinsolving and Bain 1993; Travnichek and Maceina 1994; Travnichek et al. 1995). Species that numerically dominated Angostura Reach collections (white sucker, red shiner, western mosquitofish, channel catfish, and river carpsucker, respectively) were either pool species and/or highly tolerant of degraded habitat conditions while fluvial fishes (Rio Grande silvery minnow, flathead chub, and longnose dace) were uncommon. As discussed above, red shiner are tolerant of a wide range of habitat conditions and are known to be dominant in unstable conditions (Paloumpis 1958; Matthews 1987). Western mosquitofish are also tolerant of habitat degradation and instability (Cross et al. 1985; Capone and Kushlan 1991), have notable prowess as colonizers (Brown 1987), and are known to be successful in tailwaters (Edwards 1978; Anderson et al. 1983). Thus, success of these two species within Angostura Reach is to be expected.

Recent fish community trends within the study area reveal a transition from a fish community including a variety of fluvial fishes, to a fish community comprised of tolerant, slow-water species. In 1984, Angostura Reach collections were dominated by fluvial fishes such as flathead chub (*Platygobio gracilis gulonella*) and longnose dace (Platania 1991). At that time, white sucker was present, but represented only 6.1% of the total catch (Platania 1991). In this study, white sucker was the most abundant species (41.6%) found in Angostura Reach (Table 5). Replacement of fluvial fishes by tolerant fishes appears to have occurred in Angostura Reach as it has in other systems (Paloumpis 1958; Anderson et al. 1983; Cross et al. 1985). Fluvial fishes impacted in other river systems include plains minnow (*Hybognathus placitus*), peppered chub (*Macrhybopsis tetranema*), emerald shiner (*Notropis atherinoides*), Red River shiner (*Notropis bairdi*), river shiner (*Notropis blennius*), and Arkansas River shiner (*Notropis girardi*), and flathead chub (Paloumpis 1958; Anderson et al. 1983; Cross et al. 1985; Luttrell el al. 1993; Ostrand and Wilde 2001). These species are similar to those lost from the study area including Rio Grande silvery minnow, Rio Grande speckled chub, Rio Grande shiner, phantom shiner, and Rio Grande bluntnose shiner.

As pool inhabiting species, river carpsucker, white sucker, and channel catfish should be less affected by fluctuating flows (Travnichek and Maceina 1994) and this may explain their relative success in Angostura Reach (Table 5). However, it is noteworthy that these species were primarily present in collections as young-of-year. As such, it is possible that these fish originated in Cochiti Reach, Cochiti Reservoir, or Jemez Canyon Reservoir and annual displacement of young-of-the-year through the dams could account for their abundance downstream (Walberg 1971; Walberg et al. 1971). However, the sampling method used in this study (3.0 m wide flat seine) is more effective for capturing small fluvial fishes in shallow water (e.g., Rio Grande silvery minnow, flathead chub) than for capturing large bodied fishes in deep/swift water (Morris 1960; Matthews 1986), so the rarity of larger individuals within collections is not necessarily indicative of their abundance within the study area.

Isleta Reach

Isleta Reach had the most stable fish community and flow regime of the three study reaches (Figures 2, 3). This reach is less affected by flow fluctuations below Cochiti Dam and is less likely to receive a large influx of fishes from Cochiti and Jemez Canyon reservoirs because the reservoirs are farther removed and the majority of Rio Grande flow is diverted into canals via Isleta Dam. As a result, flows downstream from Isleta Dam are relatively stable, but they are also relatively low and portions are sometimes subject to drying.

A relatively high proportion of Isleta Reach base flow sources from irrigation return flows and it is possible that irrigation and riverside drains serve as a source of fishes. Lang and Altenbach (1994) found the five species that dominated Isleta Reach collections in this study (red shiner, fathead minnow, river carpsucker, channel catfish, and western mosquitofish) within the Belen Division of the Middle Rio Grande Conservancy District (the division adjacent to and interconnected with the Isleta Reach). Red shiner was the most numerous species in the Belen Division with fathead minnow ranking second, river carpsucker ninth, channel catfish seventh, and western mosquitofish third in abundance out of 19 species (Lang and Altenbach 1994). Thus, fishes that thrive in non-fluvial habitats and within adjacent irrigation district waters numerically dominate the Isleta Reach fish community (Table 6). In fact, these five species composed 96.7% of the total catch from Isleta Reach while fluvial fishes such as Rio Grande silvery minnow, flathead chub, and longnose dace composed only 0.6% (Table 6).

Higher fish community stability in Isleta Reach reflected the relative stability of the populations of the five dominant species (Table 6; Figures 3a, 5a). As discussed above, red shiner and western mosquitofish are tolerant of reduced flows. Fathead minnow prefer stagnant waters and require stable spawning substrates where males establish breeding territories and eggs are deposited (Parker 1964; Cross 1967; Pflieger 1971, Trautman 1981). Low but relatively stable base flows in Isleta Reach (not fluctuating as in Angostura Reach) likely account for success of this species there by allowing widespread reproductive success (Figure 2a). Channel catfish tolerate a wide variety of environmental conditions and habitat types (Davis 1959; Hubert 1999). This likely explains their success in Isleta Reach although the majority of individuals collected were young-of-the-year. Thus, it is possible that Isleta Reach channel catfish originated upstream in the reservoirs and mainstem Rio Grande, or invaded from adjacent irrigation canals. However, appearance of large numbers of channel catfish into the Low Flow Conveyance Channel subsequent to operations (Smith and Hoagstrom, personal observation) suggests channel catfish are at least abundant within the lower portion of the Isleta Reach.

San Acacia Reach

Similar to Angostura Reach, San Acacia Reach had low fish community and flow regime stability, but flow fluctuation was partly due to natural flood inflows (Figures 2a, 3a). San Acacia Reach has a variable flow regime and long reaches (10 to 20 km) are subject to desiccation several days each year (U.S. Fish and Wildlife Service 1999). Natural Rio Grande inflow regime is interrupted by irrigation withdrawals upstream at Angostura, Isleta, and San Acacia dams. In addition, the river channel in the lower sections of this reach is aggrading and has become perched above the LFCC which intercepts water seeping from the river (U.S. Bureau of Reclamation 2000).

Fishes in San Acacia Reach may originate outside the reach including Isleta Reach, LFCC return, and Elephant Butte Reservoir. This is the longest uninterrupted reach of the three (Figure 1), and therefore provides the most continuous amount of fluvial habitat (during flowing conditions). The largest number of Rio Grande silvery minnow occurred in San Acacia reach, and when combined with other fluvial species such as flathead chub and longnose dace, accounted for 61.5% of all fish collected (Table 7). Nevertheless, species that thrive in non-fluvial habitats represented a moderate percentage of the total number of fish collected. After Rio Grande silvery minnow, the next four species (by abundance) were red shiner, western mosquitofish, river carpsucker, and common carp, comprising 34.2% of fish collected (Table 7).

Several species most likely originating in Elephant Butte Reservoir present in low density included white bass (*Morone chrysops*), spotted bass, largemouth bass (*Micropterus salmoides*), white crappie (*Pomoxis annularis*), and walleye (*Stizostedion vitreum*). Mentioned previously, larger individuals are most likely underrepresented in our samples due to the limitations of the gear and therefore may be a larger effect on the fish community than noted (Morris 1960). For example, other piscivores such as flathead catfish (*Pylodictis olivaris*) are known from this reach (Dudley and Platania 2002) but were not collected during this study.

Fish community stability in this reach is most closely linked to two species, red shiner and Rio Grande silvery minnow (Figure 2a, 3a). Red shiner, the second most abundant species in San Acacia Reach, accounted for most of the fish community variability. Rio Grande silvery minnow represented the majority of fish collected (59.0%) in San Acacia Reach. Most of these individuals were young-of-the-year and therefore abundant for a relatively short period of time (first appearing with high abundance in June and July, decreasing thereafter).

Overall Comparisons

Fish community differences were noted across all samples between reaches based on fish species density using Morisita's Index (Table 9; Figures 3a, 4a, 5a). But based on fish species presence/absence (Jaccard's Index), the fish communities were similar (Table 9; Figures 3b, 4b, 5b). This is most likely due to the amount of seining effort at each site (Tables 1 through 3). As many as 141 seine hauls were completed during a site visit. With this amount of effort, even relatively rare species were collected (14 of 22 species represented less than 1.0% of all fish collected; Table 4). Because the study area was depauperate overall and fish species were frequently displaced, Jaccard's Index failed to detect differences in community similarity.

Each of the three reaches represented distinct fish communities with different abiotic factors affecting each reach. Red shiner and western mosquitofish were first, second, or third most abundant species in every reach (Tables 5 through 7). These species, along with fathead minnow, persist in highly variable habitat conditions. But, San Acacia Reach fish community was most distinct, with highest Rio Grande silvery minnow densities (Tables 7, 9). Isleta Reach had highest fish community stability with non-fluvial species dominating (Figure 3a). All three reaches are affected by different habitat conditions, but all are altered to the point where non-fluvial species thrive while fluvial species such as Rio Grande silvery minnow continue to decline.

It is evident that the flow regimes of each reach have widened the gap between the already disjunct fish populations. In Angostura Reach, unstable flows support an unstable fish community comprised of non-fluvial tolerant species. In Isleta Reach, low stable flows support a stable fish community comprised of non-fluvial tolerant species. Both Angostura Reach and Isleta Reach have consistent non-fluvial sources of tolerant species from upstream reservoirs and riverside drains. San Acacia Reach has a highly unstable, somewhat natural flow regime which supports a highly unstable, somewhat natural fish community. San Acacia Reach is not as affected by non-fluvial sources of fishes, and therefore a more natural fish community. Although this reach is most natural in terms of flow regime and fish community, it is also most susceptible to channel drying over a long distance of the reach and for extended periods.

CHAPTER 2

Species Accounts and Habitat Use

INTRODUCTION

One way to compare species-specific differences is to look at species co-occurrence. Species co-occurrence is a possible indication of habitat overlap and competition between species. A high percentage of co-occurrence indicates substantial potential for interactions. A low value of percent co-occurrence, on the other hand, may indicate that past or ongoing competition or other factors have resulted in a high degree of partitioning of habitat among coexisting species (Frissell and Lonzarich 1996).

Chapter 1 discussed the overall differences in Angostura, Isleta, and San Acacia reaches by looking at overall fish community stability based on overall species relative abundance and presence/absence. Chapter 2 looks at these differences on a species by species basis as well as habitat associations of the most dominant species. The objective of chapter 2 is therefore to describe species specific habitat associations.

METHODS

Each species account contains background information on distribution and habitat use. In addition, results are summarized by species. Presence/absence data from this study was used to analyze co-occurrence for each abundant species. Presence/absence for a species was identified as the number of seine hauls (samples) containing a particular species, regardless of the number of individuals collected within a particular seine haul. Percent occurrence was calculated as the number of seine hauls containing a particular species divided by all seine hauls. Abundant species were species representing greater than 1.0% of fish collected in any reach. This allowed a species by species account of percent co-occurrence with abundant species to be constructed as well as presence/absence of abundant species within and among reaches. Average co-occurrence by reach was calculated by combining all percent co-occurrences for each species by species group. This reach by reach average was reported for each species to compare reach differences in co-occurrence.

Density (fish / m^2) and relative abundance was used to compare habitat association by species. Seine hauls were also grouped by reach to identify inter-reach differences in habitat association. The same method used to analyze overall fish habitat association (Chapter 1) was used to analyze species specific habitat association. Occurrence within each classification was used to identify which habitat category a species "used" more frequently than expected ($p < 0.05$) (Neu et al. 1974). The overall table significance was • • =•0.05, with individual test significance values (0.003) calculated using the Bonferroni simultaneous correction (• •/ N), where N = 30 (total number of tests, Neu et al. 1974). Samples were grouped by reach and analyses were based on these classifications. For variables with multiple categories, overall significance was calculated with a chi-square goodness-of-fit test. If overall test was significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). If fishes occurred significantly less than expected within a habitat category ($p < 0.003$), it was denoted with a minus (-) sign. If fishes occurred significantly more than expected within a habitat category ($p < 0.003$), it was denoted with a plus (+) sign. Both the plus (+) and minus (-) signs indicate fishes did not follow the "expected" pattern defined by all available seine hauls. If fishes did not occur significantly more or less than expected within a habitat category ($p \geq 0.003$), it was denoted with an equal (=) sign, indicating fishes followed the "expected" pattern as defined by all available seine hauls.

Habitat association was described for the ten most common fish as well as yellow bullhead (*Ameiurus natalis*) and white crappie (*Pomoxis annularis*). These two species were not collected frequently enough to describe co-occurrence, but enough collections (N = 335, 163 respectively) did allow for analysis of habitat associations. Each species was analyzed separately for habitat associations. Also, when Rio Grande silvery minnow were collected, individuals were visually separated into adult and young-of-year age classes. Although fish were not typically measured or preserved for age verification, age classification in the field allowed a cursorial analysis of differential habitat association between these two "age classes".

