HABITAT USE OF RIO GRANDE SILVERY MINNOW

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17 December 1997

EXECUTIVE SUMMARY

The primary purpose of this study was to characterize habitat use of Rio Grande silvery minnow at two sites, Rio Rancho and Socorro, in the Middle Rio Grande, NM. Habitat use was determined through a series of measurements of depth, velocity and substrate taken in the area where fish were collected. Habitat availability was measured along permanent transects at each site.

Rio Grande silvery minnow was relatively abundant at both sampling localities, but was more numerous and comprised a greater percentage of the total catch at Socorro than at Rio Rancho. Red shiner, western mosquitofish, flathead chub, fathead minnow, longnose dace and white sucker were present in moderate numbers at both sites, but the other 12 species collected during the study accounted for less than 5% of the total catch. Although the abundance of fish varied widely across time within sites, the majority of all fish were collected at the Socorro, NM site.

The mesohabitats most commonly occupied by all size-classes of Rio Grande fishes were low water velocity habitats over small substrata. Longnose dace occupied areas with greater water velocities and correspondingly larger substrata more frequently than did the rest of the ichthyofaunal community. Several other species (red shiner, flathead chub and channel catfish) also preferred higher velocity habitats but not to the degree exhibited by longnose dace. There was generally a higher degree of spatial separation between species at Socorro than at Rio Rancho. There was a moderate shift of fishes into lower water velocity habitats in the winter months.

All size-classes of Rio Grande silvery minnow primarily utilized habitats characterized by moderate depths (=15 to 40 cm), low water velocities (=4 to 9 cm/sec) and small substrata (silt or sand). The subset of mesohabitats where individuals of this species were collected differed significantly from the overall availability of mesohabitats at the sampling localities. Rio Grande silvery minnow exhibited some ontogenetic shifts in habitat use, but these occurred over a relatively narrow range of physical conditions. Smaller individuals occupied shallower and lower velocity habitats more frequently than did larger individuals. Rio Grande silvery minnow was found in similar habitats at the upper (Rio Rancho) and lower (Socorro) sampling localities. Individuals became less active in the winter months, occupying areas of cover with little or no water velocity (e.g., debris piles) much more frequently than they did in summer.

A number of anthropogenic activities directed at the Rio Grande have changed its historic channel morphology and flow regime. Two primary effects of these alterations have been a constriction of the river channel and an increased likelihood for extensive river drying. Constriction of the river channel has lead to fewer low-velocity habitats, especially during moderate or high flows. The impact of this reduction in habitat is difficult to quantify, but may be most detrimental to drifting egg and larval stages of Rio Grande silvery minnow. River drying results in the immediate loss of some of the last remaining portions of the Rio Grande silvery minnow population and poses the most serious threat to the persistence of this species.

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INTRODUCTION

The Great Plains is a vast region of central North America encompassing about 20% of the land mass of the conterminous United States. This relatively flat and gently rolling area extends east from the Rocky Mountains to the forested uplands of Minnesota and Missouri and the tall-grass prairies of Iowa and Missouri. Most plains streams in this physiographic expanse are relatively narrow and shallow with shifting sand substrata. Discharge in these streams fluctuates greatly between periods of high spring snow-melt runoff and summer drought conditions. Summer low flow periods are frequently ameliorated by isolated freshets that result from localized thunderstorms. Fish in Great Plains systems are subjected to water temperatures, flow regimes and general physicochemical conditions that fluctuate between broad extremes (Matthews, 1987).

Located at the western edge of the Great Plains, the Rio Grande is a typical plains stream ecosystem that formerly was a highly braided and aggrading system that meandered across a broad channel with sand substrata. The Middle Rio Grande is a 364 km reach that extends from the rios Grande-Chama confluence downstream to Elephant Butte Reservoir. Both the gradient of the riverbed and the volume of water contributed by Middle Rio Grande tributaries gradually decreased from upstream to downstream. Conversely, contributions of sediment by tributaries was smallest in upstream reaches and greatest in downstream sections. The Middle Rio Grande was fed by high elevation snow-pack and summer rainstorm events and was believed to have supported perennial flow throughout much of New Mexico. Maximum discharge occurred during mid- or late spring coinciding with snow-melt runoff. Summer and autumn discharge in the Middle Rio Grande was mainly dependant on the number and magnitude of rainstorms in the basin (Bullard and Wells, 1992).

Pre-impoundment spring runoff and storm events were sometimes problematic for Middle Rio Grande Valley urban and rural populations, especially as people expanded their presence in the basin. Besides the perceived need for flood control, there was a desire by agricultural concerns throughout the valley for a more reliable and relatively continuous source of water. Further, a more predictable water source was desired by downstream users of the Rio Grande because of diversion of water at more northerly points. Historic attempts to control the Middle Rio Grande were propelled primarily by these two issues (Bullard and Wells, 1992).

Beginning in the early 1900s, a series of canals, diversions, and impoundments were constructed throughout the Upper and Middle Rio Grande. Besides the attempts to regulate discharge, there was a comprehensive effort to constrict the river channel of the Rio Grande, particularly in the reach between Cochiti Pueblo and the narrows at Elephant Butte. Jetty-jacks, bank stabilization, construction of levees, river training and freeboard dikes were methods used to minimize channel movement. Collectively, these efforts resulted in a river that is currently considerably different than it was historically.

The Middle Rio Grande is now a highly regulated system subjected to numerous maintenance and management activities overseen by a vast suite of federal, state, municipal, Native American and private agencies. Three mainstem and tributary reservoirs, three diversion dams, and over 1450 km of canals and channels between Cochiti Dam and Elephant Butte Reservoir have had a profound effect on river morphology and hydrology. Between 1935 and 1989, there was about a 50% decrease in river channel area in the Middle Rio Grande. The historic Rio

Grande floodplain was reduced from widths of over 14,500 ft to <3,250 ft and the channel was confined accordingly. This was manifested in a reduction in channel capacity to <7,000 cfs for some sections of the Middle Rio Grande while other segments can still sustain 42,000 cfs for short periods (Crawford et al., 1993). While impoundments and water management practices have not changed the general annual pre-impoundment discharge pattern, they have dampened the magnitude and duration of extreme flow events and have occasionally led to extended periods of extensive river drying during the high irrigation-demand of summer months.

Comparison of historic and recent aerial photographs provided an assessment of surface changes in vegetation and a relatively good estimate of changes in terrestrial habitats. These changes included decreases in the width and meandering of the river which may have, in part, resulted in a reduction of the cottonwood bosque (Howe and Knopf, 1991). The effects of the hydrologic and morphologic modifications on the aquatic ecosystem and associated organisms have not been quantified because of the lack of a comparable historical baseline dataset. Intensive surveys of fishes in the Middle Rio Grande began in 1984 and continue to present. About 85% of all Middle Rio Grande fish collections and 90% of all museum curated fish from this river reach were taken after 1983. Collectively, these studies provided substantial information on current patterns of fish distribution and abundance in the Middle Rio Grande. Comparison of data from multiple collections at single localities suggested that changes in the fish community occurred over both spatial and temporal scales.

The first concerted effort to acquire information on changes in the ichthyofaunal community of the Middle Rio Grande was conducted between 1987-1992 (Platania, 1993). During that investigation, fish were sampled in the mainstem of the Rio Grande between Velarde and Elephant Butte Reservoir. In addition, the first fish-habitat association study on the Middle Rio Grande was undertaken. These projects provided baseline information on the distribution, abundance and habitats occupied by Middle Rio Grande fishes. Besides furnishing information on the fish community, the habitat association portion of the 1987-1992 investigation was expected to provide preliminary data on habitat use of the state listed (at that time) Rio Grande silvery minnow. Unfortunately, extremely low flow conditions existed during the habitat use portion of the study (summer and autumn of 1989 and 1990) and few Rio Grande silvery minnow (n=8) were collected despite extensive sampling efforts (n=27). The few individuals collected not only precluded analysis of Rio Grande silvery minnow habitat use, but also suggested a precipitous decline of the species in its remaining range.

Based on these and other data, the U.S. Fish and Wildlife Service prepared and submitted a proposal for listing of Rio Grande silvery minnow as an endangered species (U.S. Department of the Interior, 1993; 1994). While there were a suite of threats to the continued survival of this fish, the foremost reason for seeking federal protection was the 90-95% reduction in its historic range (Rio Grande Basin). The restriction of Rio Grande silvery minnow to a 279.8 km reach of river between Cochiti Dam and Elephant Butte Reservoir and fragmentation of that range into four segments (35.9, 65.2, 85.5, and 90.4 km long) due to diversion dam structures (Angostura, Isleta, and San Acacia) posed threats to the persistence of the species (U.S. Department of the Interior, 1994).

Middle Rio Grande dam and diversion structures do not prohibit downstream transport of eggs and larvae but do prevent upstream movement of fishes. The inability to rejuvenate upstream populations could be detrimental to Rio Grande silvery minnow since it produces semi-buoyant eggs that drift with the current for 24-48 hours prior to hatching. Laboratory and field studies have demonstrated that upon hatching, larval Rio Grande silvery minnow remain a component of the drift at least until their air bladder develops. This physiological event usually occurs about three days after hatching. Downstream transport distance of the progeny of Rio Grande silvery minnow is dependant on a variety of factors including flow magnitude and duration, water temperature, and channel morphology.

The reproductive strategy, in combination with the diversion dams, suggest that there is movement of Rio Grande silvery minnow from upstream to downstream segments. An important factor determining the rate of downstream movement is the length of the home reach. The shorter a reach, the greater the likelihood of extirpation within that reach. Four mainstem cyprinid species which had similar life-history strategies as Rio Grande silvery minnow and were historically sympatric, were extirpated by 1964 (Bestgen and Platania, 1991). Given the loss of four of the five members of this ecological guild, it was not unreasonable to presume that Rio Grande silvery minnow would likely be the next fish to be extirpated.

While water deliveries of the Middle Rio Grande are overseen by a myriad of government entities, the principal federal organization responsible for instream management of this system is the U.S. Bureau of Reclamation. In 1992, under a cooperative agreement with the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service and New Mexico Department of Game and Fish, a multi-year ichthyofaunal study in the Middle Rio Grande was undertaken. The series of studies conducted included determining the distribution and status of the fish community in the Middle Rio Grande between Cochiti Dam and Elephant Butte Reservoir, population monitoring of the fish community at 16 sites between Bernalillo and San Marcial Railroad crossing and determination of spawning period and life-history attributes of Rio Grande silvery minnow. Additional funding was provided by the U.S. Army Corps of Engineers to determine the distribution and status of the fish community in the Cochiti to San Felipe reach of the Middle Rio Grande. Several studies on the spawning behavior, early life history, clutch and batch production of eggs and winter habitat use by Rio Grande silvery minnow were also funded by the U.S. Army Corps of Engineers.

While Rio Grande silvery minnow was the primary focus in most of the investigations, post-1992 studies were fashioned to provide information on the overall fish community as well. The design of community-based instead of species-specific studies allowed for better understanding of the functional niche that Rio Grande silvery minnow occupied relative to other members of the community. A wealth of ecological studies have demonstrated that the behavior and niche of a species can be both directly and indirectly influenced by other members of the community (Werner and Hall, 1979; Schlosser, 1982; Gorman, 1988).

The final field study in the initial series of investigations was the 1994-1996 fish habitat association study with an emphasis on Rio Grande silvery minnow. That project was purposely the last conducted so that knowledge obtained during the previous three years of research could be used to more finely focus the study. During the 1992-1994 distribution, population monitoring, and life-history studies on Middle Rio Grande fishes, frequent sampling provided valuable insight into the macro-distribution of community members and the Rio Grande silvery minnow.

Fish habitat use studies provide important information regarding the ecology of a species. Microhabitat studies focus on the suite of physical parameters immediately anterior to the snout of individual fishes and generally require considerable instream visibility. Such studies are often species oriented and are not designed to obtain data for the associated fish community (Jones et al., 1984; Propst and Bestgen, 1991). Conversely, while the physical measures generated by mesohabitat studies of fishes are less specific than the former, they often provide a broader approach to the examination of habitat use (i.e., community habitat use patterns). Mesohabitat use data are comprised of mean values obtained from discrete samples made in specific habitats and yield the same set of physical measurement for all species and life stages in the sample. Thus, micro- and mesohabitat studies provide specific information on the depth, velocity and substrate in areas occupied by fishes. The only information available exclusively from microhabitat studies is more detailed information on each individual (i.e., focal point velocity, position in water column, distance to shore).

When attempting to determine habitat use of an individual taxon, it is important to examine that organism within the context of the community (Lobb and Orth, 1991). Knowledge of the ecological attributes of extinction prone fishes, including community habitat use patterns, can provide a foundation for preclusive conservation measures (Angermeier, 1995). A more accurate appraisal of an organism's overall habitat use patterns may emerge when the relative position of the species within the community matrix has been determined. The inclusion of the community in the analysis can also help define species groups and provide a general basis for species-environment gradient relationships (Taylor et al., 1993).