RESULTS

There are twelve species described in detail. Ten species were abundant. These were red shiner, common carp, Rio Grande silvery minnow, fathead minnow, flathead chub, longnose dace, river carpsucker, white sucker, channel catfish, and western mosquitofish. These ten species were represented by 116,001 specimens and comprised 99.5% of all fish collected. Of these abundant species, 6 were native and 4 were introduced. These species and their habitat associations are reported and discussed in phylogenetic order. Two other species, yellow bullhead and white crappie were not abundant enough to describe co-occurrence, therefore only habitat associations are described for these species.

Species Accounts

Red shiner, *Cyprinella lutrensis lutrensis* (Baird and Girard)

Red shiner is native to the study area (Sublette et al. 1990). The nominal species, *C. lutrensis lutrensis*, is widespread in the Central United States, occupying a wide variety of waters including rivers, streams, intermittent streams, canals, lakes, and ponds (Matthews 1987; Sublette et al. 1990). The relatively depauperate ichthyofauna of the American Southwest, plus severity of some aquatic habitats, has tended to enhance red shiner distribution and abundance (Cross 1967; Minckley 1972; Cross et al. 1985). It is tolerant of intermittent flow, and is opportunistic in reproductive behavior, using highly variable sites for egg deposition throughout spring and summer (Cross et al. 1985).

Within this study, red shiner ranked first or second in density in all reaches (Tables 4 through 7). Red shiner reached highest density in Isleta Reach, accounting for greater than 60 percent of all fish and collected while occurring in 49.7 percent of seine hauls. Highest co-occurrence was with Rio Grande silvery minnow in San Acacia Reach (60.3%) and lowest co-occurrence was with longnose dace in Isleta Reach (0.1%) (Table 10). Results correspond with differences in habitat preferences between species. Average percent co-occurrence with common species increased from upstream to downstream (Figure 6). Red shiner associated with shoreline, debris, and silt throughout all reaches and an avoidance of medium and/or fast velocities in all reaches (Table 21). Sand substrates were avoided in all reaches. There was a shift from shallow habitat in Angostura Reach to medium depth habitat in Isleta and San Acacia reaches. Red shiner was significantly associated with slackwater in Angostura Reach and slackwater / slow velocity in Isleta and San Acacia reaches.

These findings are similar to those reported by Platania (1993) in their association with low velocity habitats and silt substrates. In addition, Platania (1993) also reported an avoidance of high velocity habitats. In contrast, Platania (1993) reported an association with sand substrate while we report an avoidance of sand substrate habitats for red shiner. This is most likely due to the avoidance of deep, swifter habitats (which are predominantly sand and gravel substrate) than the avoidance of sand substrate itself. The shift of red shiner from shallow habitats in Angostura Reach to medium depth habitats downstream could also reflect their preference for low velocity habitats. As suggested by Platania (1993), red shiner may avoid cooler water temperatures as well as high velocity habitats. Relatively warm water temperatures may be restricted to shallow, low-velocity habitats in Angostura Reach more than in downstream reaches where habitat availability may be more diverse and water temperatures have moderated.

Common carp, *Cyprinus carpio* Linnaeus

In New Mexico, common carp are introduced and found in a wide variety of situations (Sublette et al. 1990). They are known to be prolific, succeeding in turbid, sluggish streams containing large amounts of organic material (Page and Burr 1991). High fecundity, early age at first spawning, longevity, and adaptability to available spawning sites have allowed highly successful reproduction in a wide range of habitats (Mauck and Summerfelt 1972).

Common carp was found throughout all reaches but never accounted for more than 2.4% of fishes collected within a particular reach (Tables 4 through 7). Common carp abundance increased from upstream to downstream. Percent co-occurrence indicated that common carp was found more often with other species than alone, but they were not commonly found with Rio Grande silvery minnow in Angostura or Isleta reaches (0.0%, 0.9% respectively), or longnose dace (0.5%) in Isleta Reach (Table 11). When comparing ratios by species, common carp was relatively frequent with red shiner (77.8%) in Isleta Reach. Average percent co-occurrence increased among common species from upstream to downstream (Figure 6). Common carp was consistently found near shoreline and/or debris, slackwater habitats with silt substrate such as backwaters (Table 22).

The percentage of fish fauna represented by common carp collected in the study area most likely underestimates their true density. This is due in part to larger individuals being collected in lower numbers than their actual density. The size seine used in this study (3.2 mm mesh seine, 3.0 m wide x 1.2 m deep) was assumed most affective for fish between 10 mm and 150 mm in length located in habitats less than 1.5 m deep. This technique of seining is geared toward capturing small fish and adult common carp reach sizes over 300 mm in length (Robison and Buchanan 1988). Therefore, the effects of common carp within this fish community must not be overlooked when examining current data.

Rio Grande silvery minnow, *Hybognathus amarus* (Girard)

As mentioned previously, Rio Grande silvery minnow is the sole remaining species of the native fluvial minnow guild including five species that occupied main channel habitats of the Rio Grande and its largest tributaries in New Mexico. Koster (1957) described the general habitat affiliation of Rio Grande silvery minnow as: ".... found in the pools and backwaters of the main rivers and creeks...They occur in schools and feed largely on the bottom mud and algae." Sublette et al. (1990) added: "While it tolerates a wide variety of habitats, it prefers large streams with slow to moderate current over a mud, sand, or gravel bottom." Bestgen and Platania (1991) stated, "Most of the *H. amarus*...were captured in low-velocity habitats that had sand substrate." The first study of mesohabitat association within the occupied range of Rio Grande silvery minnow was conducted by Platania (1993b). Platania (1993b) identified 17 mesohabitat types, seven of which were common (main channel runs, flats, and shorelines; secondary channel runs, flats, and shorelines; and islands). In his data analysis, mesohabitat, depth, velocity, and substrate were each evaluated independently. Data specific to Rio Grande silvery minnow were not obtained because specimens were absent from mesohabitat collections.

Dudley and Platania (1997) conducted a two year study to specifically determine Rio Grande silvery minnow habitat use. They utilized a similar set of visually identified mesohabitats and substrates as they had in 1993 (Dudley and Platania 1997). Dudley and Platania (1997) determined Rio Grande silvery minnow were most commonly associated with depths < 0.50 m (shallow to medium), velocities < 0.40 m / s (low to medium), and silt substrate (sometimes sand), most frequently utilizing debris pile, pool, and backwater mesohabitats. Dudley and Platania (1997) also detected difference in habitat association among Rio Grande silvery minnow length classes, with smaller individuals utilizing the shallowest and slowest waters on average. To summarize previously reported habitat association by Rio Grande silvery minnow, they occupy relatively low depths and velocities with larger individuals using deeper and swifter areas and commonly utilize debris. They and are most commonly found over silt but also utilize sand.

A total of 195 Rio Grande silvery minnow (native) were collected in Angostura and Isleta reaches, representing less than 0.3% of fish collected in these reaches (Tables 4 through 7). In contrast, Rio Grande silvery minnow was the most abundant species collected in the San Acacia Reach, comprising 59.0% of fish collected in this reach. Overall density of Rio Grande silvery minnow in San Acacia Reach (0.439 fish / m^2) was higher than either Angostura Reach (0.001 fish / m^2) or Isleta Reach (0.001 fish / m^2). Percent co-occurrence indicated Rio Grande silvery minnow was found most often with red shiner in Isleta Reach and least often with common carp in Angostura Reach and longnose dace in Isleta Reach (0.0%, both) (Table 12). Rio Grande silvery minnow co-occurrence decreased when comparing upstream to downstream reaches, while overall percent co-occurrence increased (Figure 6). This was the only species exhibiting a decreasing trend of upstream to downstream co-occurrence.

Within Angostura Reach, Rio Grande silvery minnow was collected less than expected over gravel (Table 23). Within Isleta Reach, Rio Grande silvery minnow was collected less than expected in shallow habitat. Rio Grande silvery minnow collections were associated with medium depth, slackwater, silt, and shoreline in San Acacia Reach. Rio Grande silvery minnow were collected less than expected in slow and fast velocities, deep depth, and sand or gravel substrate within San Acacia Reach. Based on field classification of the age of the fish, young-of-the-year Rio Grande silvery minnow were associated with slackwater habitats, while avoiding habitats with discernable velocity in San Acacia Reach (Table 23). In contrast, adults were associated with low velocity habitats while avoiding slackwater and medium to high velocity habitats. San Acacia Reach was the only reach where sufficient numbers of juvenile and adult Rio Grande silvery minnow were captured to identify this trend.

Rio Grande silvery minnow habitat associations were similar with previously reported studies (Dudley and Platania 1997; Watts et al. 2002). Watts et al. (2002) reported habitat use for Angostura and Isleta collections. In these collections, depth and velocity measurements for Rio Grande silvery minnow collections averaged 0.30 m and 0.18 m/sec. Although our only significant associations were found in San Acacia Reach collections, these indicated preference for medium depth and slackwater or slow velocity habitats as well. Although Watts et al. (2002) reported measured depths and velocities within seine hauls compared to qualitative observations of seine hauls in this report, these similar findings validate the use of qualitative observations.

Fathead minnow, *Pimephales promelas* Rafinesque

Fathead minnow is native to the Rio Grande, New Mexico (Sublette et al. 1990). It is abundant in pools in small, intermittent prairie creeks, with bottoms of mud or clay (Cross 1967; Matthews 1985; Sublette et al. 1990). Fathead minnow were found to occur in low-velocity waters and associated habitats in the Rio Grande by Platania (1993b). This species can be an indicator of low fish species diversity, unstable stream conditions, and is also very tolerant of organic pollution (Pflieger 1997). Because of its tolerance for high temperature, extreme turbidity, and low oxygen (Pflieger 1997), fathead minnow is well-suited for survival in conditions that may not be as favorable for more sensitive species such as Rio Grande silvery minnow.

Fathead minnow represented between 1.4% and 5.7% of all fish collected by reach (Tables 4 through 7), reaching highest abundance in Isleta Reach, where it was collected in 11.7% of all seine hauls. Fathead minnow was most frequent with red shiner (92.5%) in Isleta Reach and least frequent with longnose dace (0.2%) in Isleta Reach (Table 13). Average percent co-occurrence increased among common species from upstream to downstream (Figure 6). Fathead minnow collections revealed association with shoreline, debris, and silt (Table 24). They were associated with shallow to medium depths, slackwater, and low velocities.

Results are similar to those reported in other habitat studies of fathead minnow (Platania 1993b; Matthews 1975). The density of fathead minnow in the Isleta Reach, where it was most abundant, may be reflective of several factors including flow conditions experienced in this reach during the study. Low, stable base flows in the Isleta Reach provided favorable conditions for the reproductive strategy of fathead minnow (Fausch and Bestgen 1996). This strategy is to spawn during low flow conditions and attach eggs to solid surfaces such as vegetation (Fausch and Bestgen 1996). These low flows provide favorable conditions for in-channel vegetation growth and possible spawning locations for fathead minnow (also red shiner).

Flathead chub, *Platygobio gracilis gulonella* (Richardson)

Flathead chub is native to the Rio Grande, New Mexico (Sublette et al. 1990). Although this species is considered a large river species, in the Missouri and Mississippi drainages the flathead chub inhabits a diverse range of habitats from swift, turbid waters composed of sand and fine gravel substrates to pools of small creeks with little current and bottoms composed of coarse gravel and bedrock (Pflieger 1997). There are two recognized subspecies: *P. gracilis gracilis*, a northern and eastern form inhabiting the mainstem of large rivers including the Mississippi and Missouri rivers; and *P. gracilis gulonella*, the form recognized within the study area found in the southern and western extent of the range including the upper Rio Grande, Pecos, South Canadian, and Cimarron drainages of New Mexico (Olund and Cross 1961). *Platygobio gracilis gulonella* occupies small rivers and creeks, preferring pools with moderate currents with gently shifting sand, often found within debris piles or rootwads (Olund and Cross 1961). In New Mexico, occurrences are principally between 1,371 m and 2,438 m elevation (Sublette et al. 1990).

This species was uncommon throughout all reaches, representing 0.4% to 2.4% of the total catch by reach (Tables 4 through 7). Flathead chub collections were highest in the San Acacia Reach where they were collected in 15.2% of samples and lowest in the Isleta Reach. Highest percent co-occurrence was with red shiner (67.7%) in Isleta Reach and lowest percent co-occurrence was with longnose dace (0.0%) in Isleta Reach (Table 14). Average percent co-occurrence increased from upstream to downstream (Figure 6). Significant habitat associations of flathead chub were few and variable among reaches (Table 25). In Angostura Reach, significant associations occurred with shoreline and slackwater. In Isleta Reach, flathead chub was associated with medium depth and silt. In San Acacia Reach, flathead chub was associated with shallow shoreline.

There has been a decrease in density of flathead chub over the last decade compared to a report by Platania (1993). Similar to Platania (1993), flathead chub (along with red shiner and longnose dace) were found frequently over gravel substrates. The study area occurs within the southern extent of the range for flathead chub in the Rio Grande, therefore fluctuations in abundance may be expected. Continued monitoring of this species may provide better clarification for the variation in density for this species.

Longnose dace, *Rhinichthys cataractae cataractae* (Valenciennes)

Longnose dace is native to middle and upper elevations of the Rio Grande, New Mexico (Sublette et al. 1990). The species has relatively narrow habitat requirements, preferring gravel-rock substrates of riffle areas of small creeks up to medium sized rivers (Page and Burr 1991; Platania 1993b), and does not occupy many seemingly hospitable regions of mid- and lower latitudes of the United States (Jenkins and Burkhead 1993). The nominal subspecies, found within the study site, is identified as the eastern form. This is the most widespread subspecies of *Rhinichthys cataractae*, extending from northern Canada to northern Mexico and from the continental divide east to the Atlantic coast (Jenkins and Burkhead 1993).

A total of 413 longnose dace were collected throughout all reaches, with over 90% in Angostura Reach (Tables 4 through 7). Percent co-occurrence with common species was lowest with Rio Grande silvery minnow, flathead chub, white sucker, and western mosquitofish in Isleta Reach and white sucker in San Acacia Reach (0.0% for all) while highest percent co-occurrence was found with red shiner and Rio Grande silvery minnow in San Acacia Reach (60.0% for both) (Table 15). Average percent co-occurrence increased among common species from upstream to downstream (Figure 6). Longnose dace was associated with fast, shallow habitats consisting of gravel substrate (Table 26). Within Angostura and San Acacia reaches, longnose dace was associated with shoreline.

Distribution of longnose dace may reflects the relative amounts of riffle habitats, cooler water temperatures and/or coarser substrates more frequent in upstream reaches. Similar habitat associations were reported by Platania (1993b) including high velocity, large substrate habitats. The coarsening and armoring of substrate in Angostura Reach may provide additional habitat and subsequent increases in density for longnose dace in the future.

River carpsucker, *Carpiodes carpio elongatus* (Rafinesque)

Western river carpsucker is native to lower and middle elevations of the Rio Grande, New Mexico (Sublette et al. 1990). The slender subspecies is represented in the Rio Grande system and in other Gulf tributaries from the Rio Soto la Marina in northeastern Mexico northeastward through Texas (Hubbs and Black 1940). This species lives in large schools and feeds from the bottom (Pflieger 1991). In Ohio, the northern subspecies, *C. carpio carpio*, is found in most of the large silt-laden rivers and flood-filled ponds adjacent to the rivers (Trautman 1981).

During this study, river carpsucker accounted for 7.2% of the catch, being most abundant in Isleta Reach where it was present in 18.1% of seine hauls (Tables 4 through 7). Percent co-occurrence indicated river carpsucker was found more often with other species than alone (Table

16). River carpsucker was most commonly found with red shiner (79.6%) in Isleta Reach and least commonly with longnose dace in Isleta Reach (0.1%). Average percent co-occurrence increased from upstream to downstream (Figure 6). River carpsucker was significantly associated with shoreline, slackwater, and silt throughout all reaches and shallow habitats in Angostura and San Acacia reaches (Table 27). Within Isleta Reach it was also associated with slow velocity and medium depth.

River carpsucker represented a larger percentage of the fish community in this study (7.2%) than in previous Rio Grande fish community surveys (2.4%) by Platania (1993). The increase in relative abundance over time, although slight, is most noticeable in Isleta Reach. Isleta Reach has the highest relative abundance and density of river carpsucker. Reduced streamflows during the study period appears to be most productive for slackwater, silt associated species such as river carpsucker, red shiner, fathead minnow. Similar to Platania (1993), river carpsucker was associated with low velocity habitats over silt substrate. Run habitats with high velocities were reported by Platania (1993) as associated habitat, but no significant associations with these habitats were found in the current study.

White sucker, *Catostomus commersoni* (Lacépède)

White sucker is introduced to the Rio Grande, New Mexico (Sublette et al. 1990). It prefers gravel or rock bottomed pools with logs, brush, and other cover (Sublette et al. 1990; Pflieger 1991). In the Rio Grande, white sucker has been found most commonly in low-velocity water (< 0.50 m/sec) corresponding to its association with backwater and debris piles (Platania 1993). White sucker appears to be tolerant to turbidity, siltation, and other organic and inorganic pollutants than any other species of sucker, surviving in waters low in oxygen and dense aquatic vegetation (Trautman 1981).

Overall, white sucker was the third most abundant species, most abundant in Angostura Reach (Tables 4 through 7). Percent co-occurrence indicated white sucker was most frequently found with red shiner in Isleta Reach (78.0%) and least frequently with longnose dace in Isleta and San Acacia reaches (0.0% for both, Table 17). Average percent co-occurrence increased from upstream to downstream (Figure 6). Habitat associations indicated significant association with shoreline, slackwater, and silt in all reaches (Table 28). In Angostura Reach, white sucker was also associated with debris and slow velocities in shallow or deep habitats.

The majority of white sucker collected were in Angostura Reach (94.9%), with relatively few individuals occurring in downstream reaches. This possibly indicates that individuals are being displaced from upstream sources such as Cochiti Reach and Cochiti Reservoir. White sucker represent a much larger proportion of the fish community than previous collections (Platania 1991, Platania 1993b). Since fish were identified and enumerated in the field, age and length information were not collected for many fish including white sucker. Nevertheless, white sucker associations with slackwater habitats indicate that most were likely young-of-the-year individuals.

Yellow bullhead, *Ameiurus natalis* (Lesueur)

Yellow bullhead is introduced to the Rio Grande, New Mexico and has become established in some of the larger canals and rivers (Koster 1957; Sublette et al. 1990). This species is found in a range of habitats including clear, medium-sized streams with rocky bottoms or clear lakes with aquatic vegetation and avoids strong current (Sublette et al. 1990; Pflieger

1991). In New Mexico, similar to the black bullhead (*Ameiurus melas*), it is found most often over a mud bottom in small ponds, creeks, and canals (Koster 1957).

There were 335 yellow bullhead collected, representing 0.4% of the total catch (Tables 4 through 7). Limited collection of this species did not allow for co-occurrence to be analyzed. Habitat observations did however indicate significant association with shoreline in Angostura and Isleta reaches (Table 29). In Isleta Reach, yellow bullhead was associated with slow velocity, medium depth, and silt substrates. This was the only bullhead species collected, with black bullhead known to occur within the study area but not collected in this study. Yellow bullhead collections were very rare in Platania's (1993b) report on habitat associations within the study area and therefore not analyzed. Although limited, our findings of yellow bullhead indicate increased abundance. Habitat associations in the Rio Grande represent a baseline of information for this species.

Channel catfish, *Ictalurus punctatus* (Rafinesque)

Channel catfish is introduced to the Rio Grande, New Mexico (Sublette et al. 1990). This catfish occurs in a wide variety of habitats and is often associated with submerged cover (Pflieger 1991). Channel catfish can occupy essentially all available habitat types year-round (Brooks et al. 2000). Juvenile channel catfish (most encountered during seining) may be more tolerant of current than adults and can overwinter in areas with relatively strong current utilizing shelter provided by any minimal velocity breaks (Trautman 1981).

Channel catfish was most abundant in Isleta Reach (Tables 4 through 7). Overall, it was second only to red shiner in percent occurrence within seine hauls (11.5%). Channel catfish was least abundant in Angostura Reach. Percent co-occurrence indicated channel catfish was most frequent with red shiner in Isleta Reach (77.9%) and least common with longnose dace in San Acacia Reach (0.0%) (Table 18). Average percent co-occurrence increased among common species from upstream to downstream (Figure 6). Although channel catfish was mostly found with shoreline and debris, there was no consistent category of habitat with which it associated (Table 30).

As with other species that may reach sizes over 200 mm in total length, most individuals encountered during seining are most likely juveniles and sub-adults. Platania (1993b) reported a wide physical niche for channel catfish in the Rio Grande, being collected in a wide variety of habitats. Similar results in the current study emphasize the varying habitat conditions that channel catfish utilize. The ontogenetic shifts in habitat preferences therefore probably account for some of the differing observations among studies (Hubert 1999). Habitat use of channel catfish may overlap with native species, especially in downstream reaches where densities and co-occurrence are highest. In addition to habitat overlap, other negative interactions may play a role in the structure of the fish community. This is the most abundant predatory fish species located within the study area. The negative interactions of this introduced species must not be overlooked when considering the decline of some native species such as Rio Grande silvery minnow.

Western mosquitofish, *Gambusia affinis* (Baird and Girard)

Western mosquitofish is native to lower elevations of the Rio Grande, New Mexico and Texas (Sublette et al. 1990), but is most likely introduced upstream of Elephant Butte Reservoir including the study area (Platania 1991). This species is found in a wide variety of habitats, but prefers shallow, vegetated, backwater pools with little current (Robison and Buchanan 1988).

This species is tolerates high salinities (twice that of saltwater) and temperatures (42° C for brief periods; Robison and Buchanan 1988), as well as extremes in total ammonia (> 10 ppm) and nitrates (> 100 ppm) known to be lethal to most freshwater fish (Hubbs 2000). It is a habitat specialist found in shallow, marginal waters having no noticeable current and dense aquatic vegetation or other cover (Pflieger 1997).

Western mosquitofish was second most abundant overall, reaching highest density in Isleta Reach (0.100 / m^2; Tables 4-7). Percent co-occurrence indicated western mosquitofish was most frequently found with red shiner in Isleta Reach (81.9%) and least frequently with longnose dace (0.0%) in Isleta Reach (Table 19). Average percent co-occurrence increased from upstream to downstream (Figure 6). Habitat associations indicated significant association with shoreline, slackwater, and silt in all reaches (Table 31). In addition, western mosquitofish was associated with debris in Angostura Reach, and in slow velocity habitat in San Acacia Reach (Table 31).

Similar habitat associations were reported by Platania (1993b). Slackwater habitats occupied by western mosquitofish may also areas used by larval and adults of other species including Rio Grande silvery minnow. Although western mosquitofish is native throughout most of the historical range of Rio Grande silvery minnow, competition may occur where slackwater habitats are limiting, such may be the case in Angostura Reach. The ability of the western mosquitofish to occupy marginal habitats and their high densities in this study suggests that low-flow habitat conditions during this study were most suitable for them. For example, drying conditions can isolate pools of fish. If these isolated pools are subjected to several days of no flow the ability of western mosquitofish to outlive other species and in fact increase in density appears to benefit this species.

White crappie, *Pomoxis annularis* Rafinesque

White crappie is introduced to the Rio Grande, New Mexico where it prefers warm, somewhat turbid, lentic habitats (Sublette et al. 1990). No centrarchid is native to the study area and stocking programs and reservoir escapees have made determination of the ranges and relative abundances of these fish difficult (Platania 1993b).

White crappie was the only centrarchid collected in sufficient numbers to assess distribution and habitat patterns. This species represented only 0.1% of fish collected during the study period, with 162 of the 163 individuals collected in Angostura and Isleta reaches. Only the analysis of habitat association was performed on collections of this species. White crappie were relatively uncommon, therefore we were unable to accurately analyze co-occurrence with other species. Density of white crappie was highest in Angostura Reach, declining downstream (Tables 4 through 7). White crappie associated with shoreline, debris, slackwater, slow velocity, medium depth, and silt substrate in Angostura and Isleta reaches (Table 32).

The ability to occupy turbid habitats may explain this species relative success compared to other centrarchids. This species, along with other centrarchids, are collected infrequently but represent a possible predator for other fishes including Rio Grande silvery minnow. The association of white crappie with debris was similarly found for 9 of the other 11 species described here. Debris is an important source of velocity shelter in the Rio Grande, especially in Angostura Reach, where channel widths are decreased and low velocity areas may be limiting.

DISCUSSION

Co-occurrence of common species revealed trends among and across reaches. Generally, correlation ratios were positive (95.0%), indicating that species were found together more often than separately (Tables 10 through 19), which would be expected. There was also a decreasing trend in the correlation ratios across reaches indicating that species were clumped more often in Angostura Reach than in San Acacia Reach, while Isleta Reach ratios were intermediate. This may indicate a relatively lower amount of habitat availability in the upstream reaches compared with San Acacia Reach. Common fishes exhibited differences in habitat association between reaches (Tables 21 through 32). Most species utilized shallow, slow habitat in all reaches. The primary exception was longnose dace. Many species were also associated with debris and shoreline. This is not surprising because dominant species in the study area (red shiner and western mosquitofish) are known to occupy exactly these habitats.

Low density of Rio Grande silvery minnow in Angostura Reach corresponded with high ratios of co-occurrence with other fishes. In relation to Rio Grande silvery minnow, several trends indicate possible habitat limitations in the upper reaches. Their habitat association varied between reaches, which may be a response to differences in habitat availability. For example, when comparing co-occurrence of Rio Grande silvery minnow collected with red shiner, correlation ratios dropped from 3.6 in Angostura Reach to 1.5 in Isleta Reach and 1.4 in San Acacia Reach. Thus, Rio Grande silvery minnow were collected more often in seine hauls within Angostura Reach containing red shiner than in downstream reaches. This decreasing trend of co-occurrence from upstream to downstream was consistent with all common species compared with Rio Grande silvery minnow. Relatively low Angostura Reach fish density suggests that resources are more abundant downstream and diverse habitats are more available which supports the hypothesis that fishes are clumped because resources (e.g., habitat, forage) are patchy upstream. In Isleta Reach, where the density of Rio Grande silvery minnow was also low (0.0011 / m^2 compared to 0.0006 / m^2), the ratio of co-occurrence was less, indicating a change in the above relationships.