Studies of the abundance, distribution and habitat use patterns of fishes in streams of the Great Plains have typically employed a community level approach (e.g., Matthews and Hill, 1980; Matthews and Robison, 1988; Bramblett and Fausch, 1991; Lobb and Orth, 1991; Meador and Matthews, 1992; Taylor et al., 1993; Matthews et al., 1994). There are often multi-species assemblages occupying the numerous habitats created by meandering of tributary and mainstem braided channels that typify prairie streams. Works by W. J. Matthews, University of Oklahoma, (see previous citations) demonstrated the utility of extensive surveys of the ichthyofauna of a stream to discern the subtleties of habitat use patterns and abundance in response to a variable environment.

Techniques employed for studying habitat use of fishes in Great Plains streams are largely dictated by physical conditions. Most of these streams are typified by high levels of suspended silt especially during periods of high flow. Low visibility within many Great Plains streams makes it difficult or impossible to make underwater observations to ascertain focal velocity and position of fish in the water column.

Electrofishing is often used as a technique in the study of fish habitat use, but may be ineffective under certain conditions. The conductivity of the water combined with the low visibility often dictates whether this technique can be employed. The data collected by electrofishing is comparable to that collected through other sampling techniques, such as seining, because a discrete area is sampled (mesohabitat) versus a specific point for each individual (microhabitat).

The mesohabitat approach of this investigation allowed for the determination of patterns of habitat use at a community level. Comparisons between species permitted extrapolation of the amount and complexity of overlap in habitat use among taxa. Patterns were investigated on both temporal and spatial scales for community members and also analyzed by ontogenetic stage for Rio Grande silvery minnow. Comparisons of habitat use and habitat availability provided an estimate of habitat selectivity by species and life stages.

The widespread degradation of stream habitats and proliferation of nonnative fishes throughout North America have apparently lead to the decline or disappearance of many native fishes (Neves and Angermeier, 1990; Propst and Bestgen, 1991; Martinez et al., 1994; Warren and Burr, 1994; McElroy and Douglas, 1995; Stanford et al., 1996). Knowledge of habitat requirements of imperiled fish species is widely recognized as an important factor to develop effective recovery strategies (Jones et al., 1984; Rinne, 1992; Martin, 1995). The decline in the distribution and abundance of native fishes throughout plains streams in the American Southwest has led to federal designation of many stream reaches as critical habitat. Portions of a drainage considered critical habitat are usually able to support the species of interest and therefore must have special management consideration and protection.

It is often difficult to obtain detailed habitat preference information of imperiled fishes, even within their critical habitat, because of their rarity or annual population fluctuations. In addition, reduced distributions of these species make it difficult to determine the range of or relative importance of habitats historically occupied. The most populous reaches of a species range are of particular interest when obtaining information on its habitat requirements.

The goal of the 1994-1996 habitat association study was to determine the mesohabitat associations of Rio Grande silvery minnow and what position that species occupied in the fish community. Mesohabitat availability data provided a longitudinal and temporal characterization of habitat distribution and abundance. Data on the availability of mesohabitats also enabled a quantified evaluation of habitats preferred and avoided by selected life-stages of Rio Grande silvery minnow across seasons and between sites.

STUDY AREA

The headwaters of the Rio Grande are located in the San Juan Mountains of southern Colorado. The Rio Grande flows for about 750 km through New Mexico. The Rio Chama is the only major tributary of the Rio Grande in New Mexico and confluences with it near the town of Española. Snowmelt from northern New Mexico and southern Colorado provides the majority of water in the Rio Grande, but is supplemented by transmontane diversions from the San Juan River drainage (Colorado River basin). The highest flow in the Rio Grande occurs following spring snowmelt, while the lowest flow occurs in late summer and autumn. Low flow later in the year is due, in part, to the large diversions of water out of the river channel into irrigation canals. Summer thunderstorms periodically augment low flow in discrete reaches, but do not ensure that the river channel will remain wetted. Precipitation in the region is low and averages <25 cm/year (Gold and Denis, 1985).

The Middle Rio Grande was defined as the reach between the rios Grande-Chama confluence (Chamita) and Elephant Butte Reservoir. This reach changes considerably through its 364 km length. At high elevations, the Middle Rio Grande was a narrow, canyon-bound cold river with large substrata and a salmonid-dominated fish community. In contrast, downstream areas were 50-250 m wide, sand-bottomed, and supported a warmwater fish community. Our area of interest within this reach was limited to the current range of the Rio Grande silvery minnow (i.e., downstream of Cochiti Dam to the inflow of Elephant Butte Reservoir).

Our upper sample site was located about 6.4 km downstream of the NM State Highway 44 Bridge in the town of Rio Rancho, NM (Sandoval County; 35°16’58.9"N, 106°35’53.3"W) (Figure 1). The lower site was located about 160 km downstream of the Rio Rancho site and was near the Socorro low-flow conveyance channel bridge at Socorro, NM (Socorro County, 34°04’04.5"N, 106°53’28.3"W). Flow data for the Rio Rancho sampling locality was provided by Albuquerque USGS gaging station (# 0833000, 35°05’21"N, 106°40’48"W), while flow data for the Socorro sampling locality was provided by San Acacia USGS gaging station (# 083549000, 34°15’23"N, 106°53’18"W). The general trend at both sites was an increase in flow in spring (March-May) followed by a decrease in summer/autumn (July-October) of each year throughout the study period (Figure 2). Highest flow generally occurred in spring as a result of snow-melt and irrigation water releases. Lowest flow occurred during summer when most of the available discharge was diverted to agriculture. Winter flow (November-February) generally increased to moderate levels at the end of the irrigation season, but was notably lower than spring flow. The only exception to this pattern was in the spring of 1996 when flow in the river at both gages remained low due to a winter drought and water diversions to agriculture. Flow at the Albuquerque gage (i.e., Rio Rancho site) was generally higher than flow below San Acacia Dam (i.e., Socorro site) throughout the year.

The Rio Rancho site was composed primarily of main or secondary channel runs. There was a narrow strip of cottonwood bosque on both banks at this site. Instream vegetation (attached algae) was minimal with the exception of riffle mesohabitats. Total length of the study site was about 200 meters so as to include a broad array of habitats. The northern portion of the site was narrow (<80 m) with most of the flow along the east side of the channel. The dominant substrata at the northern portion of the site was sand and water velocities >50 cm/s were common. There was a secondary channel on the west bank that only carried water during the highest flows of the year. During periods of low flow, the secondary channel retained water and became a large backwater with no measurable water velocities.

In the middle portion of the Rio Rancho study site, flow was confined to a narrow channel (<50 m) along the east bank. There were no secondary channels and few habitats with water velocities <50 cm/s. Some riffles, typified by a cobble substrata, were present in the main channel. On the west side of the river channel was a wide (>60 m) sand/gravel bar that was about 10-50 cm higher than the level of the water.

The majority of flow at the southern portion of the Rio Rancho study site was along the west bank. As the channel crossed from the east to the west bank, there were a series of shallow fast riffles with gravel or cobble substrata mixed with main channel runs. There was a secondary channel on the east bank that carried small amounts of flow during periods of moderate to high flow, but that was dry during low flow.

The Rio Grande near Socorro was ephemeral, wide and meandering with a predominantly sand-silt substrata. Riparian vegetation at this site consisted of a mixture of salt cedar and cottonwood trees. There was a high degree of habitat heterogeneity with lower velocity mesohabitats represented even at higher flow. Instream vegetation was almost never present. The total length of the Socorro study site was about 250 meters to represent the wide range of mesohabitats present. The channel width was generally >100 m with the majority of the flow along the east side of the channel. Main channel runs were abundant and water velocities >50 cm/s and depths >50 cm were common on the east side of the river. However, high velocity water (>80 cm/s) comprised <10% of the available total at this site and riffles were not present. Gravel substrata was only rarely present and cobble was absent. Several secondary channels carried flow along portions of the west side throughout the length of the study site. Secondary channels were characterized by high habitat heterogeneity (i.e., backwaters, debris piles, pools and shoreline habitats). During periods of low flow, secondary channels would transform into backwaters or isolated pools. A large island with terrestrial vegetation was present at the

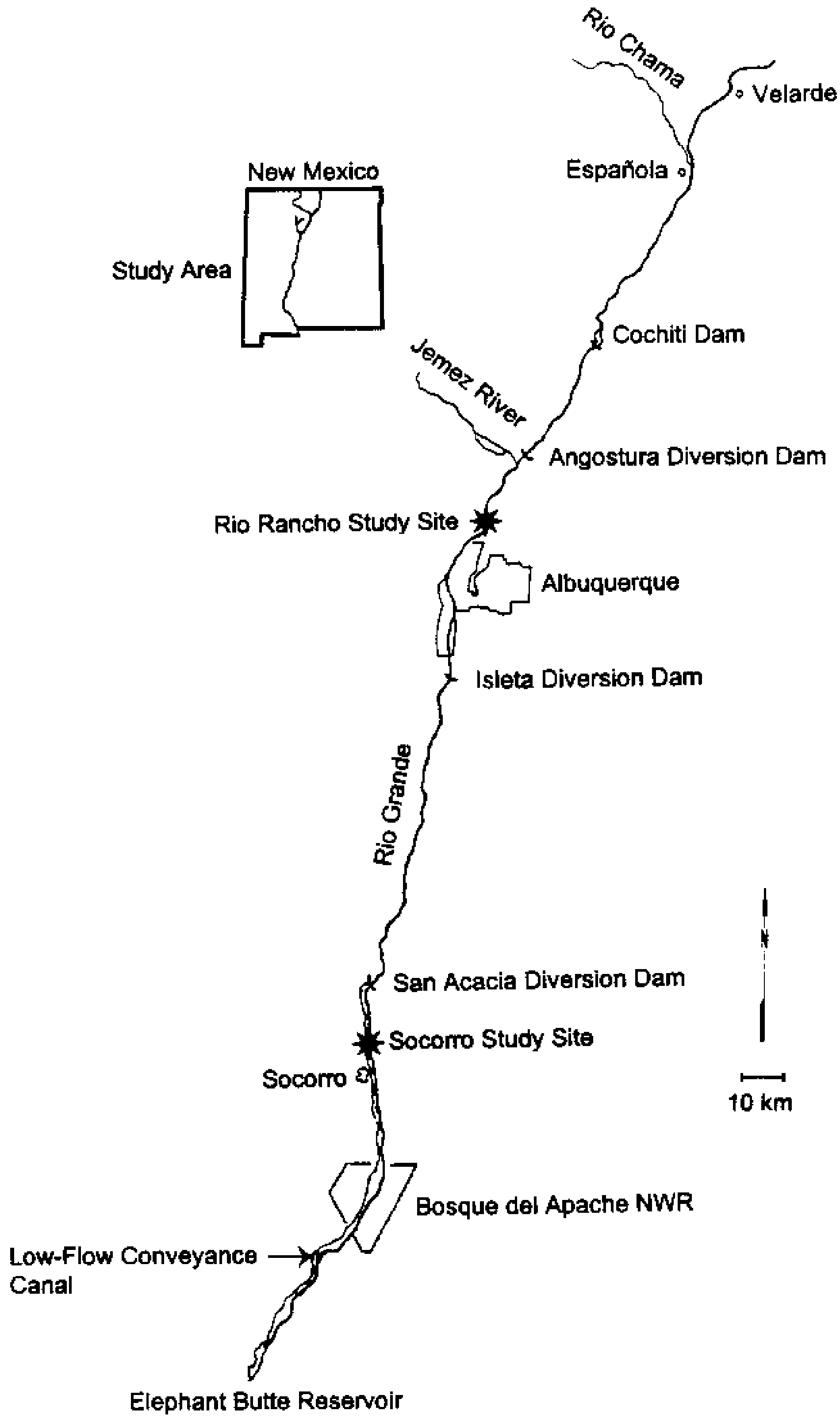


Figure 1. Map of Middle Rio Grande study area.

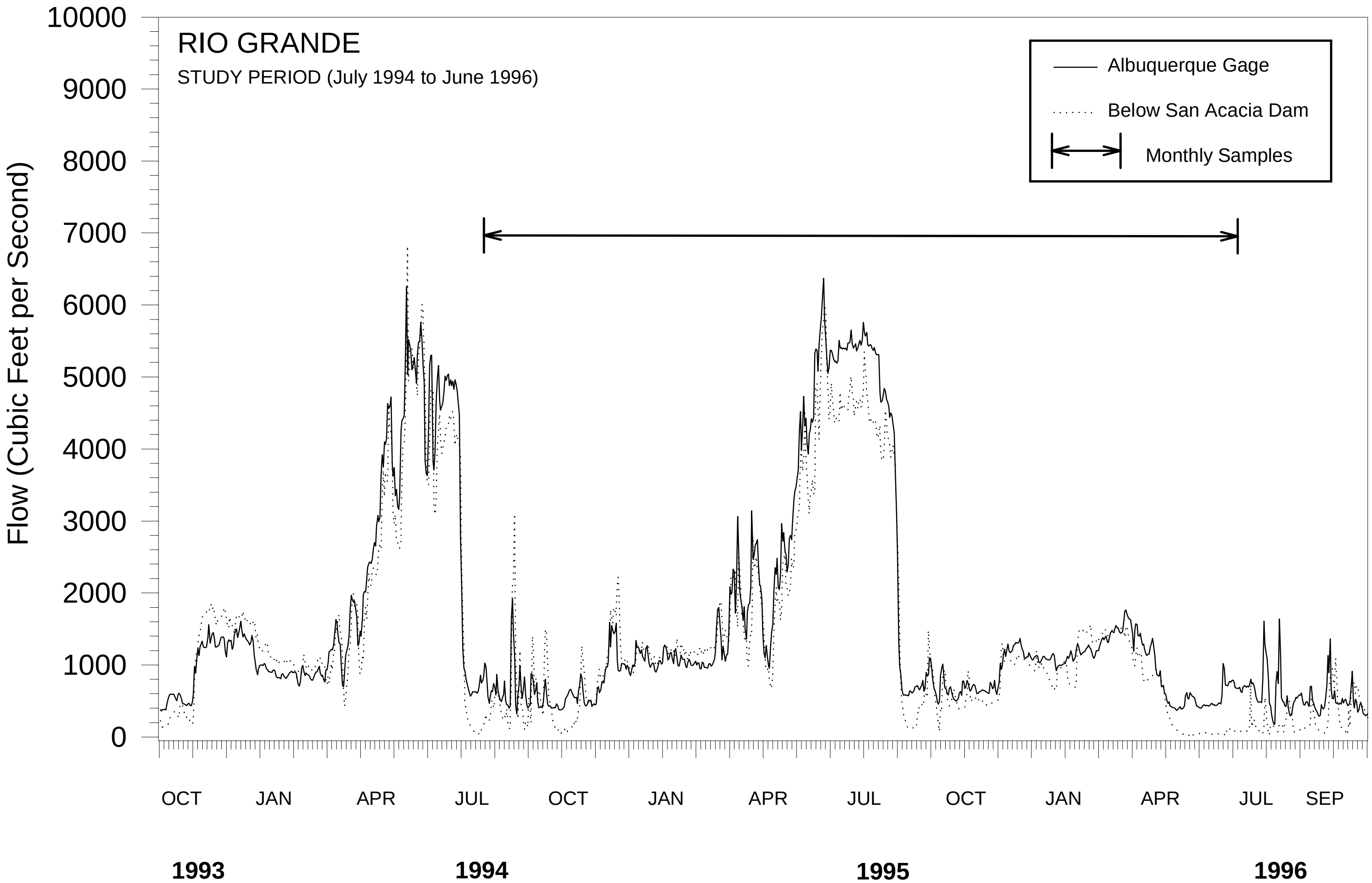


Figure 2. Hydrograph of the Rio Grande at Albuquerque and the San Acacia Dam for water years 1994-1996.

southern end of the site. There was often flow on both sides of the island with the majority of discharge on the east side.

The Rio Rancho and Socorro sample sites, which were located near the northern and southern edges of the range of Rio Grande silvery minnow respectively, were selected to provide information on the longitudinal variation of habitat conditions and habitat use of Middle Rio Grande fishes. Habitats at the sites were characteristic of their representative reaches of the Middle Rio Grande. The Rio Rancho sample site was generally characterized by cooler water temperatures, higher water velocities and larger substrata than the Socorro sample site.

Habitat availability was determined at both sites monthly from October 1995 to June 1996. Habitat availability included a determination of mesohabitat type and a measure of depth, velocity and substrate at three meter intervals across the potentially wetted channel along ten equally spaced permanent transects within the study area. Transects were marked by tee-posts were sunk into the east-bank and corresponding florescent surveyors flags attached to trees about 5 m above the west-bank. Transects were perpendicular to discharge and spaced to include the upper and lower ends of the areas sampled within the site. In segments where the banks were not well defined, the width of the channel was based on 1994-1995 observations of maximum channel width. The potentially wetted channel designated the maximum width that might become wetted during some portion of the year. This methodology was chosen to ensure that the same number of data points were measured during the peaks of spring flow and low flow of autumn.

METHODS

This study was structured to determine habitat use of Rio Grande silvery minnow and its associated fish community from July 1994 to June 1996 at two Middle Rio Grande sites. The dataset collected during this study permitted analysis of general spatial and temporal trends in habitat selected by resident fish species. Monthly sampling efforts afforded the opportunity to critically analyze the effect time, space, and ontogeny had on habitats selected by species and size-specific cohorts. The differences in water temperatures and flow patterns across seasons were reflected in fish habitat use patterns and were the basis for sorting the dataset into two broad categories. In this report, summer refers to April through September (spring/summer) and winter refers to October through March (autumn/winter).

Scientific and common names of fishes in this report follow Robins et al. (1991) (Table 1). Common names, arranged in phylogenetic order, are used in tables and the report. The common and scientific names of species not included in Table 1 are provided in the text.

Fish were obtained by rapidly drawing a two-person 2.1 m x 1.8 m small mesh (0.5 cm) seine through discrete mesohabitats (usually <10 m). Each seine haul received a unique alphanumeric code and captured fish were held, for later processing, in a five-gallon bucket marked with that code. Fish were identified to species in the field, measured to the nearest 1 cm standard length (SL) and then released. Mesohabitat types followed Platania (1993) and substrate designations were based on a modified Wentworth classification for substrate particle size (Table 2). All available aquatic mesohabitat types were randomly sampled regardless of whether fish were generally caught in those areas (Bain and Finn, 1991). Main and side channel runs were not sampled proportionally, however, since they comprised the vast majority of available habitats but only rarely produced fish.

Table 1. Scientific and common names and species abbreviations ( ) of fish collected from the Rio Grande at Rio Rancho and Socorro, NM.

Scientific Name	Common Name and Abbreviation	
Order Clupeiformes		
Family Clupeidae	herrings	
Dorosoma cepedianum	gizzard shad	(GZS)
Order Cypriniformes		
Family Cyprinidae	carps and minnows	
Cyprinella lutrensis	red shiner	(RDS)
Cyprinus carpio	common carp	(CCA)
Hybognathus amarus	Rio Grande silvery minnow	(RGM)
Pimephales promelas	fathead minnow	(FHM)
Platygobio gracilis	flathead chub	(FHC)
Rhinichthys cataractae	longnose dace	(LND)
Family Catostomidae	suckers	
Carpiodes carpio	river carpsucker	(RCS)
Catostomus commersoni	white sucker	(WHS)
Order Siluriformes		
Family Ictaluridae	bullhead catfishes	
Ameiurus melas	black bullhead	(BBH)
Ameiurus natalis	yellow bullhead	(YBH)
Ictalurus punctatus	channel catfish	(CCT)
Order Cyprinodontiformes		
Family Poeciliidae	livebearers	
Gambusia affinis	western mosquitofish	(MOS)
Order Perciformes		
Family Percichthyidae	temperate basses	
Morone chrysops	white bass	(WHB)

Table 1. Scientific and common names and species abbreviations ( ) of fish collected from the Rio Grande at Rio Rancho and Soccoro, NM.

Scientific Name	Common Name and Abbreviation	
Order Perciformes		
Family Centrarchidae	sunfishes	
Lepomis cyanellus	green sunfish	(GNS)
Lepomis macrochirus	bluegill	(BGL)
Micropterus salmoides	largemouth bass	(LMB)
Pomoxis annularis	white crappie	(WCR)
Family Percidae		
Perca flavescens	yellow perch	(YWP)

Table 2. Mesohabitat and substrate types, codes, and definitions used in the Middle Rio Grande, NM.

Mesohabitat Types

Primary

MC	**Main channel-** the section of the river which carries the majority of the flow; there can be only one main channel.
SC	**Secondary channel-** all channels not designated as the main channel; there can be zero or several secondary channels at a site.

Secondary

BW	**Back water-** a body of water, connected to the main channel, with no appreciable flow; often created by a drop in flow which partially isolates a former channel.
ED	**Eddy-** a pool with current moving opposite to that in the channel.
FL	**Flats-** a region of uniform shallow depth, moderate velocity, and sand substrate.
IP	**Isolated pool-** a pool which is not connected to the main or secondary channel; frequently a former backwater which is no longer connected to the main or secondary channel.
PO	**Pool-** the portion of the river that is deep and with relatively little velocity com pared to the rest of the channel.
RI	**Riffle-** a shallow and high velocity habitat where the water surface is irregular and broken by waves; generally indicates gravel-cobble substrate.
RU	**Run-** a reach of relatively fast velocity water with laminar flow and a non-turbu lent surface.
SH	**Shoreline-** usually a shallower, lower velocity area that is adjacent to shore. This designation precedes other mesohabitat types (i.e. SHRU= shoreline run or SHRI= shoreline riffle).

Table 2. Mesohabitat and substrate types, codes, and definitions used in the Middle Rio Grande, NM.

Substrate Types[1]

BO	**Boulder-** diameter > 256 mm
CO	**Cobble-** diameter between 64-256 mm
GR	**Gravel-** diameter between 2-64 mm
SA	**Sand-** diameter between 0.0625-2 mm
SI	**Silt-** diameter < 0.0625 mm

[1] - Modified Wentworth classification for substrate particle size (Cummins, 1962)

The perimeter of each sampled habitat was marked with fluorescent surveyors flags attached to 1.2 m wooden dowel-rods. Depth, velocity, and substrate were determined at three equally spaced points across the width of each seine haul at each meter along the length of the area sampled. Depth (cm) and velocity (cm/s) were measured with a Marsh-McBirney flowmeter mounted on a top-set wading rod with the latter value taken at 0.6 water column depth.

In October 1995, we began taking concurrent measures of habitat availability at the study sites. Habitat availability measures were not included in the original scope of work because such measures were being taken by FLO Engineering, Inc., under a contract with the U.S. Bureau of Reclamation, at numerous cross-sections throughout the Middle Rio Grande. (FLO Engineering, Inc., 1996a; FLO Engineering, Inc., 1996b). However, we felt it necessary to extensively sample habitat availability at our sampling sites to characterize the degree of change within the range of extremes in the annual hydrograph.

Canonical Correspondence Analysis (CCA) was used to provide a visual representation of the habitats occupied by fish by life stage and across temporal and spatial scales. The CCA was pioneered by C.J.F. ter Braak (1986) as a multivariate analysis technique that directly related species abundance to measured environmental gradients. This technique generates a graphic that illustrates how the composition and abundance of a community of species or size-classes vary as environmental conditions change along a gradient (ter Braak, 1986; 1987a; 1987b; 1988). This unique ability has defined CCA as an important direct gradient analysis technique in ecological studies (Palmer, 1993).

The graphical representation of CCA includes an origin from which all environmental gradient arrows radiate. The origin is the average habitat occupied (based on all environmental variables) by the community. The length of a particular environmental gradient arrow from the origin is a relative measure of its power in predicting the overall spatial variation in the abundance of the community (e.g., a graph with a long velocity gradient arrow and a short depth gradient arrow would indicate that velocity is a more powerful predictor than depth of how species or size-classes are segregated). The more a species is positively segregated from the rest along a particular environmental gradient (i.e., occupying higher velocity water or deeper areas), the further it will appear (graphically) from the origin in the direction of the environmental gradient arrow. If a species is negatively segregated from other species along an environmental gradient (i.e., occupying lower velocity water or shallow areas), it will appear on the reverse side of the origin in the opposite direction of the environmental gradient arrow.

Native species were coded by solid black symbols while nonnative species were coded by hollow or patterned symbols. Rio Grande silvery minnow was coded by a black triangle for comparison between CCA diagrams. Correlations between linear combinations of environmental variables and weighted mean species scores were determined for all CCA analyses to quantify the strength of the relationship between environmental gradients and variation in the fish assemblage.

General trends in the habitat use (spatial and temporal) of all fish, except black bullhead (only collected in one sample), encountered during the study were analyzed. Other species were excluded from a particular CCA analysis if they were only collected in one sample. As several species included in our analysis were only rarely encountered, the overall species data were examined using CCA rather than other less powerful statistical methods.

Habitat use and availability datasets were normally distributed with homogenous variances. However, tests involving small subsets of the habitat use data (i.e., fish size-classes) had slightly heterogenous variances . A logarithmic transformation was preformed on all non-normally distributed data and used in subsequent data analyses. Means and standard errors generated with the logarithmic equation were back-transformed using an antilog formula (Sokal and Rohlf, 1995).

Analysis of variance (ANOVA) was used to test for spatial and temporal differences in habitat use and availability for continuous variables (depth and velocity). A three-way (size, space and time) factorial ANOVA (PROC GLM; SAS Institute, 1990) was used to test whether higher-order interactions were accounting for variation in the habitats selected by different size-classes of Rio Grande silvery minnow. A two-way (space and time) factorial ANOVA was used to test whether combinations of site and season accounted for variation in habitat availability or in overall species habitat use. In addition to analyzing data with ANOVA, a MANOVA (multi-variate analysis of variance) was used to test whether the habitat use or availability data (all dependent variables combined) were affected by ontogeny, space, or time. When appropriate, analyses were also preformed to account for nested temporal effects at each site. Tukey's studentized range test was used to detect differences in all potential pair-wise comparisons as it reduces the experiment-wise error rate (Type I errors) when making multiple comparisons.

Analysis of covariance (ANCOVA; PROC GLM; SAS Institute, 1990) was used to determine whether similar-sized individuals at different sites and between seasons occupied similar habitats (e.g., were 40 mm SL Rio Grande silvery minnow collected in similar habitats at both Rio Rancho and Socorro). The primary reason for using the ANCOVA procedure was to ensure that comparisons of the spatial or temporal shifts in habitat use were not confounded by the effects of variable size-class structures. In the ANCOVA procedure, standard length was used as the covariate (i.e., analyses standardized around this variable) and adjusted least-squares means of depths and velocities occupied were compared. An alpha level of 0.05 was set as a minimum for all ANCOVA analyses.