There was an increasing percentage of co-occurrence from upstream to downstream for all species other than Rio Grande silvery minnow. This coincides with increases in percent occurrence and overall fish density. This trend would be expected for species without specific habitat requirements, or those with decreasing amounts of preferred habitat and densities in San Acacia Reach compared to upstream reaches. Two factors likely produced this trend. First, relative restriction of shallow, low-velocity to shorelines in Angostura Reach could have reduced suitable Rio Grande silvery minnow habitat abundance there. This hypothesis is supported by the differences in Rio Grande silvery minnow habitat associations between reaches (Watts et al. 2002). Rio Grande silvery minnow may have been forced to occupy different habitat in Angostura Reach, where they were more likely to encounter other fish species. The reverse may be true for other species, with suitable habitats least common in San Acacia Reach, causing them to co-occur more frequently. Second, much higher Rio Grande silvery minnow density in San Acacia Reach could have increased the likelihood that the species would occur without other species.

The trend for Rio Grande silvery minnow to show lowest percentages of co-occurrence in San Acacia Reach while densities of the majority of fish species in this reach are the highest would suggest that more habitat is available in this reach compared to upstream reaches. It is important to note that while many species in this study including Rio Grande silvery minnow were collected in shallow/slackwater habitats most frequently, this does not indicate an exclusive need for this habitat type. As previously mentioned, the highest densities of Rio Grande silvery minnow (San Acacia Reach) corresponded to the lowest levels of co-occurrence with other species. This suggests an increased level of available habitat diversity which provides a wider range of velocities and depths throughout a wider range of streamflows.

Fluvial and sensitive native fish species have mostly disappeared from the study area. Flathead chub and longnose dace are more typical of headwater streams and maintain limited presence while Rio Grande silvery minnow, the sole remaining representative of the mainstem Rio Grande fluvial fish community, is in steep decline (Dudley and Platania 2002). Otherwise, the fish community is homogenized, with a few widespread species having variable success, depending upon reach-specific habitat conditions. With habitat conditions continuing to degrade, and drought and river intermittency seeming inevitable, it is likely that the species previously adapted to life in the mainstem Rio Grande will continue to decline.

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Table 1. Summary of fish community surveys in Angostura Reach between July 1999 and April 2001. Section, river kilometers (km), dates of sampling (Initiation, Conclusion), number of collections trips to each site/section (Visits), total sampling effort (Hauls and Area), total fish density (Total), and Rio Grande silvery minnow density (RGSM) are provided. # = less than 0.001 fish / m^2.

Section	km	Initiation	Conclusion	Visits	Hauls	Area (m^2)	Total (fish / m^2)	RGSM (fish / m^2)
1	325.6 – 320.3	Sep. 1999	Feb. 2001	14	1,065	27,661.8	0.488	0.001
2	320.3 – 305.9	Jul. 1999	Apr. 2001	23	1,495	34,100.0	0.308	#
3	305.9 – 293.4	Sep. 1999	Mar. 2001	20	1,304	29,947.2	0.211	0.001
4	293.4 – 285.3	Jul. 1999	Apr. 2001	23	1,586	35,615.1	0.105	#
Total	325.6 – 285.3	Jul. 1999	Apr. 2001	80	5,450	127,324.1	0.267	0.001

Table 2. Summary of fish community surveys in Isleta Reach between July 1999 and April 2001. Site, river kilometers (km), dates of sampling (Initiation, Conclusion), number of collections trips to each site/section (Visits), total sampling effort (Hauls and Area), total fish density (Total), and Rio Grande silvery minnow density (RGSM) are provided. # = less than 0.001 fish / m^2.

Site	km	Initiation	Conclusion	Visits	Hauls	Area (m^2)	Total (fish / m^2)	RGSM (fish / m^2)
Isleta Dam	270.9	Oct. 2000	Apr. 2001	5	185	3,352.8	0.473	0.001
Isleta Drain Return	265.6	Oct. 2000	Apr. 2001	4	134	2,266.5	0.559	0.001
NM Hwy. 49 bridge	258.2	Oct. 1999	Apr. 2001	16	519	10,867.8	0.570	0.004
Tomé	250.7	Mar. 2000	Apr. 2001	11	398	7,533.6	1.034	0.001
Calle del Rio	244.0	Mar. 2000	Apr. 2001	12	420	8,562.6	0.495	#
NM Hwy. 6 bridge	239.2	Oct. 1999	Apr. 2001	15	496	10,815.9	0.380	0.001
El Paso Gasline	230.4	Mar. 2000	Nov. 2000	9	291	6,740.1	0.784	0.001
NM Hwy. 109 bridge	225.6	Mar. 2000	Apr. 2001	12	405	8,733.6	1.028	0.001
Feeder ditch 3	225.3	Oct. 1999	Feb. 2000	4	75	2,014.5	0.262	0.001
Abo Arroyo confluence	222.7	Mar. 2000	Apr. 2001	12	402	8,112.6	0.940	0.003
Pino Draw confluence	216.0	Mar. 2000	Apr. 2001	12	405	9,029.7	0.594	#
U.S. Highway 60	209.0	Jul. 1999	Feb. 2000	8	155	4,499.7	0.148	0.001
Maes Arroyo confluence	208.0	Mar. 2000	Apr. 2001	12	399	7,906.8	0.668	#
Rio Puerco confluence	202.4	Mar. 2000	Apr. 2001	12	401	8,709.6	0.631	n/c
Sevilleta NWR	198.4	Jan. 2000	Jan. 2000	1	9	238.5	0.021	n/c
Total	270.9 – 98.4	Jul. 1999	Apr. 2001	145	4,694	99,384.3	0.648	0.001

Table 3. Summary of fish community surveys in San Acacia Reach between June 1999 and June 2001. Site, river kilometers (km), dates of sampling (Initiation, Conclusion), number of collections trips to each site/section (Visits), total sampling effort (Hauls and Area), total fish density (Total), and Rio Grande silvery minnow density (RGSM) are provided. # = less than 0.001 fish / m^2.

Site	km	Initiation	Conclusion	Visits	Hauls	Area (m^2)	Total (fish / m^2)	RGSM (fish / m^2)
San Acacia Dam	185.8	Jun. 2001	Jun. 2001	1	11	153.9	4.750	0.305
Lemitar	172.8	Jul. 1999	Jun. 2001	6	95	2,088.3	0.776	0.158
Socorro	160.6	Jun. 1999	May 2001	8	123	3,121.8	0.473	0.219
Brown Arroyo confluence	150.4	Jun. 1999	Jun. 2001	8	104	2,119.2	0.745	0.170
Bosquecito	144.0	Jun. 1999	Jun. 2001	9	110	2,592.9	0.372	0.201
US Hwy. 380 bridge	139.4	Jun. 1999	Sep. 1999	5	69	1,620.0	0.347	0.257
BDANWR, north boundary	134.6	Jun. 1999	Jun. 2001	5	120	3,310.5	0.353	0.225
BDANWR	126.2	Jun. 1999	Jun. 2001	9	138	3,715.4	1.089	0.901
Tiffany Junction	114.9	Jun. 1999	Jun. 2001	8	116	3,003.3	0.860	0.702
San Marcial	109.8	Jun. 1999	Jan. 2000	8	109	2,462.4	1.286	0.868
Fort Craig	102.4	Sep. 1999	Sep. 1999	1	3	51.0	0.176	n/c
LFCC confluence	92.8	May 2001	May 2001	1	10	168.9	1.415	n/c
Total	185.8 – 92.8	Jun. 1999	Jun. 2001	69	1,008	24,407.6	0.743	0.439

Table 4. Numbers (N) and percentage of species found in seine collections from the Rio Grande, NM in Angostura, Isleta, and San Acacia reaches combined. Collections were made between June 1999 and June 2001. # = less than 0.1% or less than 0.001 fish / m^2. For status N=native, I=introduced (non-native).

Species	Status	N	% of total	Percent Occurrence	Density (fish / m^2)
gizzard shad *Dorosoma cepedianum*	I	10	#	0.1	#
red shiner *Cyprinella lutrensis lutrensis*	N	53,300	45.7	32.5	0.212
common carp *Cyprinus carpio*	I	1,337	1.2	3.1	0.005
Rio Grande silvery minnow *Hybognathus amarus*	N	10,907	9.4	4.9	0.043
fathead minnow *Pimephales promelas*	N	4,377	3.8	7.0	0.017
flathead chub *Platygobio gracilis gulonella*	N	1,183	1.0	4.7	0.005
longnose dace *Rhinichthys cataractae cataractae*	N	413	0.4	2.0	0.002
river carpsucker *Carpiodes carpio elongatus*	N	8,393	7.2	10.9	0.033
white sucker *Catostomus commersoni*	I	14,933	12.8	7.9	0.060
smallmouth buffalo *Ictiobus bubalus*	N	10	#	#	#
yellow bullhead *Ameiurus natalis*	I	335	0.3	0.9	0.001
channel catfish *Ictalurus punctatus*	I	4,187	3.6	11.5	0.017
brown trout *Salmo trutta*	I	3	#	#	#
western mosquitofish *Gambusia affinis*	I	16,971	14.6	11.1	0.068
white bass *Morone chrysops*	I	6	#	#	#
green sunfish *Lepomis cyanellus*	I	21	#	0.1	#
bluegill *Lepomis macrochirus speciosus*	N	12	#	0.1	#
spotted bass *Micropterus punctulatus*	I	15	#	0.1	#
largemouth bass *Micropterus salmoides*	I	13	#	0.1	#
white crappie *Pomoxis annularis*	I	163	0.1	0.5	0.001
yellow perch *Perca flavescens*	I	3	#	#	#
walleye *Stizostedion vitreum*	I	13	#	0.1	#
TOTAL		116,605	100.0	49.7	0.464

Table 5. Numbers (N) and percentage of species found in seine collections from the Rio Grande, NM in the Angostura Reach. Collections were made between July 1999 and April 2001. # = less than 0.1% or less than 0.1 fish / m^2. For status N=native, I=introduced (non-native).

Species	Status	N	% of total	Percent Occurrence	Density (fish / m^2)
gizzard shad *Dorosoma cepedianum*	I	3	#	#	#
red shiner *Cyprinella lutrensis lutrensis*	N	9,640	28.3	17.1	0.076
common carp *Cyprinus carpio*	I	124	0.4	0.8	0.001
Rio Grande silvery minnow *Hybognathus amarus*	N	82	0.2	0.7	0.001
fathead minnow *Pimephales promelas*	N	487	1.4	3.0	0.004
flathead chub *Platygobio gracilis gulonella*	N	508	1.5	4.5	0.004
longnose dace *Rhinichthys cataractae cataractae*	N	387	1.1	3.7	0.003
river carpsucker *Carpiodes carpio elongatus*	N	1,096	3.2	4.4	0.009
white sucker *Catostomus commersoni*	I	14,177	41.6	13.3	0.111
yellow bullhead *Ameiurus natalis*	I	66	0.2	0.8	0.001
channel catfish *Ictalurus punctatus*	I	1,169	3.4	7.2	0.009
brown trout *Salmo trutta*	I	3	#	0.1	#
western mosquitofish *Gambusia affinis*	I	6,156	18.1	8.9	0.049
white bass *Morone chrysops*	I	2	#	#	#
green sunfish *Lepomis cyanellus*	I	20	0.1	0.3	#
bluegill *Lepomis macrochirus speciosus*	N	10	#	0.2	#
spotted bass *Micropterus punctulatus*	I	7	#	0.1	#
white crappie *Pomoxis annularis*	I	110	0.3	0.6	0.001
yellow perch *Perca flavescens*	I	3	#	#	#
walleye *Stizostedion vitreum*	I	7	#	0.1	#
TOTAL		34,057	100.0	36.9	0.267

Table 6. Numbers (N) and percentage of species found in seine collections from the Rio Grande, NM in the Isleta Reach. Collections were made between July 1999 and April 2001. # = less than 0.1% or less than 0.1 fish / m^2. For status N=native, I=introduced (non-native).

Species	Status	N	% of total	Percent Occurrence	Density fish / m^2
gizzard shad *Dorosoma cepedianum*	I	4	#	0.1	#
red shiner *Cyprinella lutrensis lutrensis*	N	39,362	61.1	49.7	0.396
common carp *Cyprinus carpio*	I	777	1.2	4.6	0.008
Rio Grande silvery minnow *Hybognathus amarus*	N	113	0.2	1.2	0.001
fathead minnow *Pimephales promelas*	N	3,643	5.7	11.7	0.037
flathead chub *Platygobio gracilis gulonella*	N	245	0.4	2.7	0.003
longnose dace *Rhinichthys cataractae cataractae*	N	5	#	0.1	#
river carpsucker *Carpiodes carpio elongatus*	N	6,704	10.4	18.1	0.068
white sucker *Catostomus commersoni*	I	693	1.1	3.0	0.007
yellow bullhead *Ameiurus natalis*	I	226	0.4	1.1	0.002
channel catfish *Ictalurus punctatus*	I	2,609	4.1	15.5	0.026
western mosquitofish *Gambusia affinis*	I	9,942	15.4	13.9	0.100
white bass *Morone chrysops*	I	3	#	#	#
green sunfish *Lepomis cyanellus*	I	1	#	#	#
bluegill *Lepomis macrochirus speciosus*	N	2	#	#	#
spotted bass *Micropterus punctulatus*	I	6	#	0.1	#
largemouth bass *Micropterus salmoides*	I	12	#	0.3	#
white crappie *Pomoxis annularis*	I	52	0.1	0.5	0.001
walleye *Stizostedion vitreum*	I	4	#	0.1	#
TOTAL		64,403	100.0	60.2	0.648

Table 7. Numbers (N) and percentage of species found in seine collections from the Rio Grande, NM in the San Acacia Reach. Collections were made between June 1999 and June 2001. # = less than 0.1% or less than 0.1 fish / m^2. For status N=native, I=introduced (non-native).

Species	Status	N	% of total	Percent Occurrence	Density fish / m^2
gizzard shad *Dorosoma cepedianum*	I	3	#	0.3	#
red shiner *Cyprinella lutrensis lutrensis*	N	4,298	23.7	35.6	0.176
common carp *Cyprinus carpio*	I	436	2.4	8.1	0.018
Rio Grande silvery minnow *Hybognathus amarus*	N	10,712	59.0	45.0	0.439
fathead minnow *Pimephales promelas*	N	247	1.4	6.3	0.010
flathead chub *Platygobio gracilis gulonella*	N	430	2.4	15.2	0.018
longnose dace *Rhinichthys cataractae cataractae*	N	21	0.1	1.5	0.001
river carpsucker *Carpiodes carpio elongatus*	N	593	3.3	12.8	0.024
white sucker *Catostomus commersoni*	I	63	0.4	2.1	0.003
smallmouth buffalo *Ictiobus bubalus*	N	10	0.1	0.5	#
yellow bullhead *Ameiurus natalis*	I	43	0.2	1.3	0.002
channel catfish *Ictalurus punctatus*	I	409	2.3	16.8	0.017
western mosquitofish *Gambusia affinis*	I	873	4.8	9.3	0.036
white bass *Morone chrysops*	I	1	#	0.1	#
spotted bass *Micropterus punctulatus*	I	2	#	0.2	#
largemouth bass *Micropterus salmoides*	I	1	#	0.1	#
white crappie *Pomoxis annularis*	I	1	#	0.1	#
walleye *Stizostedion vitreum*	I	2	#	0.2	#
TOTAL		18,145	100.0	69.5	0.743

Table 8. Fish species diversity by study reach from June 1999 through June 2001. Hill's numbers (N0, N1, N2) and *J* of Pielou were used to assess diversity. N0 = species richness, N1 = number of abundant species (inverse natural log of Shannon's index), N2 = number of very abundant species (reciprocal of Simpson's index), *J* of Pielou = species evenness.

	Angostura	Isleta	San Acacia
N0	20	19	18
N1	4.53	3.39	2.77
N2	3.46	2.42	2.44
J of Pielou	0.50	0.41	0.35

Table 9. Similarity of fish faunas from each study reach based on all collections from June 1999 through June 2001. Morisita's and Jaccard's index values given for each reach combination.

Morisita's Index

	Angostura	Isleta
Isleta	0.60	-
San Acacia	0.23	0.39

Jaccard's Index

	Angostura	Isleta
Isleta	0.86	-
San Acacia	0.73	0.85

Table 10. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing red shiner. First line indicates the number (N) of seine hauls present and percent co-occurrence of red shiner within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
red shiner *Cyprinella lutrensis lutrensis*	**932**	**17.1**	**2333**	**49.7**	**358**	**35.6**
common carp *Cyprinus carpio*		1.2		7.2		14.2
Rio Grande silvery minnow *Hybognathus amarus*		2.5		1.9		60.3
fathead minnow *Pimephales promelas*		12.1		21.8		13.4
flathead chub *Platygobio gracilis gulonella*		12.9		3.7		26.3
longnose dace *Rhinichthys cataractae cataractae*		8.5		0.1		2.5
river carpsucker *Carpiodes carpio elongatus*		13.1		29.1		22.9
white sucker *Catostomus commersoni*		25.5		4.8		3.9
channel catfish *Ictalurus punctatus*		11.5		24.4		23.5
western mosquitofish *Gambusia affinis*		28.6		22.8		17.9
Average		12.9		12.9		20.5

Table 11. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing common carp. First line indicates the number (N) of seine hauls present and percent co-occurrence of common carp within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
common carp *Cyprinus carpio*	**44**	**0.8**	**216**	**4.6**	**82**	**8.1**
red shiner *Cyprinella lutrensis lutrensis*		25.0		77.8		62.2
Rio Grande silvery minnow *Hybognathus amarus*		0.0		0.9		75.6
fathead minnow *Pimephales promelas*		13.6		38.9		31.7
flathead chub *Platygobio gracilis gulonella*		20.5		3.2		22.0
longnose dace *Rhinichthys cataractae cataractae*		2.3		0.5		4.9
river carpsucker *Carpiodes carpio elongatus*		2.3		50.9		46.3
white sucker *Catostomus commersoni*		63.6		26.9		15.9
channel catfish *Ictalurus punctatus*		31.8		36.6		23.2
western mosquitofish *Gambusia affinis*		29.5		26.4		41.5
Average		21.0		29.1		35.9

Table 12. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing Rio Grande silvery minnow. First line indicates the number (N) of seine hauls present and percent co-occurrence of Rio Grande silvery minnow within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
Rio Grande silvery minnow *Hybognathus amarus*	**38**	**0.7**	**56**	**1.2**	**454**	**45.0**
red shiner *Cyprinella lutrensis lutrensis*		60.5		75.0		48.0
common carp *Cyprinus carpio*		0.0		1.9		13.9
fathead minnow *Pimephales promelas*		23.7		26.5		9.7
flathead chub *Platygobio gracilis gulonella*		23.7		10.6		19.4
longnose dace *Rhinichthys cataractae cataractae*		7.9		0.0		2.0
river carpsucker *Carpiodes carpio elongatus*		18.4		27.3		22.5
white sucker *Catostomus commersoni*		26.3		3.5		3.7
channel catfish *Ictalurus punctatus*		15.8		19.5		23.4
western mosquitofish *Gambusia affinis*		29.0		21.0		13.2
Average		22.8		20.6		17.3

Table 13. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing fathead minnow. First line indicates the number (N) of seine hauls present and percent co-occurrence of fathead minnow within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
fathead minnow *Pimephales promelas*	**164**	**3.0**	**550**	**11.7**	**63**	**6.3**
red shiner *Cyprinella lutrensis lutrensis*		69.5		92.5		76.2
common carp *Cyprinus carpio*		3.7		15.1		41.3
Rio Grande silvery minnow *Hybognathus amarus*		5.5		2.9		69.8
flathead chub *Platygobio gracilis gulonella*		15.9		3.3		28.6
longnose dace *Rhinichthys cataractae cataractae*		12.2		0.2		6.3
river carpsucker *Carpiodes carpio elongatus*		26.2		52.0		41.3
white sucker *Catostomus commersoni*		50.6		8.9		7.9
channel catfish *Ictalurus punctatus*		17.1		35.6		30.2
western mosquitofish *Gambusia affinis*		54.3		42.7		46.0
Average		28.3		28.1		38.6

Table 14. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing flathead chub. First line indicates the number (N) of seine hauls present and percent co-occurrence of flathead chub within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
flathead chub *Platygobio gracilis gulonella*	**245**	**4.5**	**127**	**2.7**	**153**	**15.2**
red shiner *Cyprinella lutrensis lutrensis*		49.0		67.7		61.4
common carp *Cyprinus carpio*		0.4		5.5		11.8
Rio Grande silvery minnow *Hybognathus amarus*		3.7		4.7		60.8
fathead minnow *Pimephales promelas*		10.6		14.2		11.8
longnose dace *Rhinichthys cataractae cataractae*		13.5		0.0		4.6
river carpsucker *Carpiodes carpio elongatus*		12.2		29.9		22.9
white sucker *Catostomus commersoni*		20.4		7.1		2.6
channel catfish *Ictalurus punctatus*		10.2		29.9		20.3
western mosquitofish *Gambusia affinis*		19.2		12.6		13.7
Average		15.5		19.1		23.3

Table 15. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing longnose dace. First line indicates the number (N) of seine hauls present and percent co-occurrence of longnose dace within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
longnose dace *Rhinichthys cataractae cataractae*	**202**	**1.5**	**5**	**0.1**	**15**	**3.7**
red shiner *Cyprinella lutrensis lutrensis*		39.1		40.0		60.0
common carp *Cyprinus carpio*		0.5		20.0		26.7
Rio Grande silvery minnow *Hybognathus amarus*		1.5		0.0		60.0
fathead minnow *Pimephales promelas*		9.9		20.0		26.7
flathead chub *Platygobio gracilis gulonella*		16.3		0.0		46.7
river carpsucker *Carpiodes carpio elongatus*		6.4		20.0		26.7
white sucker *Catostomus commersoni*		35.1		0.0		0.0
channel catfish *Ictalurus punctatus*		12.4		40.0		13.3
western mosquitofish *Gambusia affinis*		12.9		0.0		26.7
Average		14.9		15.6		31.9

Table 16. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing river carpsucker. First line indicates the number (N) of seine hauls present and percent co-occurrence of river carpsucker within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
river carpsucker *Carpiodes carpio*	**240**	**4.4**	**850**	**18.1**	**129**	**12.8**
red shiner *Cyprinella lutrensis lutrensis*		50.8		79.6		63.6
common carp *Cyprinus carpio*		3.8		13.1		29.5
Rio Grande silvery minnow *Hybognathus amarus*		2.9		1.9		78.3
fathead minnow *Pimephales promelas*		17.9		33.6		20.2
flathead chub *Platygobio gracilis gulonella*		12.5		4.5		27.1
longnose dace *Rhinichthys cataractae cataractae*		5.4		0.1		3.1
white sucker *Catostomus commersoni*		42.5		6.7		5.4
channel catfish *Ictalurus punctatus*		22.9		33.4		22.5
western mosquitofish *Gambusia affinis*		37.5		31.1		33.3
Average		21.8		22.7		31.4

Table 17. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing white sucker. First line indicates the number (N) of seine hauls present and percent co-occurrence of white sucker within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
white sucker *Catostomus commersoni*	**725**	**13.3**	**141**	**3.0**	**21**	**2.1**
red shiner *Cyprinella lutrensis lutrensis*		32.8		78.0		66.7
common carp *Cyprinus carpio*		3.6		40.4		61.9
Rio Grande silvery minnow *Hybognathus amarus*		1.4		0.7		81.0
fathead minnow *Pimephales promelas*		11.4		34.0		23.8
flathead chub *Platygobio gracilis gulonella*		6.9		6.4		19.0
longnose dace *Rhinichthys cataractae cataractae*		9.8		0.0		0.0
river carpsucker *Carpiodes carpio elongatus*		14.1		39.7		33.3
channel catfish *Ictalurus punctatus*		14.8		18.4		4.8
western mosquitofish *Gambusia affinis*		21.9		19.1		38.1
Average		13.0		26.3		36.5

Table 18. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing channel catfish. First line indicates the number (N) of seine hauls present and percent co-occurrence of channel catfish within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
channel catfish *Ictalurus punctatus*	**392**	**7.2**	**728**	**15.5**	**169**	**16.8**
red shiner *Cyprinella lutrensis lutrensis*		27.3		77.9		49.7
common carp *Cyprinus carpio*		2.6		10.3		11.2
Rio Grande silvery minnow *Hybognathus amarus*		1.5		1.5		62.1
fathead minnow *Pimephales promelas*		7.1		26.8		11.2
flathead chub *Platygobio gracilis gulonella*		6.4		5.2		18.3
longnose dace *Rhinichthys cataractae cataractae*		3.3		0.3		0.0
river carpsucker *Carpiodes carpio elongatus*		14.0		5.2		17.2
white sucker *Catostomus commersoni*		27.3		1.2		0.6
western mosquitofish *Gambusia affinis*		18.4		2.2		10.7
Average		12.0		14.5		20.1

Table 19. Percent co-occurrence of abundant species (greater than 1.0% total abundance) found within seine hauls containing western mosquitofish. First line indicates the number (N) of seine hauls present and percent co-occurrence of western mosquitofish within all seine hauls in that reach.