A chi-square contingency table (PROC FREQ; SAS Institute, 1990; Zar, 1984) was used to test for differences between the frequencies of different substrata and mesohabitat types occupied by fish and those available. This procedure was also used to test for size-specific, spatial and temporal differences in habitat associations. This test was used primarily because of its ability to test for differences between two independent samples measured on a nominal scale. Cells with an expected frequency of <1 were not used in the analysis. In addition, no analysis was performed if >20% of the cells had expected frequencies of <5 or if n <20 (Cochran, 1954). Mesohabitats without fish were not included in the analysis, but are presented in a descriptive format in the results.

Most chi-square statistical analyses that compared species-specific mesohabitat and substrata use with availability did not meet the tests assumptions. The large differences between mesohabitat types and substrata across scales (ontogenetic, spatial and temporal) and between use and availability datasets resulted in low expected frequencies that violated the rules of the test. A graphical rather than a statistical approach was used in the results section to analyze differences in the substrata and mesohabitat types occupied by fishes.

Means determined from the series of depth, velocity and substrate measures taken for each habitat use sample were assigned to the fish occupying that area. Sampling of discrete mesohabitat types allowed calculation of average values that were representative of the area seined. The assumption that habitat parameters in the area sampled were relatively homogeneous was tested by determining the coefficient of variation for each area seined. With the exception of naturally heterogenous habitats (e.g., shoreline habitats and backwaters), data were excluded from the analysis if the coefficient of variation exceeded 50%. This value was based on work done by the U.S. Fish and Wildlife Service (Bovee, 1986), our biological opinion of the data, and with the presumption that discrete mesohabitats should be fairly homogenous entities. Less than 5% of the measurements were excluded from the data set using these criteria.

Habitat use data were analyzed using a binary (presence/absence) weight. As such, measures of habitat had the same importance, in the statistical analyses, regardless of the number of fish present. Although CPUE (catch per unit effort) was determined for all samples, this measure was not used to characterize habitat use/selection. However, to ensure that there were no large discrepancies between the outcome of statistical analyses using the binary and CPUE weights, tests were ran using both weights for comparative purposes. Habitat measurements from samples without fish were not included in the analyses.

RESULTS

SUMMARY OF 1994-1996 COLLECTING ACTIVITIES

A total of 17 species represented by 3,174 fishes was taken in the 24 collections made at the Rio Rancho site from July 1994-June 1996 (Table 3). The majority of the catch was distributed relatively evenly across five species (red shiner, Rio Grande silvery minnow, flathead chub, longnose dace and white sucker) that accounted for 77.7% of the total catch (Figure 3). Individually, these species comprised between 8.2-28.0% of the total catch.

White sucker was the numerically dominant species accounting for 28.0% of the total site catch. This was also the most frequently encountered fish occurring in 27.8% of the samples. The next four most abundant species were cyprinids. Rio Grande silvery minnow was taken in 24.7% (n= 88) of the seine hauls at this site and was the second most abundant taxon. Flathead chub was the third most abundant fish at the Rio Rancho site, but the second most frequently encountered species. Red shiner was the only other fish comprising more than 10% of the catch and present in more than 20% of the samples.

Table 3. Summary of ichthyofaunal composition and collection data from July 1994 to June 1996 in the Middle Rio Grande, Rio Rancho, NM.

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	% OF TOTAL	FREQUENCY OF OCCURRENCE[2]	%FREQUENCY OF OCCURRENCE[2]
HERRINGS					
gizzard shad	I	42	1.32	2	0.6
CARPS AND MINNOWS					
red shiner	N	328	10.33	80	22.5
common carp	I	17	0.54	16	4.5
Rio Grande silvery minnow	N	598	18.88	88	24.7
fathead minnow	N	131	4.13	59	16.6
flathead chub	N	389	12.26	95	26.7
longnose dace	N	261	8.22	53	14.9
SUCKERS					
river carpsucker	N	49	1.54	24	6.7
white sucker	I	890	28.04	99	27.8
BULLHEAD CATFISHES					
black bullhead	I	-	——	-	-
yellow bullhead	I	1	0.03	1	0.3
channel catfish	I	58	1.83	21	5.9
LIVEBEARERS					
western mosquitofish	I	218	6.87	46	12.9
TEMPERATE BASSES					
white bass	I	29	0.91	14	3.9
SUNFISHES					
green sunfish	I	19	0.60	8	2.2
bluegill	I	6	0.19	3	0.8
largemouth bass	I	-	——	-	-
white crappie	I	127	4.00	22	6.2
PERCHES					
yellow perch	I	11	0.35	5	1.4
TOTAL	3,174				

[1] N = native; I = introduce

[2] Frequency and % frequency of occurrence in total number of seine hauls at this site (n = 356)

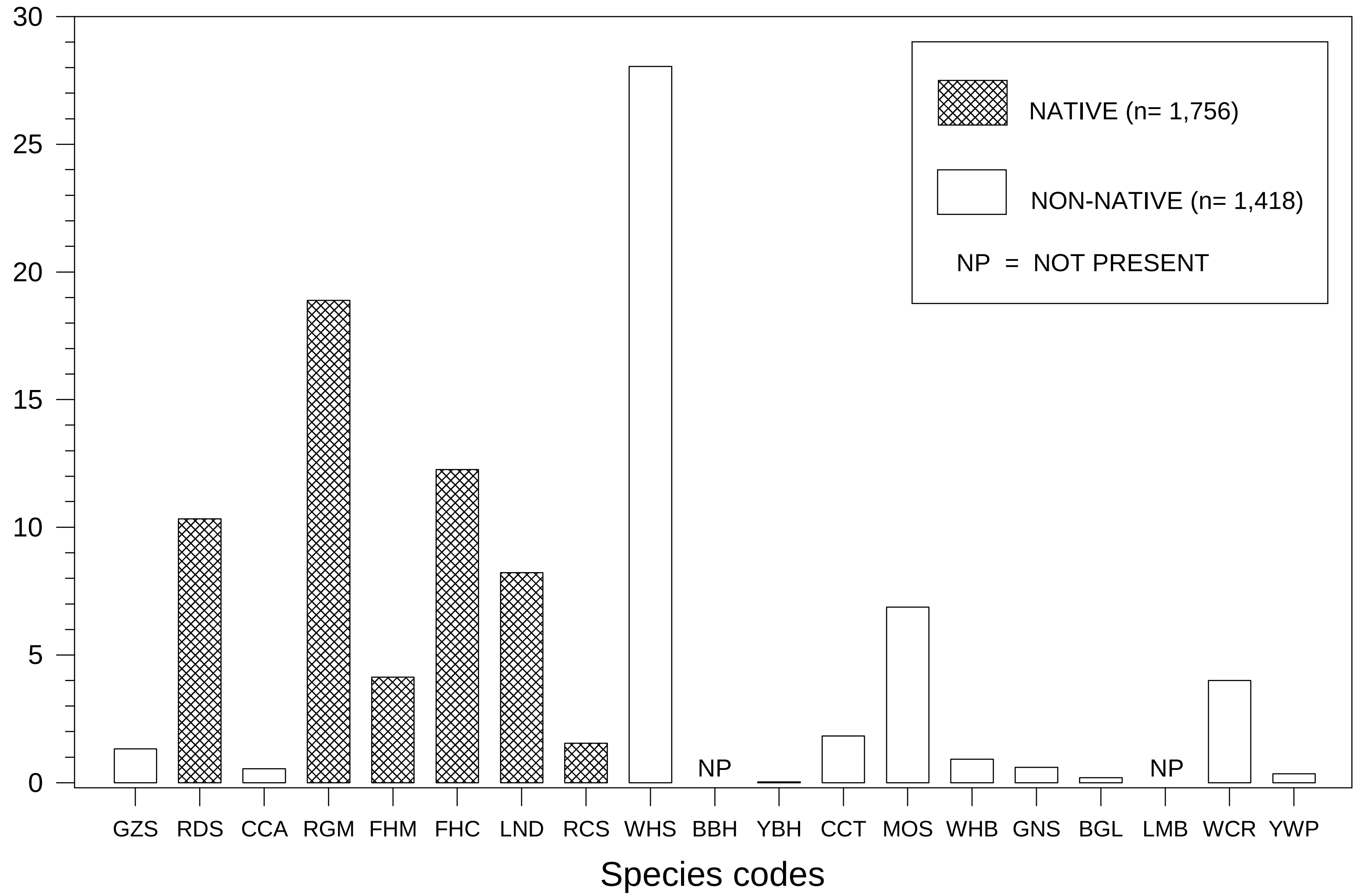


Figure 3. Ichthyofaunal composition of the Rio Grande, based on sampling July 1994 to June 1996, at the Rio Rancho sampling locality. (Species codes are listed in Table 1)

Although the Socorro locality yielded one less species than the Rio Rancho site, there were four times as many fish (n= 12,851) at the former site as compared with the latter (n=3,174) (Table 4). There was a large difference in the relative abundance of Rio Grande silvery minnow between sampling sites. This species was the most frequently encountered and most abundant species at the Socorro site, occurring in 67.1% of the samples and accounting for 90.8% of the total catch (Figure 4). The numerical dominance of Rio Grande silvery minnow at this site during the study period was primarily the result of four collections (July 1994, September 1994, December 1995 and January 1996) that produced 8,410 Rio Grande silvery minnow or 72.1% of the total Socorro-Rio Grande silvery minnow catch. Rio Grande silvery minnow in the July 1994 (n= 1,665) and September 1994 (n= 1,029) samples were mostly the 1994-cohort. Most of July and September=s 1994 Rio Grande silvery minnow were taken in a long (40 m), warm (32^{o}C), shallow backwater. In the two winter samples (December 1995 and January 1996), which yielded large numbers of Rio Grande silvery minnow, individuals were found in deep, low-velocity waters of secondary channels among instream debris. Over 3,000 Rio Grande silvery minnow were collected from one 2 x 2 m submerged tumbleweed during January 1996 at Socorro. Conversely our next seine haul, made in a less complex debris pile 3 m downstream of the aforementioned tumbleweed, yielded only 20 fish.

There were little differences in absolute number of red shiner, common carp and fathead minnow between sites. Flathead chub and longnose dace, which were relatively common at the Rio Rancho site, were very rare at Socorro. Longnose dace was present in only two Socorro samples.

There was an inverse correlation between the Rio Rancho and Socorro sites in the abundances of white sucker and river carpsucker. While white sucker (n= 890) was about 95% of the catostomid catch at Rio Rancho, river carpsucker was much more numerous (n=208) than white sucker (n=12) at Socorro. Besides the differences in relative abundance, there were almost four times as many catostomid specimens collected at Rio Rancho as at Socorro.

There was a greater presence in both species-richness and number of introduced game fish (perciformes) at the Rio Rancho site (species= 5; n= 192) as compared with the Socorro site (species= 3; n=9). White bass and yellow perch, while each comprising <1% of the total Rio Rancho catch, were not found at the Socorro sampling locality. White crappie was relatively abundant (n=127) at Rio Rancho, but not at Socorro (n=6).

The Socorro site yielded black bullhead, yellow bullhead and channel catfish while only the latter two species were taken at Rio Rancho. Channel catfish, which was relatively common throughout the Middle Rio Grande, were twice as abundant at Socorro (n= 124) as compared to Rio Rancho (n= 58).

Catch rate of fish during this study varied both spatially and temporally (Figure 5). During the first year of collecting activities (July 1994-June 1995) at Rio Rancho, the catch rate ranged between 5.9 and 111.1 fish per 100 m^2 of water sampled (= 48.1 fish/100 m^2). At the Socorro site, the mean annual catch rate (110.6 fish/100 m^2) during the first year was over twice that of Rio Rancho, and both minimum and maximum monthly catches were considerably higher (range= 27.1-601.2 fish/100 m^2). During the first year, there was a general temporary trend of increasing catch rate at the Rio Rancho site and decreasing catch rate at Socorro.

The mean annual catch rate at both sites increased during the second year of the investigation (July 1995-June 1996) to over twice what is was in the previous year. There was

Table 4. Summary of ichthyofaunal composition and collection data from July 1994 to June 1996 in the Middle Rio Grande, Soccoro, NM.

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	% OF TOTAL	FREQUENCY OF OCCURRENCE[2]	% FREQUENCY OF OCCURRENCE[2]
HERRINGS					
gizzard shad	I	1	0.01	1	0.3
CARPS AND MINNOWS					
red shiner	N	413	3.21	104	26.3
common carp	I	29	2.26	13	3.3
Rio Grande silvery minnow	N	11,672	90.83	265	67.1
fathead minnow	N	121	0.94	31	7.5
flathead chub	N	172	1.34	73	18.5
longnose dace	N	20	0.02	2	0.5
SUCKERS					
river carpsucker	N	208	1.62	50	12.7
white sucker	I	12	0.09	4	1.0
BULLHEAD CATFISHES					
black bullhead	I	2	0.02	1	0.3
yellow bullhead	I	12	0.09	5	1.3
channel catfish	I	124	0.96	58	14.7
LIVEBEARERS					
western mosquitofish	I	74	0.58	21	5.3
TEMPERATE BASSES					
white bass	I	-	——	-	-
SUNFISHES					
green sunfish	I	-	——	-	-
bluegill	I	1	0.01	1	0.3
largemouth bass	I	2	0.02	2	0.5
white crappie	I	6	0.05	2	0.5
PERCHES					
yellow perch	I	-	——	-	-
TOTAL	12,851				

[1] N = native; I = introduced
[2] Frequency and % frequency of occurrence in total number of seine hauls at this site (n = 395)

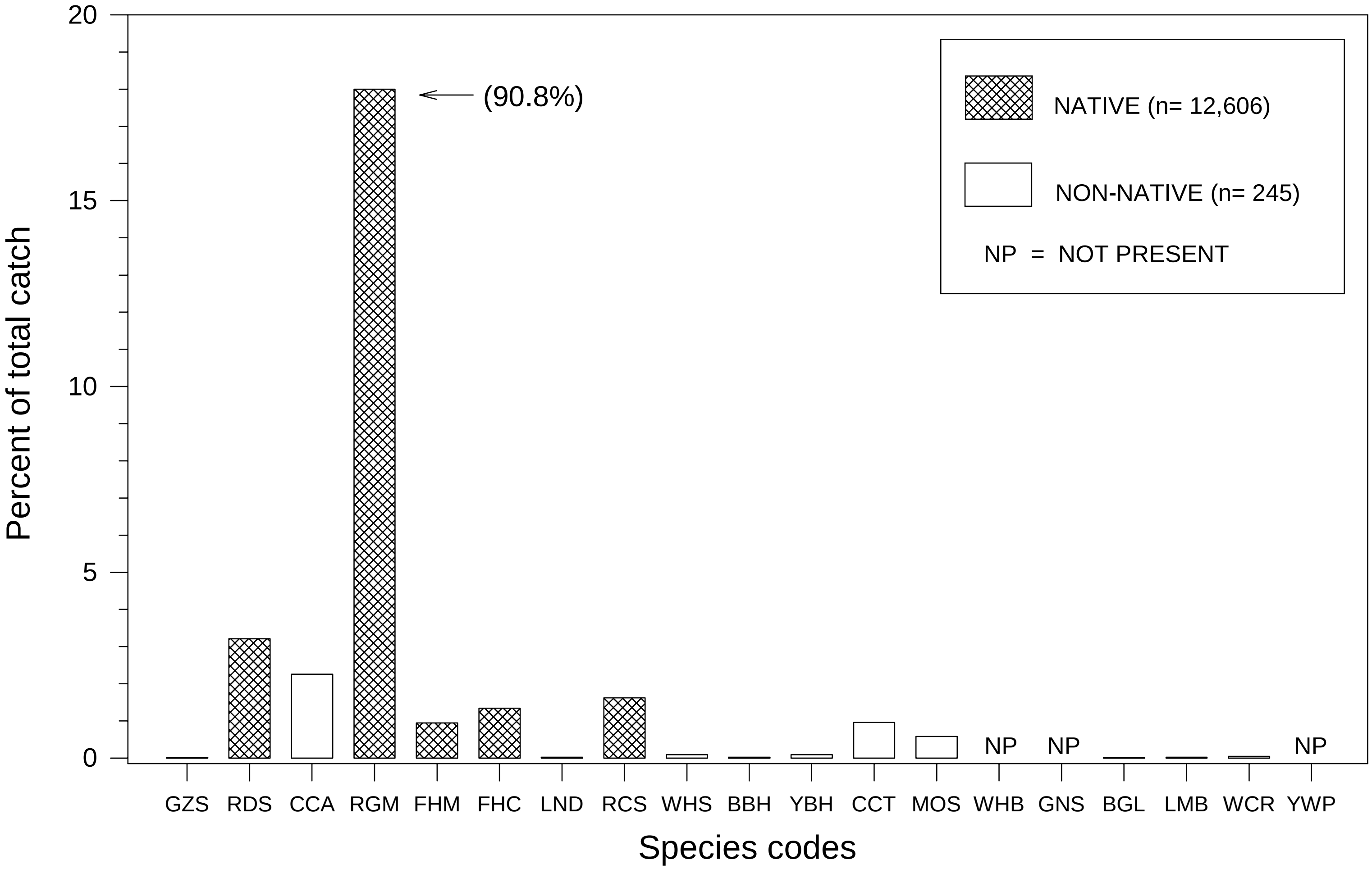


Figure 4. Ichthyofaunal composition of the Rio Grande, based on sampling July 1994 to June 1996, at the Socorro sampling locality. (Species codes are listed in Table 1)

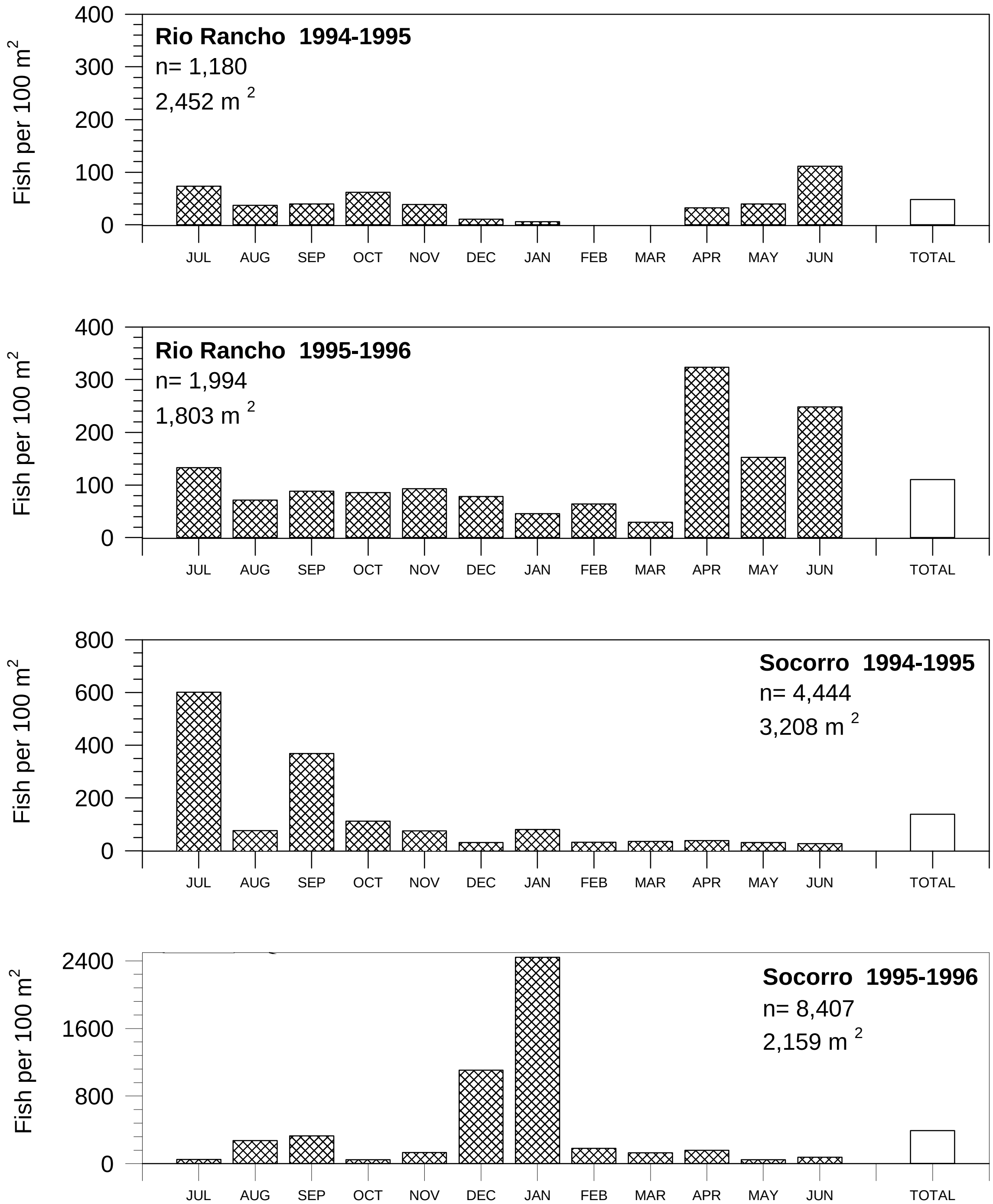


Figure 5. Fish catch rates (CPUE) by month for the two sampling localities (Rio Rancho and Socorro) in the Rio Grande. (Note different scales for y-axis).

little change in the Rio Rancho catch rate between July and March but in April 1996 catch rate peaked at 323.2 fish/100 m^2. Much of this increase was due to reduced flow in the Rio Grande which resulted in an unseasonal concentration of fish. A general catch rate pattern observed during the two year period at Rio Rancho was low catch during winter (December-March) and highest catch rates from April-June. Two winter 1995-1996 collections at Socorro resulted in anomalous catch rates of 1,109.1 and 2,440.3 fish/100 m^2. Two seine hauls yielded large numbers of Rio Grande silvery minnow, which were concentrated among instream debris. The next highest 1995-1996 Socorro catches were in September (330.2 fish/100 m^2) and August (273.6 fish/100 m^2) and were more typical of the catches throughout the rest of the study. With the exception of the two winter collections, catches at Socorro were greatest in early-summer to autumn and decreasing gradually until the next summer.

Rio Grande silvery minnow

Monthly length frequency histograms were constructed for both Rio Rancho and Socorro collections of Rio Grande silvery minnow. These data, in combination with concurrent life-history studies, demonstrated that there may be as many as three age-classes (0, 1, 2) of Rio Grande silvery minnow present at a specific time. The population at both sites was comprised primarily of age-0 and 1 fish, with age-2 individuals being extremely rare. There were relatively few differences in the monthly age-structure of Rio Grande silvery minnow between sites.

In July 1994, age-0 individuals numerically dominated the catch at both sites. A single age-2 silvery minnow was also taken in July 1994 at Rio Rancho (Figure 6). This was the only collection from that site which simultaneously produced all three age-classes of this species.

Age-0 Rio Grande silvery minnow numerically dominated the catch at both sites from July 1994 throughout the rest of the calendar year. This trend continued into the next year when age-0 fish (1994 cohort) become age-1 fish (1 January is the nominal birthday) and age-1 fish (1993 cohort) become age-2. Between January and June 1995, only 11 Rio Grande silvery minnow were caught at Rio Rancho, all of which were age-1 individuals. Conversely, during this same period at Socorro, 387 Rio Grande silvery minnow were taken of which only 6 (1.6%) were age-2 individuals (Figure 7).

In 1995, age-0 Rio Grande silvery minnow were first collected in July at Socorro and August at Rio Rancho. The appearance of age-0 (1995 cohort) Rio Grande silvery minnow during these months at these sites was also marked by the decline of age-1 fish. The August 1995 Socorro sample was only the second collection in this study that produced all three Rio Grande silvery minnow age-classes.

With the exception of March 1996, both the 1994 and 1995 Rio Grande silvery minnow cohorts were present in each of the monthly collections at Socorro between September 1995 and April 1996. As was observed during the previous year, the younger age-class (1995 cohort) numerically dominated the samples. During this same period at Rio Rancho, both cohorts (1994-1995) were present only in September and November 1995. The absence of age-0 Rio Grande silvery minnow from the last collections at both sites (June 1996) suggested that either this species had not yet had a notable spawn in 1996 or that larvae were present in uncharacteristically low numbers.

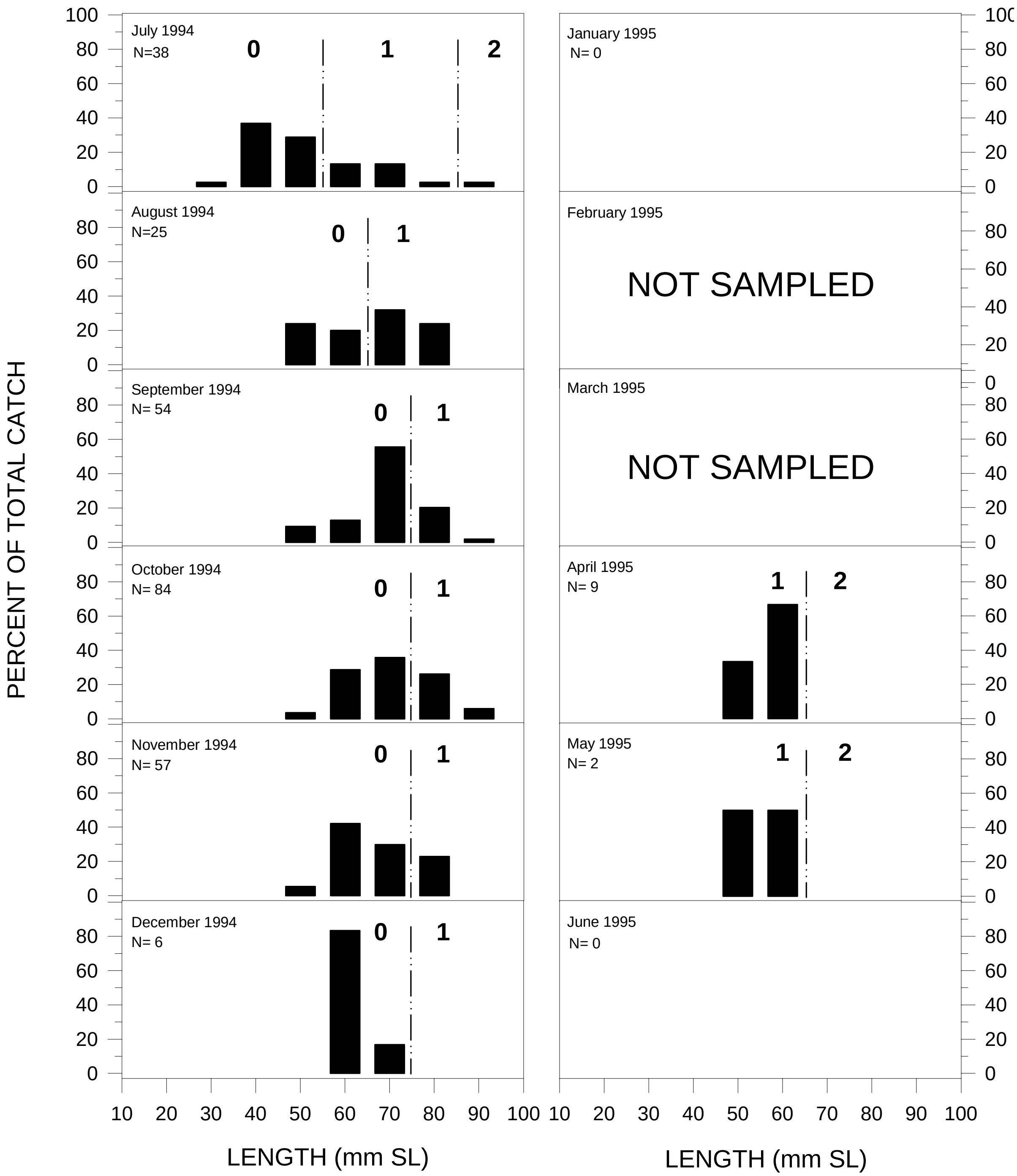


Figure 6. Rio Grande silvery minnow length frequency histograms by collecting date at the Rio Rancho sampling locality in the Rio Grande (0,1,2 designate age-classes; broken line separates putative age-classes).