Species	Angostura		Isleta		San Acacia	
	N	%	N	%	N	%
western mosquitofish *Gambusia affinis*	**485**	**8.9**	**652**	**13.9**	**94**	**9.3**
red shiner *Cyprinella lutrensis lutrensis*		55.3		81.9		68.1
common carp *Cyprinus carpio*		3.3		8.7		36.2
Rio Grande silvery minnow *Hybognathus amarus*		2.3		1.8		72.3
fathead minnow *Pimephales promelas*		18.4		36.2		30.9
flathead chub *Platygobio gracilis gulonella*		8.0		0.6		46.8
longnose dace *Rhinichthys cataractae cataractae*		5.4		0.0		4.3
river carpsucker *Carpiodes carpio elongatus*		18.6		40.8		45.7
white sucker *Catostomus commersoni*		33.0		4.1		8.5
channel catfish *Ictalurus punctatus*		14.8		28.5		19.1
Average		17.7		22.5		36.9

Table 20. Occurrence of habitat variables within seine hauls tested with chi-square. Samples are separated by reach and by occurrence of fish. Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all available seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all available seine hauls. For example, seine hauls within Angostura reach that contained fish had a higher occurrence of shoreline habitat than "expected". For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • •=0.05. Individual test significance values (0.00167) were calculated using the Bonferroni correction (• •/N), where N = 30 total number of tests.

	Angostura		Isleta		San Acacia	
	With Fish	No Fish	With Fish	No Fish	With Fish	No Fish
Shoreline	+	-	+	-	+	-
Debris	+	-	=	=	=	=
Velocity	*	*	*	*	*	*
Slackwater	+	-	=	=	+	-
Slow	=	=	+	-	+	-
Medium	-	+	-	+	-	+
Fast	=	=	-	+	-	+
Depth	*	*	=	=	=	=
Shallow	+	=	=	=	=	=
Medium	=	=	=	=	=	=
Deep	-	=	=	=	=	=
Substrate	*	*	*	*	*	*
Silt	+	-	+	-	+	-
Sand	-	+	-	+	-	+
Gravel	=	=	=	=	=	=

Table 21. Occurrence within habitat variables for red shiner (*Cyprinella lutrensis lutrensis*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • •=0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• •/N), where N = 15 total number of tests.

red shiner (*Cyprinella lutrensis lutrensis*)			
	Angostura	Isleta	San Acacia
Shoreline	+	+	+
Debris	+	+	+
Velocity	*	*	*
Slackwater	+	=	+
Slow	=	+	+
Medium	-	-	-
Fast	=	-	-
Depth	*	*	*
Shallow	+	-	-
Medium	=	+	+
Deep	-	-	-
Substrate	*	*	*
Silt	+	+	+
Sand	-	-	-
Gravel	=	=	=

Table 22. Occurrence within habitat variables for common carp (*Cyprinus carpio*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • •=•0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• •/N), where N = 15 total number of tests.

common carp (*Cyprinus carpio*)			
	Angostura	Isleta	San Acacia
Shoreline	+	+	+
Debris	+	=	+
Velocity	*	*	*
Slackwater	+	+	+
Slow	-	=	-
Medium	-	-	-
Fast	N/A	-	-
Depth	=	=	*
Shallow	=	=	-
Medium	=	=	+
Deep	=	=	=
Substrate	*	*	*
Silt	+	+	+
Sand	-	-	-
Gravel	-	N/A	=

Table 23. Occurrence within habitat variables for Rio Grande silvery minnow (*Hybognathus amarus*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. Parenthesis () with "A" indicate differences in association by adult Rio Grande silvery minnow. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table $\alpha =$ 0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (α/N), where N = 15 total number of tests.

Rio Grande silvery minnow (*Hybognathus amarus*)			
	Angostura	Isleta	San Acacia
Shoreline	=	=	+ (A =)
Debris	+	+	+
Velocity	=	=	*
Slackwater	=	=	+ (A -)
Slow	=	=	- (A +)
Medium	=	=	-
Fast	N/A	=	-
Depth	=	*	*
Shallow	=	-	=
Medium	=	=	+
Deep	=	=	-
Substrate	*	=	*
Silt	= (A +)	=	+
Sand	=	=	-
Gravel	-	=	- (A =)

Table 24. Occurrence within habitat variables for fathead minnow (*Pimephales promelas*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • • =•0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• • / N), where N = 15 total number of tests.

fathead minnow (*Pimephales promelas*)			
	Angostura	Isleta	San Acacia
Shoreline	+	+	+
Debris	+	+	=
Velocity	*	*	*
Slackwater	+	+	+
Slow	+	+	=
Medium	-	-	-
Fast	-	-	-
Depth	*	*	*
Shallow	=	+	-
Medium	=	=	+
Deep	-	-	=
Substrate	*	*	*
Silt	+	+	+
Sand	-	-	-
Gravel	-	-	=

Table 25. Occurrence within habitat variables for flathead chub (*Platygobio gracilis gulonella*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • •=•0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• •/ N), where N = 15 total number of tests.

flathead chub (*Platygobio gracilis gulonella*)			
	Angostura	Isleta	San Acacia
Shoreline	+	-	+
Debris	=	=	=
Velocity	*	*	*
Slackwater	+	-	=
Slow	=	=	=
Medium	-	=	=
Fast	-	=	-
Depth	=	*	*
Shallow	=	-	+
Medium	=	+	=
Deep	=	=	-
Substrate	*	*	=
Silt	=	+	=
Sand	-	-	=
Gravel	=	=	=

Table 26. Occurrence within habitat variables for longnose dace (*Rhinichthys cataractae cataractae*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • •=•0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• •/N), where N = 15 total number of tests.

longnose dace (*Rhinichthys cataractae cataractae*)			
	Angostura	Isleta	San Acacia
Shoreline	+	=	+
Debris	=	=	=
Velocity	*	=	=
Slackwater	=	N/A	=
Slow	-	=	=
Medium	=	=	=
Fast	+	N/A	N/A
Depth	*	=	*
Shallow	+	=	+
Medium	-	=	=
Deep	=	=	N/A
Substrate	*	=	*
Silt	=	=	=
Sand	-	=	=
Gravel	+	=	+

Table 27. Occurrence within habitat variables for river carpsucker (*Carpiodes carpio elongatus*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • • =0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• • / N), where N = 15 total number of tests.

river carpsucker (*Carpiodes carpio elongatus*)			
	Angostura	Isleta	San Acacia
Shoreline	+	+	+
Debris	+	-	=
Velocity	*	*	*
Slackwater	+	+	+
Slow	-	+	=
Medium	-	-	-
Fast	-	-	N/A
Depth	*	*	*
Shallow	+	-	+
Medium	-	+	-
Deep	-	-	-
Substrate	*	*	*
Silt	+	+	+
Sand	-	-	-
Gravel	-	-	+

Table 28. Occurrence within habitat variables for white sucker (*Catostomus commersoni*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • •=•0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• • / N), where N = 15 total number of tests.

white sucker (*Catostomus commersoni*)			
	Angostura	Isleta	San Acacia
Shoreline	+	+	+
Debris	+	=	=
Velocity	*	*	*
Slackwater	+	+	+
Slow	+	+	-
Medium	-	-	-
Fast	-	N/A	N/A
Depth	*	*	=
Shallow	+	-	=
Medium	-	=	=
Deep	+	+	=
Substrate	*	*	*
Silt	+	+	+
Sand	-	-	-
Gravel	-	=	N/A

Table 29. Occurrence within habitat variables for yellow bullhead (*Ameiurus natalis*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • •=0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• •/N), where N = 15 total number of tests.

yellow bullhead (*Ameiurus natalis*)			
	Angostura	Isleta	San Acacia
Shoreline	+	+	=
Debris	+	=	=
Velocity	*	*	=
Slackwater	=	-	=
Slow	-	+	=
Medium	=	-	=
Fast	=	-	=
Depth	*	*	=
Shallow	+	=	=
Medium	-	+	=
Deep	-	-	=
Substrate	*	*	=
Silt	=	+	=
Sand	-	-	=
Gravel	=	N/A	N/A

Table 30. Occurrence within habitat variables for channel catfish (*Ictalurus punctatus*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • • =0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• • / N), where N = 15 total number of tests.

channel catfish (*Ictalurus punctatus*)			
	Angostura	Isleta	San Acacia
Shoreline	=	+	+
Debris	+	+	=
Velocity	*	*	*
Slackwater	=	-	+
Slow	+	+	=
Medium	-	=	=
Fast	-	-	-
Depth	*	*	=
Shallow	=	-	=
Medium	=	+	=
Deep	-	+	=
Substrate	=	*	*
Silt	=	+	+
Sand	=	-	-
Gravel	=	=	N/A

Table 31. Occurrence within habitat variables for western mosquitofish (*Gambusia affinis*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • • = 0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• • / N), where N = 15 total number of tests.

western mosquitofish (*Gambusia affinis*)			
	Angostura	Isleta	San Acacia
Shoreline	+	+	+
Debris	+	=	=
Velocity	*	*	*
Slackwater	+	+	+
Slow	-	-	+
Medium	-	-	=
Fast	-	-	-
Depth	*	*	*
Shallow	+	+	-
Medium	-	-	+
Deep	-	-	-
Substrate	*	*	*
Silt	+	+	+
Sand	-	-	-
Gravel	-	-	=

Table 32. Occurrence within habitat variables for white crappie (*Pomoxis annularis*) tested with chi-square. Samples are separated by reach (Angostura, Isleta, and San Acacia). Habitat occurrence - "less than expected", + "more than expected" indicates variable did not follow the "expected" pattern as defined by all seine hauls. Habitat occurrence = "equal" indicates variable followed the "expected" pattern as defined by all seine hauls. Habitat occurrence "N/A" indicates that this species was not collected in this particular category. For variables with multiple categories, overall significance is calculated with a chi-square test, denoted by *. If overall test is significant, subsequent individual categories were analyzed with Bonferroni *z* statistic as described by Neu et al. (1974). Overall table • • = 0.05. Individual test significance values (0.003) were calculated using the Bonferroni correction (• • / N), where N = 15 total number of tests.

white crappie (*Pomoxis annularis*)			
	Angostura	Isleta	San Acacia
Shoreline	+	=	+
Debris	+	=	-
Velocity	*	*	*
Slackwater	+	+	+
Slow	-	-	N/A
Medium	-	-	N/A
Fast	N/A	-	N/A
Depth	*	=	*
Shallow	=	=	N/A
Medium	+	=	+
Deep	-	=	N/A
Substrate	*	*	*
Silt	+	+	N/A
Sand	-	-	N/A
Gravel	=	N/A	+

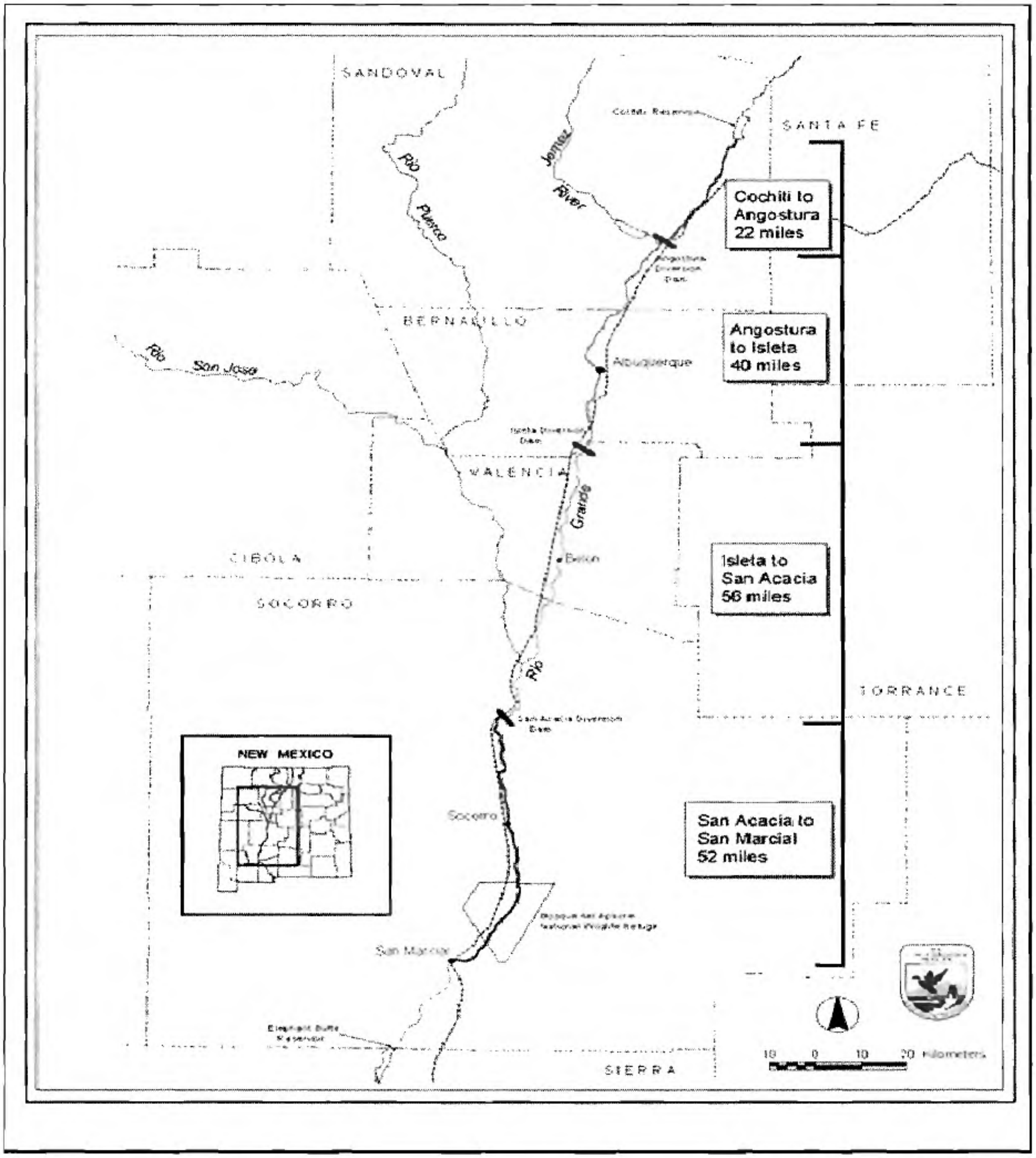


Figure 1. Map of the study area within the Rio Grande, New Mexico

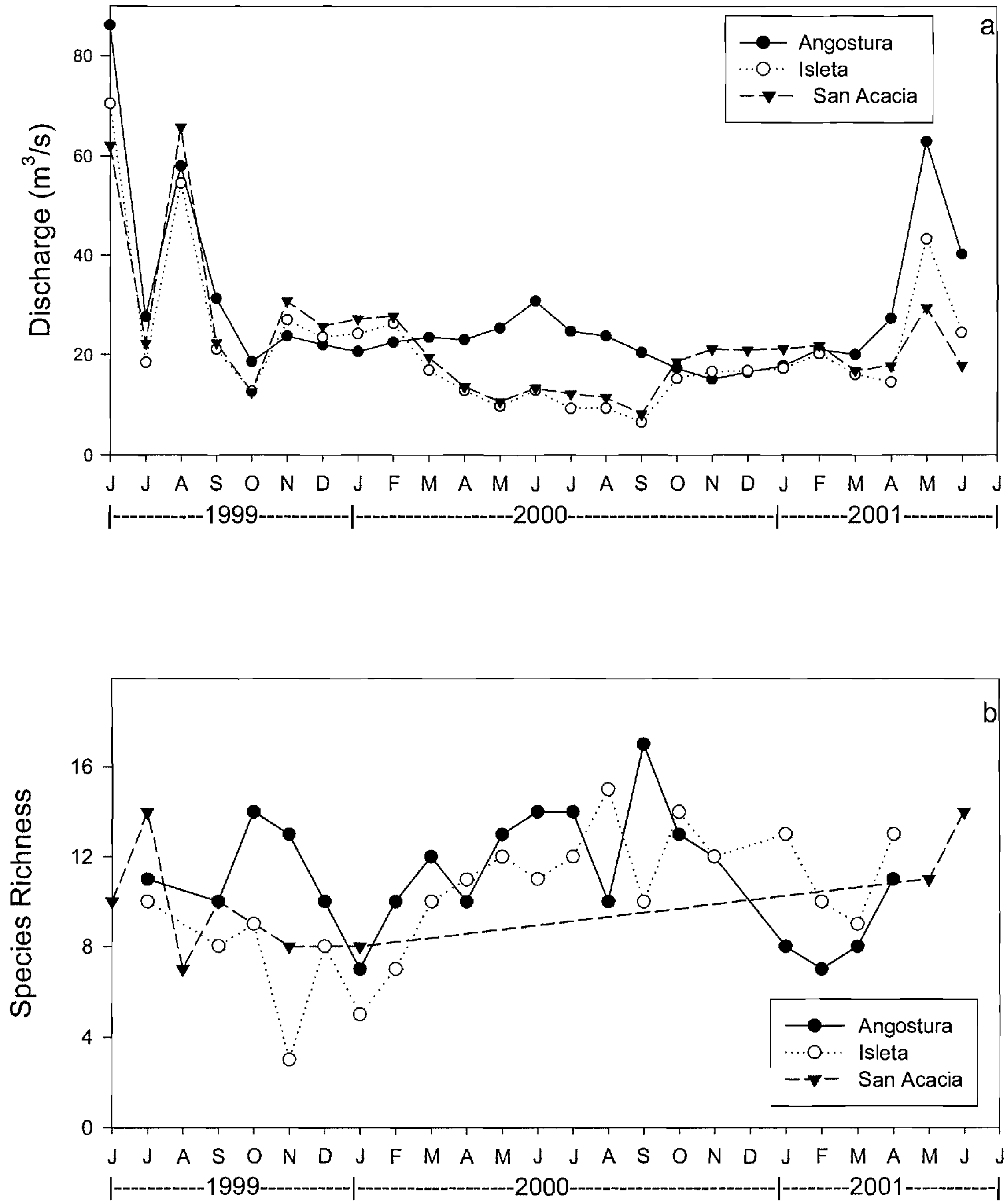
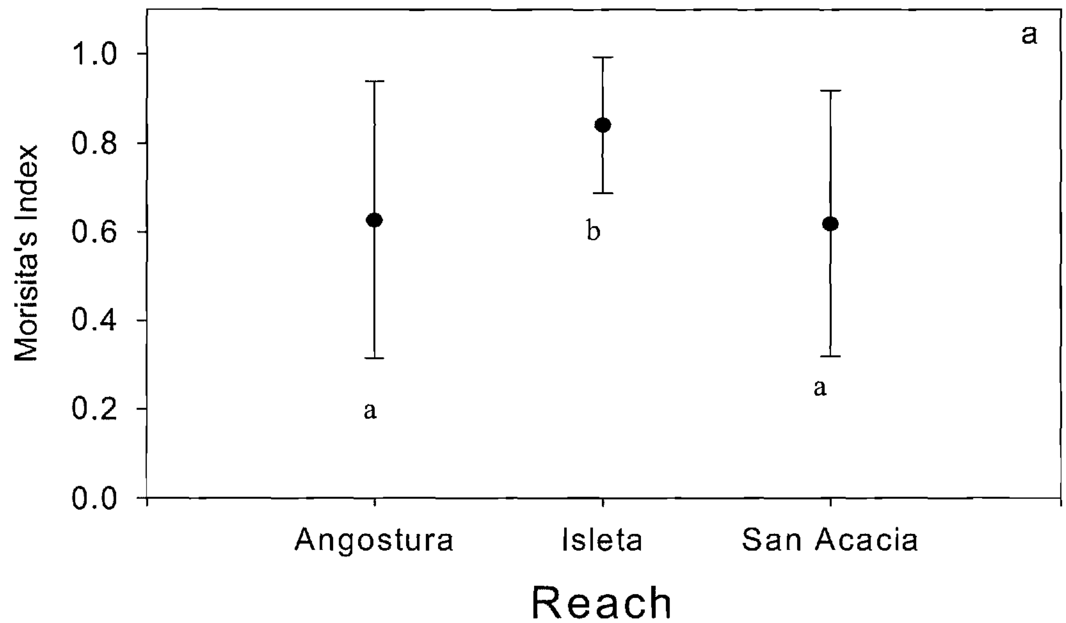


Figure 2. Temporal changes in fish community in three reaches of the middle Rio Grande, New Mexico: a-mean monthly streamflow, b-species richness (number of species captured).



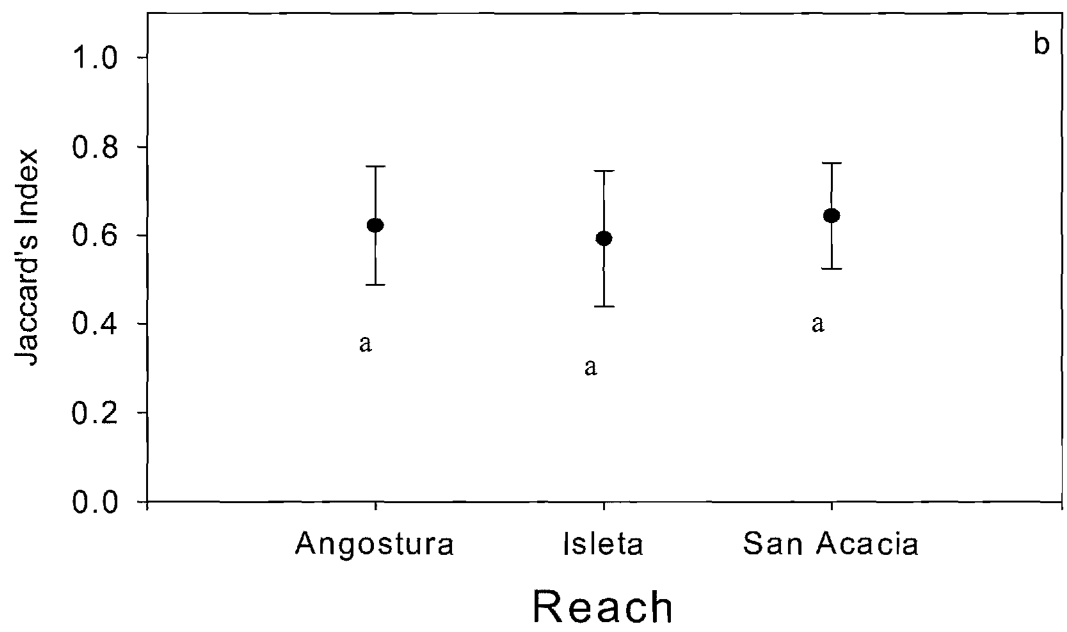


Figure 3. Mean and standard deviation of Morisita's (a) and Jaccard's (b) index values calculated for all pair-wise comparisons of the spatial fish community across sample dates for each of the three sampled reaches in the Middle Rio Grande, New Mexico. Higher means with less variation indicates a more stable fish community within a site. Different letters represent significant ($p < 0.05$) differences between means.