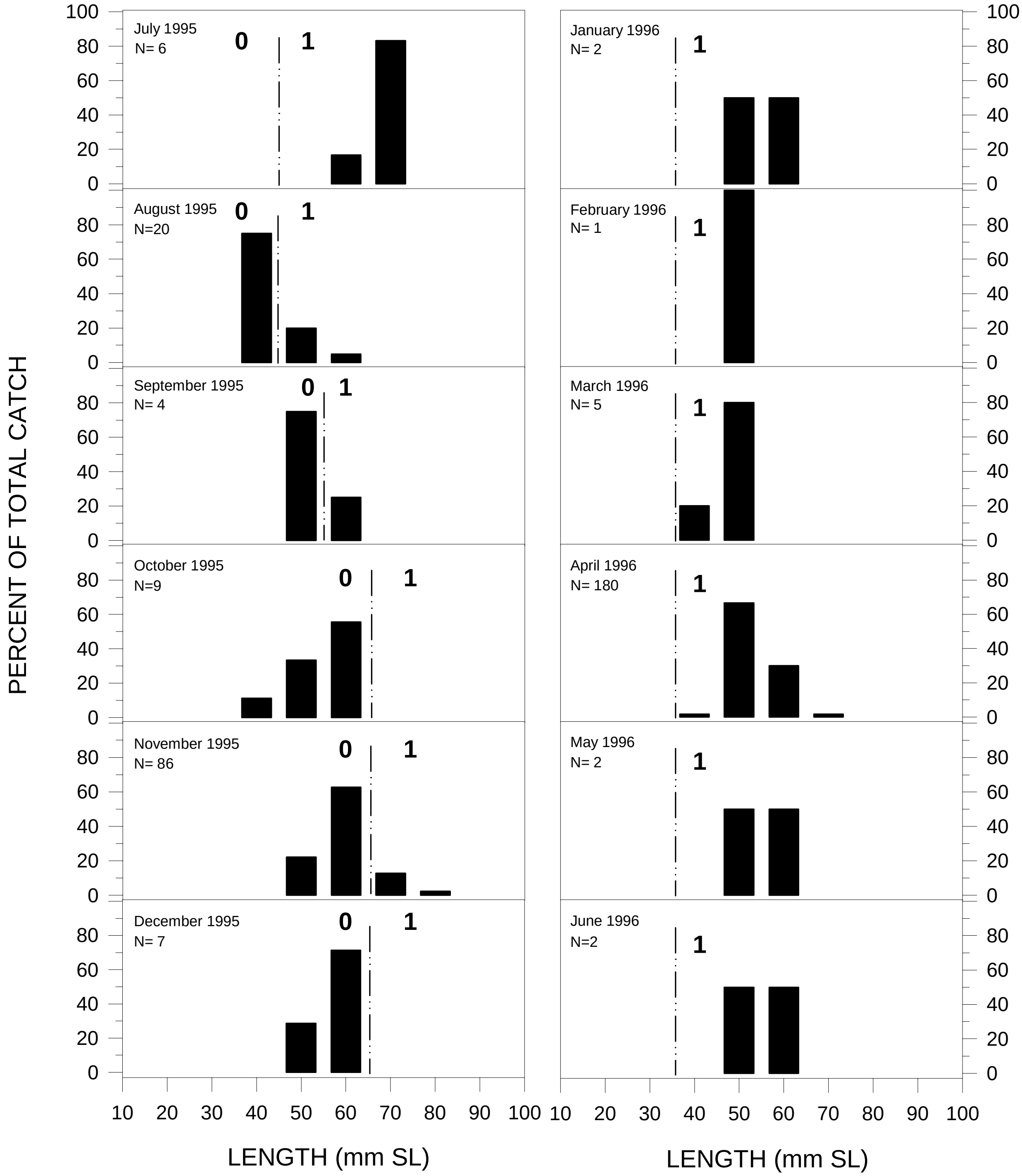


Figure 6. Rio Grande silvery minnow length frequency histograms by collecting date at the Rio Rancho sampling locality in the Rio Grande (0,1,2 designate age-classes; broken line separates putative age-classes).

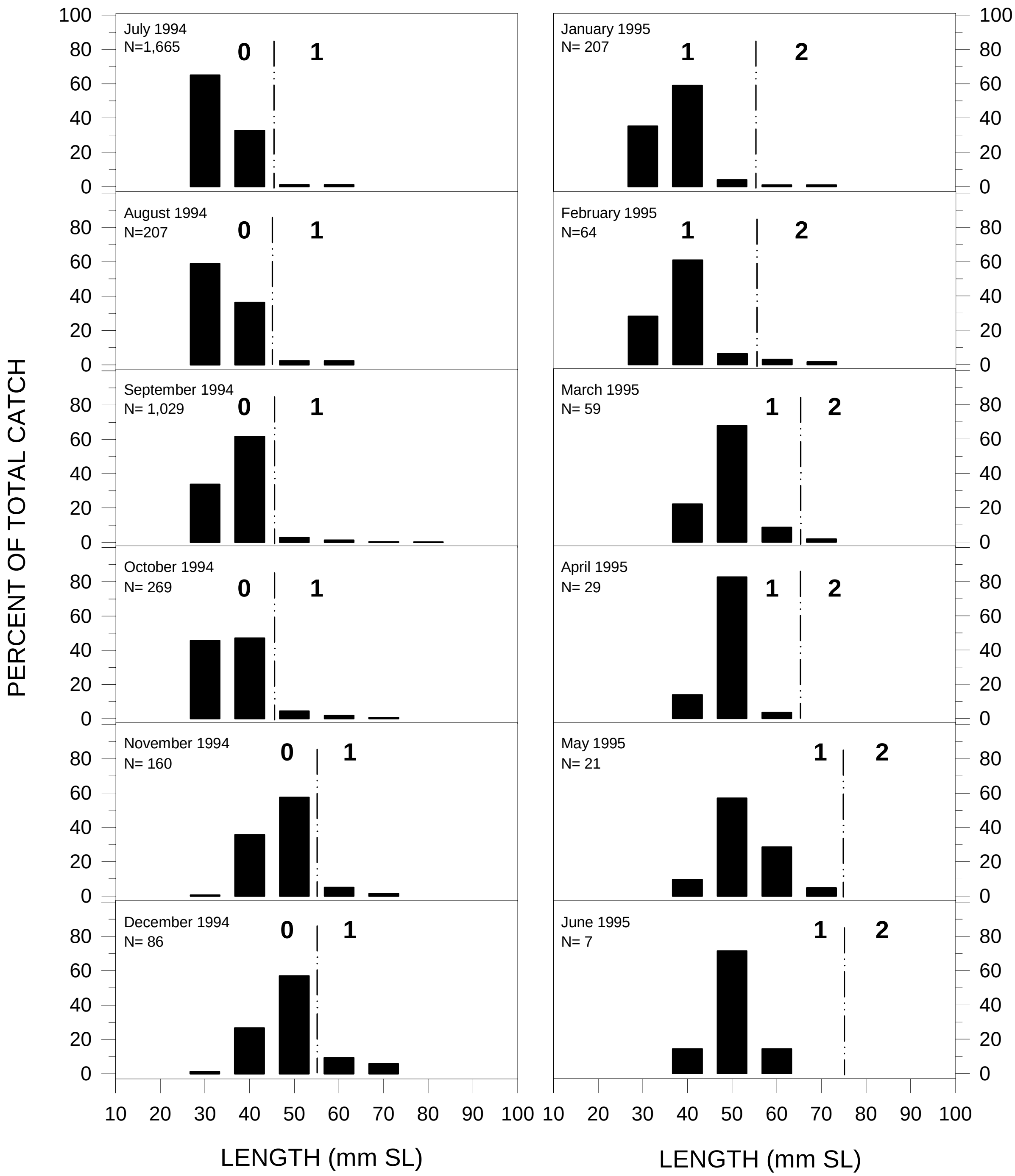


Figure 7. Rio Grande silvery minnow length frequency histograms by collecting date at the Socorro sampling locality in the Rio Grande (0,1,2 designate age-classes; broken line separates putative age-classes).

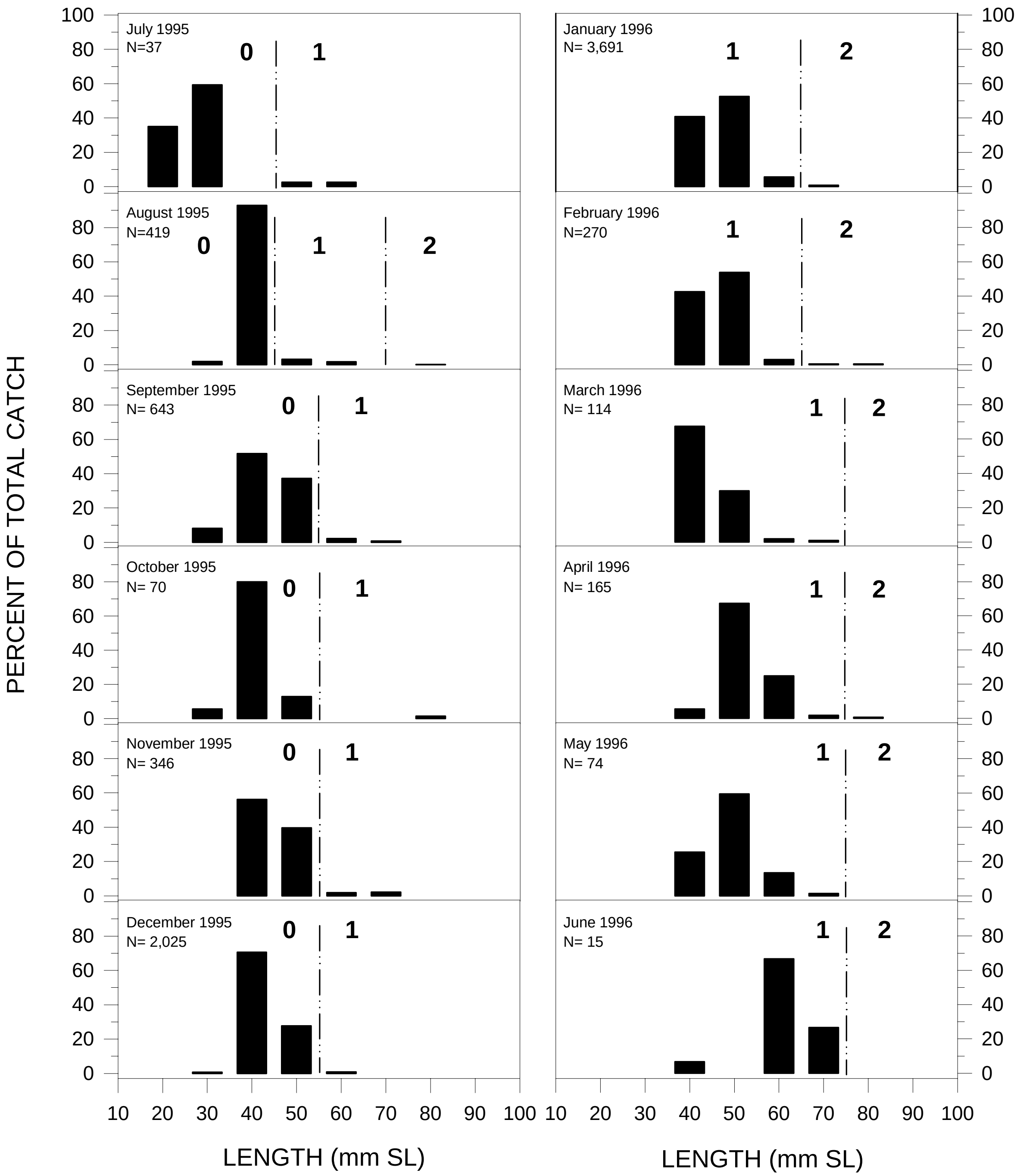


Figure 7. Rio Grande silvery minnow length frequency histograms by collecting date at the Socorro sampling locality in the Rio Grande (0,1,2 designate age-classes; broken line separates putative age-classes).