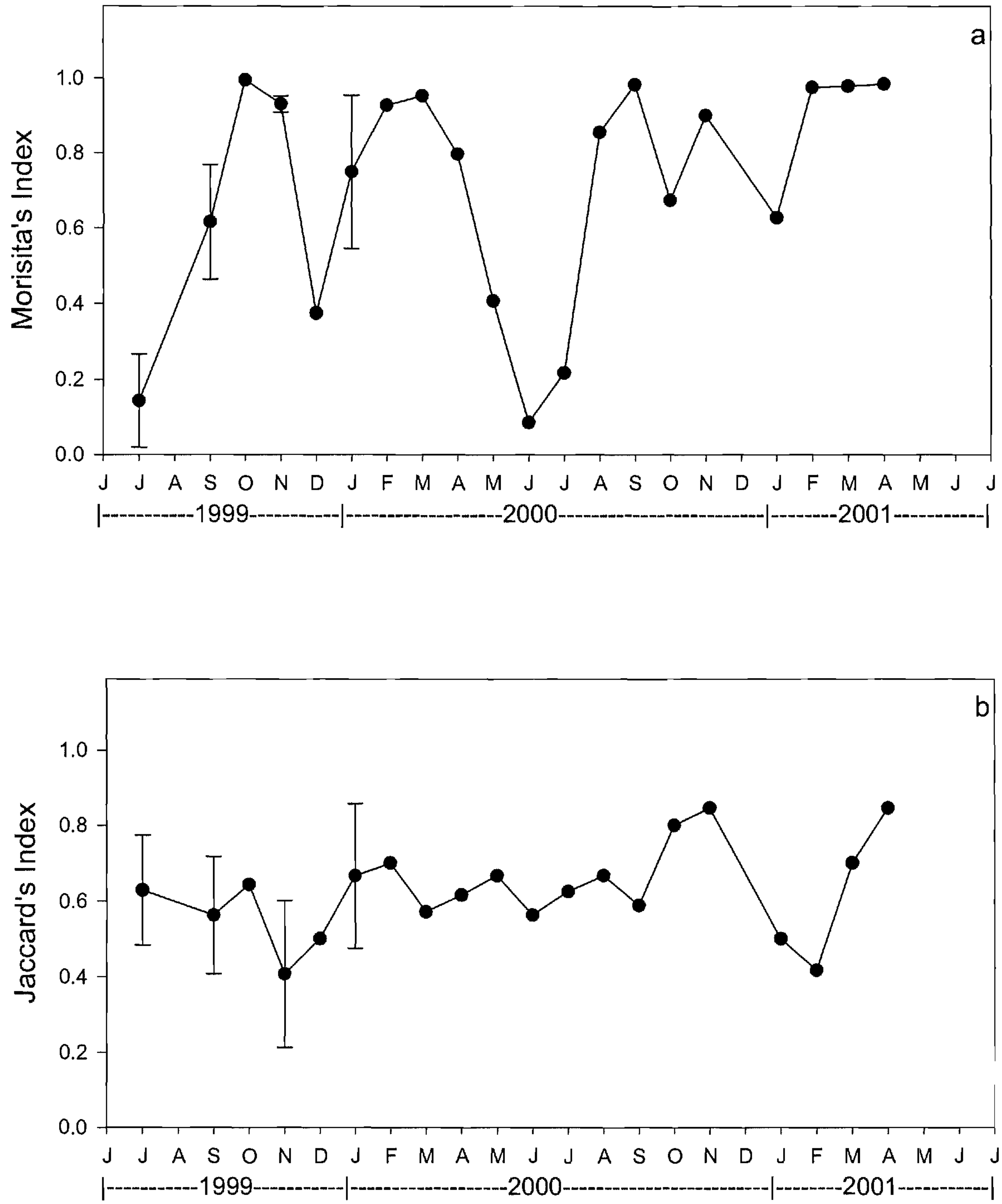
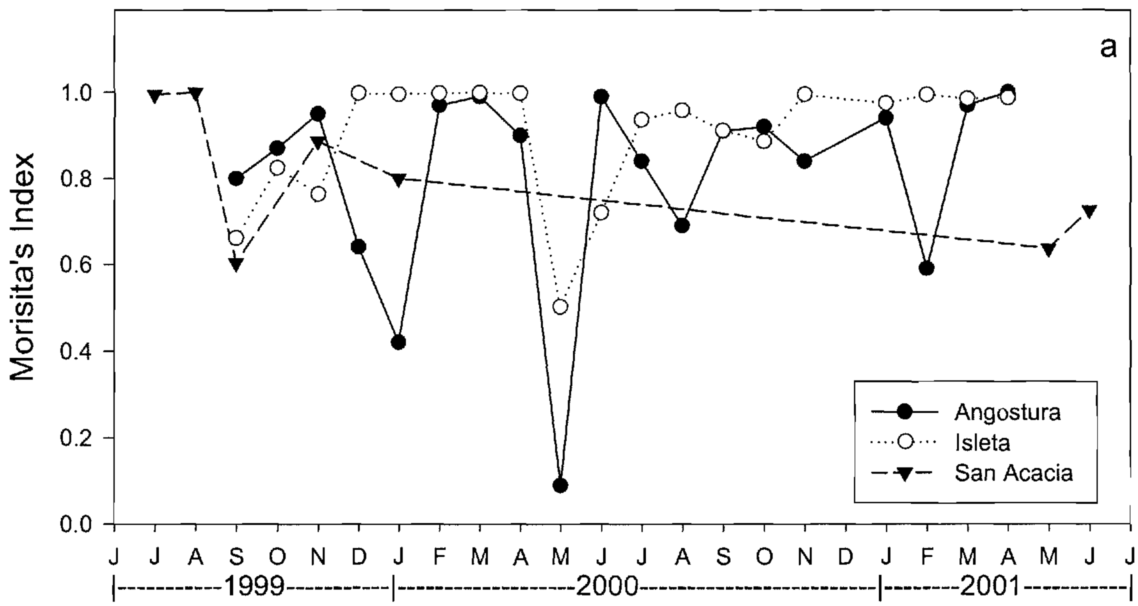


Figure 4. Temporal changes in fish community in three reaches of the middle Rio Grande, New Mexico. Morisita's (a) and Jaccard's (b) index values calculated for all monthly pair-wise comparisons of the fish community among the three reaches.



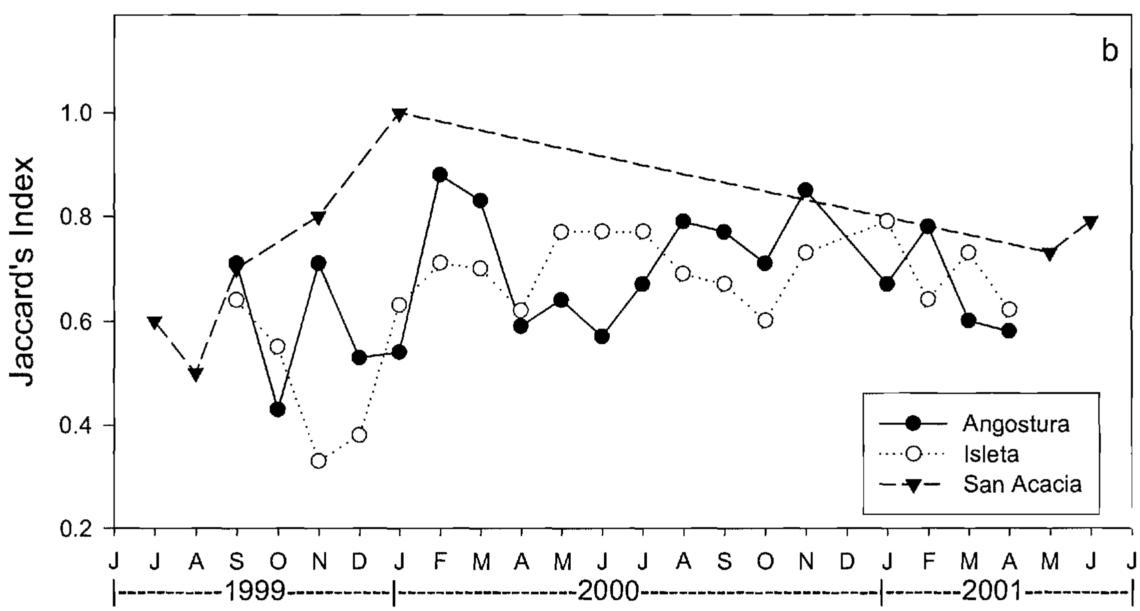


Figure 5. Temporal changes in fish community in three reaches of the middle Rio Grande, New Mexico. Mean and standard deviation of Morisita's (a) and Jaccard's (b) index values calculated for the similarity of the fish community with the community in the previous month in that reach

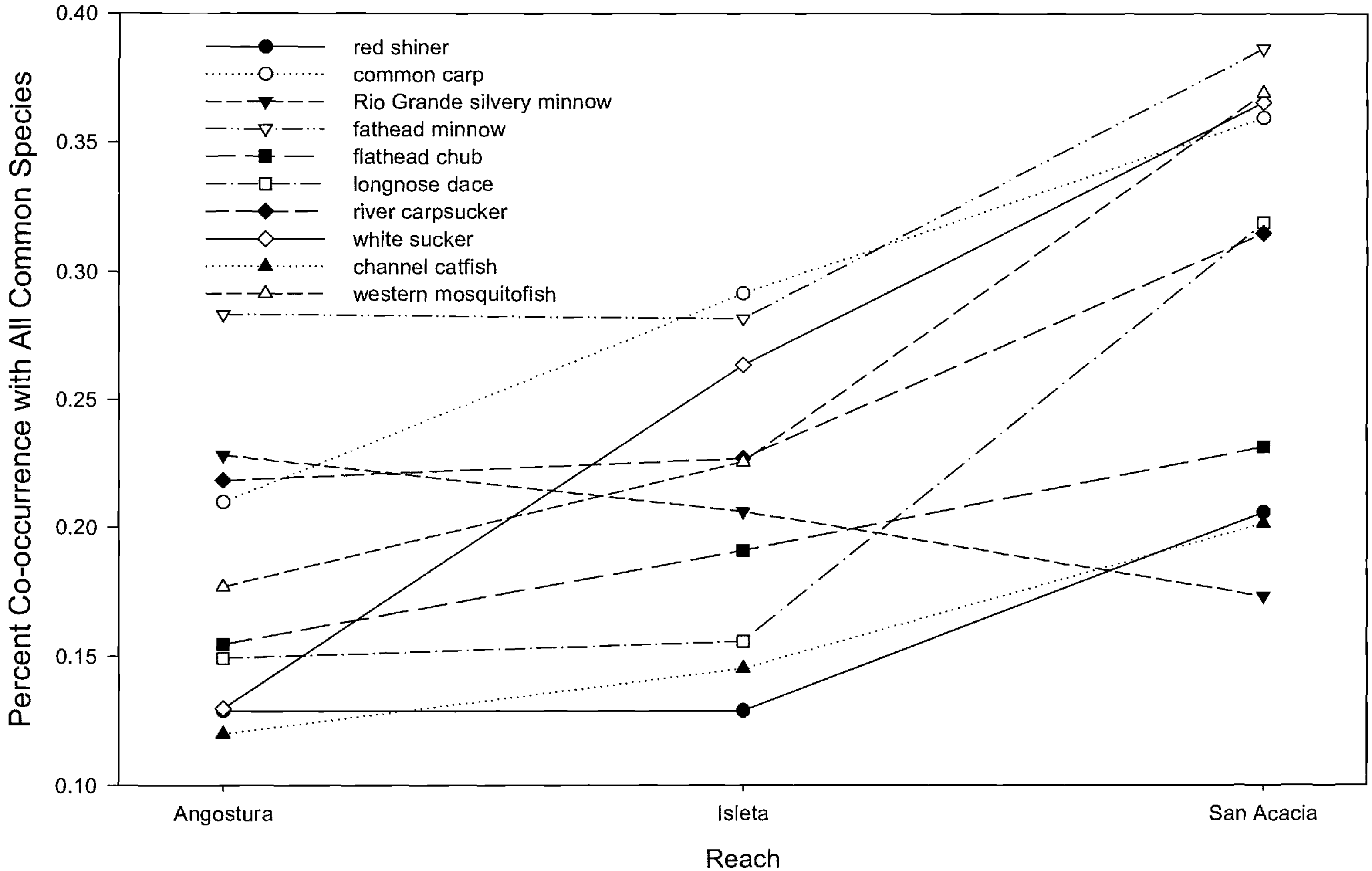


Figure 6. Average percent co-occurrence of common species with all other common species by reach.

Appendix A. Description of mesohabitat categories used in classification of seine hauls.

Run – Flowing habitat with direction of flow generally parallel with the adjacent shore. Substrate of variable particle size, largely dependent upon current velocity, and water surface slope roughly similar to the overall stream gradient. Run mesohabitat is the dominant mesohabitat type, but runs vary greatly in character (e.g., depth and velocity).

Main-channel Pool – Flowing habitat with flow direction generally parallel with the adjacent shore, deep and slow compared to adjacent habitats. Substrate particle size is variable, largely dependent upon current velocity, water surface slope is less than the overall stream gradient. Main-channel pool mesohabitat is relatively uncommon and highly variable.

Backwater – Slackwater areas most commonly found at the downstream end of abandoned channels. Substrate particle size is fine, most commonly silt. Backwater mesohabitat is inundated by water from the adjacent flowing channel with water commonly 'backing' into the abandoned channel outflow. Backwater mesohabitat is uncommon.

Riffle – Flowing habitat with flow direction generally parallel with the adjacent shore, shallow and steep compared to adjacent habitats. Substrate particle size is coarse, usually gravel, but may also consist of armored substrate. Riffle mesohabitat is uncommon, declining in abundance from upstream to downstream.

Plunge – A turbulent pool created by water spilling over a channel feature such as a riffle, dune crest, or debris pile. Substrate particle size is variable, depending upon velocity. Plunge mesohabitat is most common in sand-bed channels where it is associated with downstream dune faces.

Isolated Pool – An abandoned, remnant pool in a high-flow channel, sometimes fed by subsurface seepage. Substrate particle size is fine, typically silt. Isolated pool mesohabitat is uncommon and usually ephemeral.

Bank – Flowing habitat along a submerged feature similar to shoreline that is parallel to flow, constituting a dramatic change in depth. Substrate particle size is typically sand, but varies depending upon velocity. Bank mesohabitat is most common in sand-bed channels, typically associated with dune bypass channels and confluence pools.

Embayment – Slackwater mesohabitat in which flow direction is perpendicular to adjacent river banks. Substrate particle size is fine, typically silt; velocity is always much reduced from the adjacent channel. Embayment mesohabitat is common, most abundant in wide/braided river channels.

Confluence Pool – Turbulent pool created at the junction of two flowing channels (e.g., downstream of island or sandbar), typically bounded by steep banks on both sides, generally the deepest main channel habitat. Substrate particle size is coarse, commonly gravel or coarse sand. Confluence pool mesohabitat is only common in braided channels with alluvial substrate and adequate flow.

Forewater – Slackwater area most commonly associated with abandoned inlets of high flow channels that remain inundated by adjacent waters. Substrate particle size is fine, usually silt and similar to embayments but usually lacking an eddy fence (i.e., not created by upstream obstruction). Forewater mesohabitat is uncommon because high-flow channel inlets are normally high in relative elevation, and are dewatered as the high flow channel is abandoned.

Appendix B. Memorandum of Understanding between the City of Albuquerque, Public Works Department, Water Resources Management and the U.S. Fish and Wildlife Service Southwest Region, Albuquerque, New Mexico.

And

Scope of Work - Intensive Surveys of the Rio Grande in the Albuquerque and Belen Reaches for U.S. Army Corps of Engineers, Albuquerque, New Mexico by U.S. Fish and Wildlife Service, New Mexico Fishery Resources Office, Albuquerque, New Mexico.