HABITAT AVAILABILITY

During this study, habitat availability was represented by a broad range of depths and velocities (Figure 8). The majority of depth measures along habitat availability transects were <40 cm, although 18.7% of depths were >80 cm (=47 cm). Depths >120 cm were only rarely encountered. Areas of moderately-high water velocity (>50 cm/s) comprised 41.6% of all measured points (=44 cm/s). Sand was the most frequently encountered substrate (67%) along habitat transects with silt, gravel and cobble each comprising about 10% of the available substrata. Boulders were rarely encountered during our sampling. The most common habitat type was main channel run (72%). Riffles were only present in the main channel and were rare (1.5%). Low-velocity habitats (backwaters, debris piles and pools) were relatively uncommon and together accounted for 16.4% of the total.

The upstream sampling locality (Rio Rancho) had a broader range of depths, velocities and substrata than did our downstream site (Socorro) (Figure 9). There were relative few differences in the Rio Rancho histogram plot of water depths between 10 and 100 cm (=52 cm). The only depths not frequently encountered at Rio Rancho were >100 cm (8%). Conversely, the depth distribution at Socorro was unimodal with 51.6% of depths <30 cm (=42 cm). Deeper water areas at Socorro were consistently less common than at Rio Rancho (p<0.01).

Both sites had a broad range of water velocities with moderately-high velocity habitats (>50 cm/s) comprised over 30% of the respective totals. The most common water velocities at Socorro were <30 cm/s (=38 cm/s) while at Rio Rancho they were 60-80 cm/s (=48 cm/s) (p<0.01). In summer (April-September), there were site differences (p<0.01) in availability of depths and velocities. However, in winter (October-March), there was no differences in the availability of depths between sites and, although statistically significant, the between site differences in water velocities were not extreme (Rio Rancho =50 cm/s, Socorro =44 cm/s).

While sand was the dominate substrate at both sites, the riverbed at Rio Rancho was composed of larger-sized materials (i.e., more gravel and cobble) than at Socorro (i.e., more silt and sand) (p<0.01). Boulders were only encountered at the Rio Rancho site. Main channel runs were the most common mesohabitat at both sites (>70%). Low-velocity habitats (backwaters and pools) were rare at both sites with no category accounting for >10% of the total. Riffles were only present at Rio Rancho (3%).

There were some changes in availability of depths, velocities and substrata at Rio Rancho over the duration of the sampling period (Figure 10). Mean depth was usually about 50 cm with shallow areas being more common in October 1995 and April 1996. The highest mean depth at Rio Rancho (=62 cm) was recorded in January 1996. Mean water velocities at this site ranged from 39 cm/s (April 1996) to 58 cm/s (January 1996). There were no differences between seasonal (i.e., winter versus summer) availability of depths at Rio Rancho (p<0.05), but there were differences in the availability of water velocities (winter =50 cm/s, summer =44 cm/s; p<0.01). Additionally, about half of the 28 pair-wise comparisons between specific dates (i.e., every month) at Rio Rancho were different (<0.05) for both depth and velocity.

The substrata at Rio Rancho consisted of primarily sand (code=2) with larger substrata such as gravel and cobble (codes=3 and 4 respectively) increasing the mean value to about 2.5. Rio Rancho was typified by smaller substrates in April-June 1996 which coincided with decreased water velocity (i.e., flow conditions appear to have created a sediment

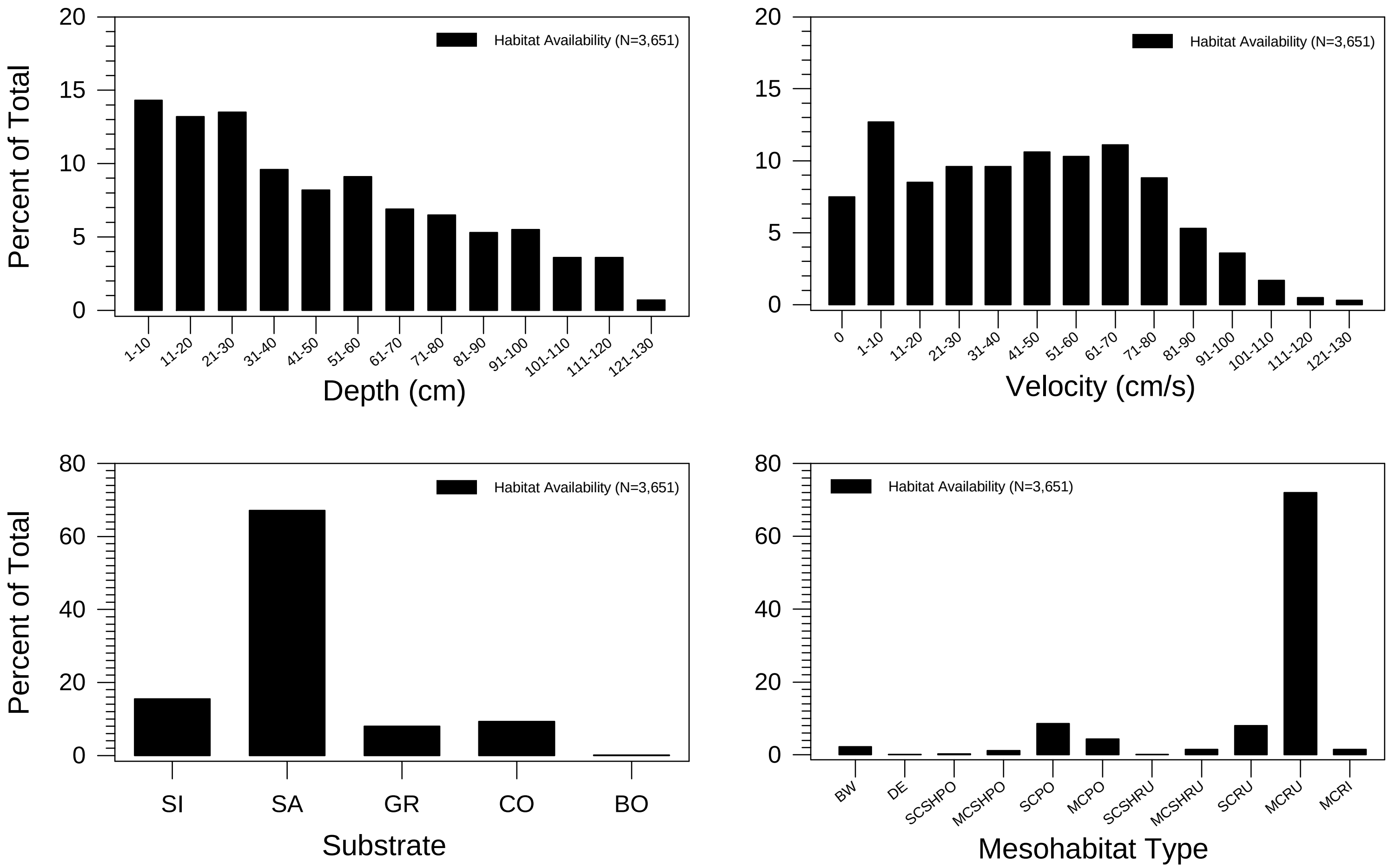


Figure 8. Habitat availability combined for both sampling localities in the Rio Grande.

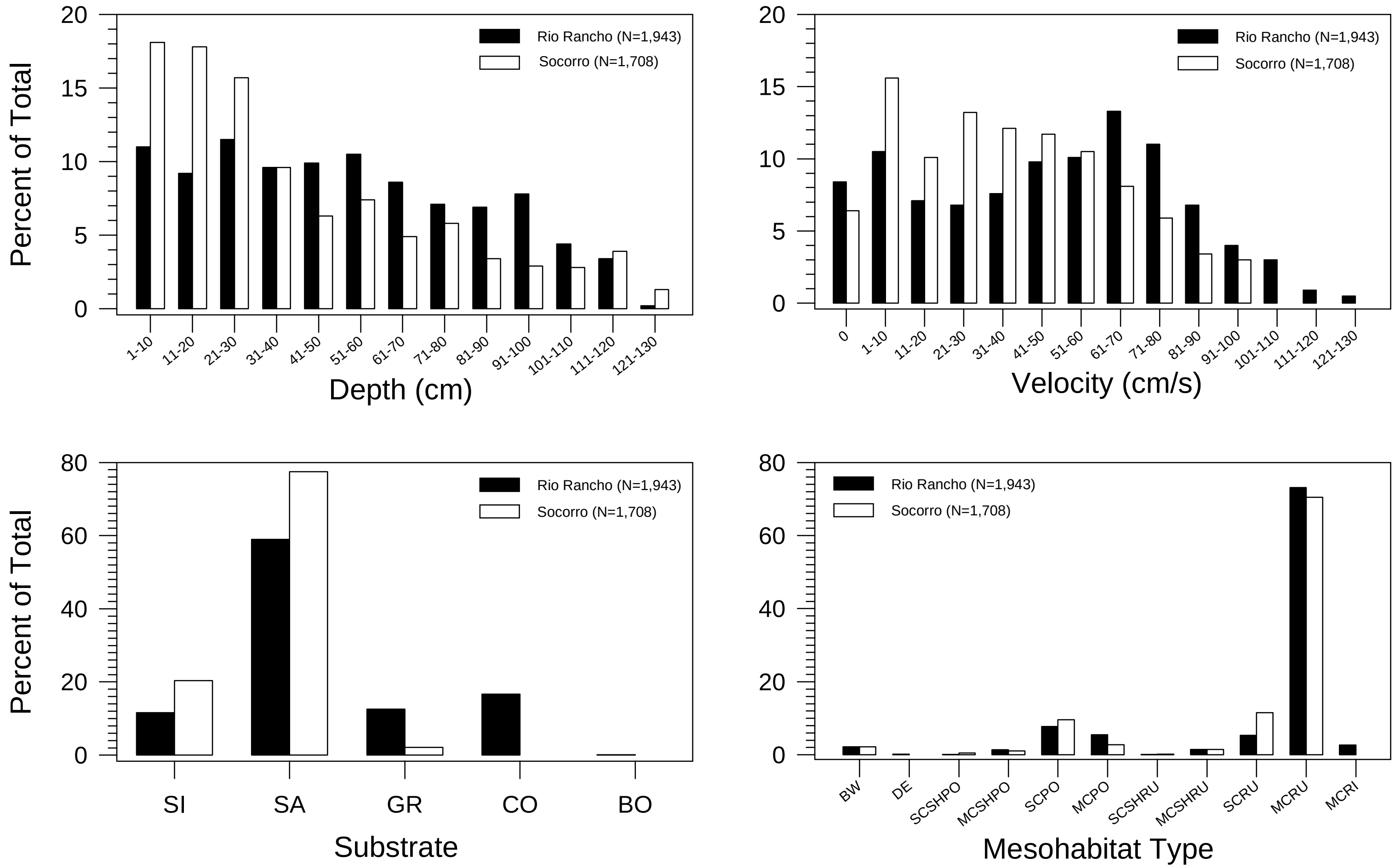


Figure 9. Habitat availability broken down by sampling locality in the Rio Grande.

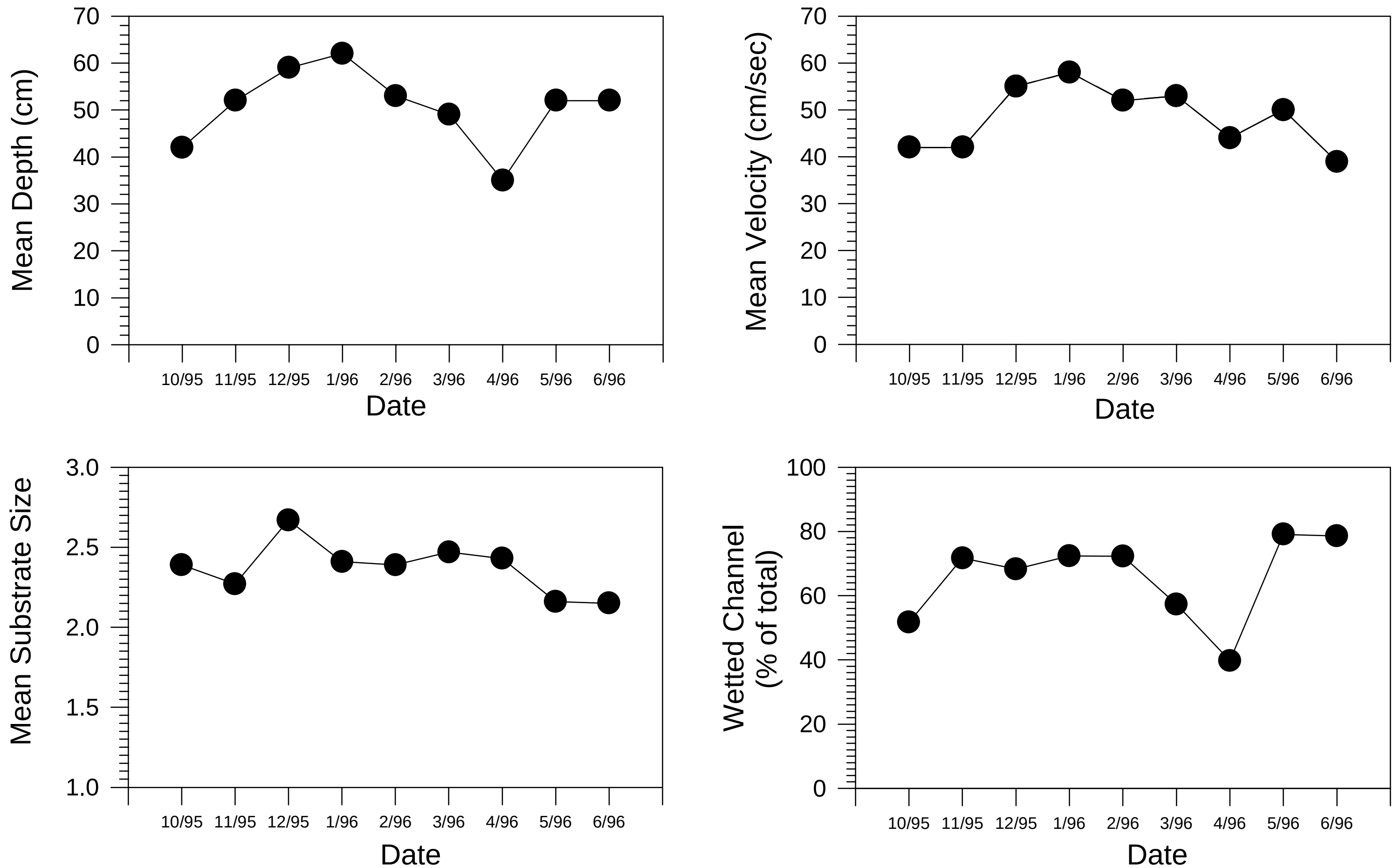


Figure 10. Habitat availability by sampling date at the Rio Rancho sampling locality in the Rio Grande.

depositional period). The percentage of the wetted Rio Rancho channel changed throughout the year with higher water depths corresponding positively to increased channel width. During low flow in April 1996, only 39.8% of the Rio Rancho potentially wetted channel (i.e., vegetated bank to vegetated bank) was inundated.

Socorro exhibited dramatic changes in available habitats between October 1995 and June 1996 (Figure 11). Mean depth at Socorro ranged from 14 cm (June 1996) to 61 cm (December 1996). The most dramatic drop in mean depth at Socorro occurred in April 1996 as a result of decreased flow due to Middle Rio Grande water operations. Change in water velocities at Socorro mirrored that of depths (range of =14 cm/s to 61 cm/s). There were differences ($p<0.01$) in the availability of depths and velocities at Socorro over seasons (depth winter =51 cm, summer =16 cm; velocity winter =46 cm/s, summer =15 cm/s), and between specific dates (20 of 28 pair-wise comparisons resulted in $p<0.05$). Sand was the dominant substrate at this site throughout the year with other substrata being less frequently encountered. The percent change in the Socorro wetted channel fluctuated greatly throughout the sampling period from 76.3% in November 1995 to 17.8% in April 1996.

Both Rio Rancho and Socorro exhibited winter and summer trends in habitat availability (Figures 12 and 13). At both sites there was a decrease in summer, compared to winter, in water depths, velocities, and high velocity mesohabitat types. This pattern was more pronounced at Socorro than Rio Rancho as most flow in the river was diverted into Middle Rio Grande Conservancy District Canals at points downstream of Rio Rancho but upstream of Socorro.

HABITAT USE BY RIO GRANDE FISHES

Fish Community

Habitats collectively occupied by all species were characterized by shallow depths, low water velocities and small substrata (Figure 14). The majority of individuals occupied depths <30 cm, water velocities <10 cm/s and substrata dominated by silt. There was a bimodal distribution to the histogram plot of depths occupied by fish with individuals being most common in water <20 cm deep and between 31-40 cm deep.

Depths and velocities occupied by fish differed significantly ($p<0.01$) from available habitats. Fish were most frequently taken in low-velocity habitats such as backwaters (17.2%), debris piles (34.0%) and pools (36.0%). Some individuals were present in high water velocities (>50 cm/s) and associated mesohabitat types (riffles) but they were rarely collected in main channel run habitats (2.3%). This occurrence was in marked contrast to the high abundance of deep and high velocity habitats that dominated both sites.

There was only a moderate degree of habitat separation between different species of fish (Figure 15). The majority of native and nonnative fishes were tightly clustered in CCA space with only a few species, such as longnose dace and channel catfish, diverging from the remaining taxa. The correlation of species abundance and environmental variables was strongest along the first two axes of analysis (r^2=0.713 [axis 1] and r^2=0.495 [axis 2]). Velocity and substrate were strongly correlated with axis 1 (r^2=0.801 and r^2=0.771 respectively), but only velocity was robust in explaining the variation along axis 2 (r^2=0.719). Depth did not explain much of the spatial separation of species along either axis (r^2=0.015 [axis 1] and r^2=0.111 [axis 2]). Velocity and substrate explained almost all of the species-specific instream separation. Of the 66 species pair-

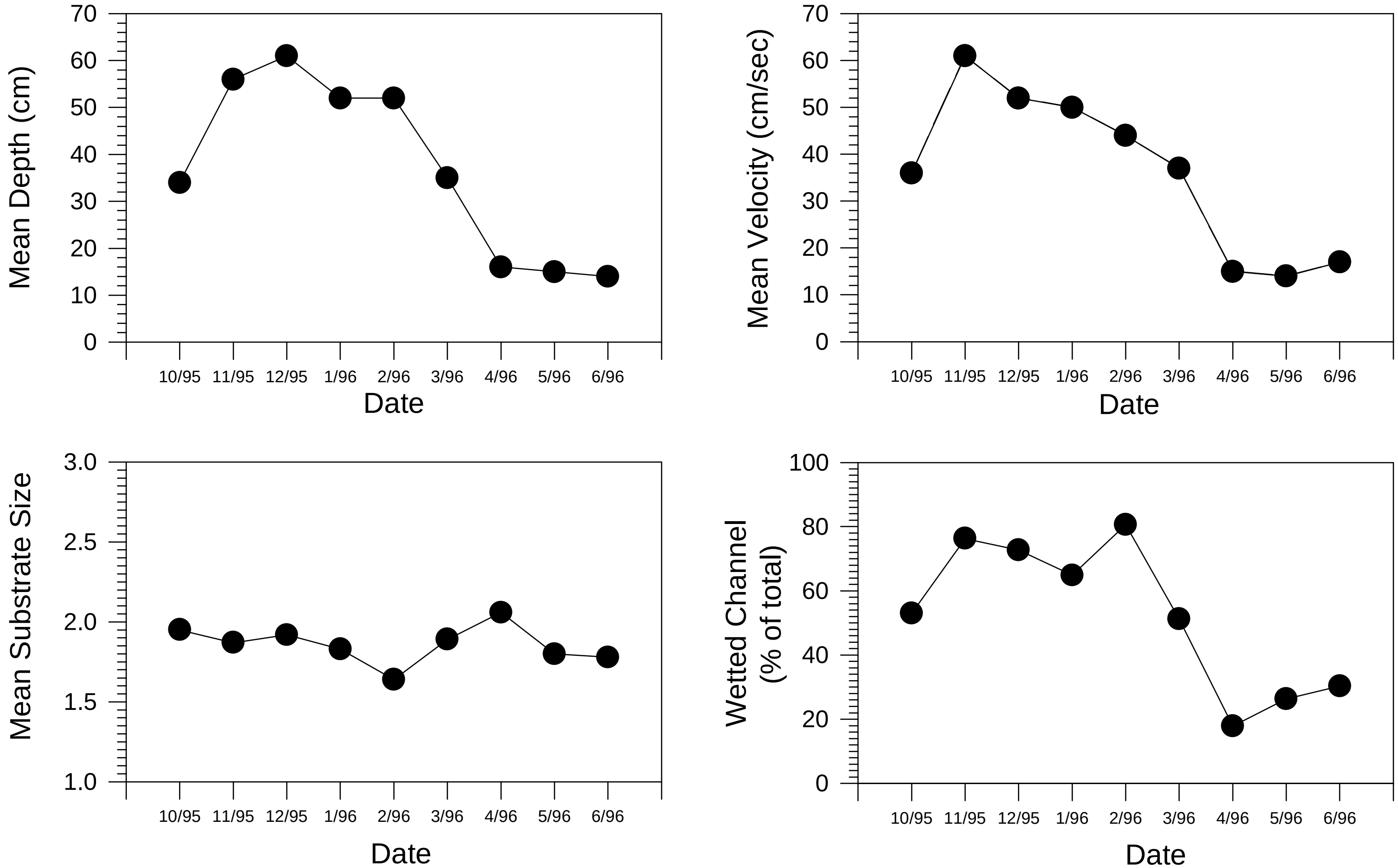


Figure 11. Habitat availability by sampling date at the Socorro sampling locality in the Rio Grande.

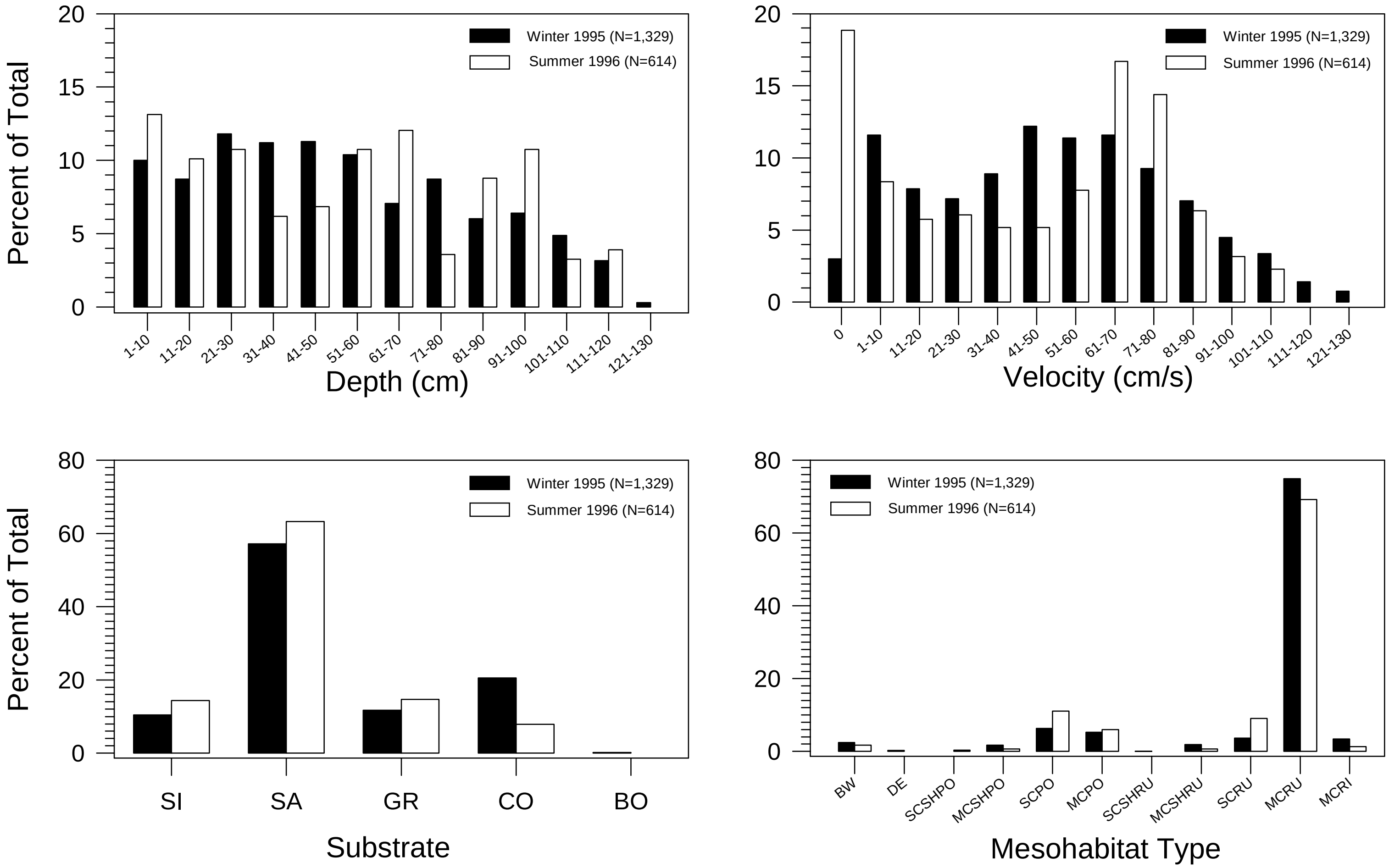


Figure 12. Habitat availability by season at the Rio Rancho sampling locality in the Rio Grande.

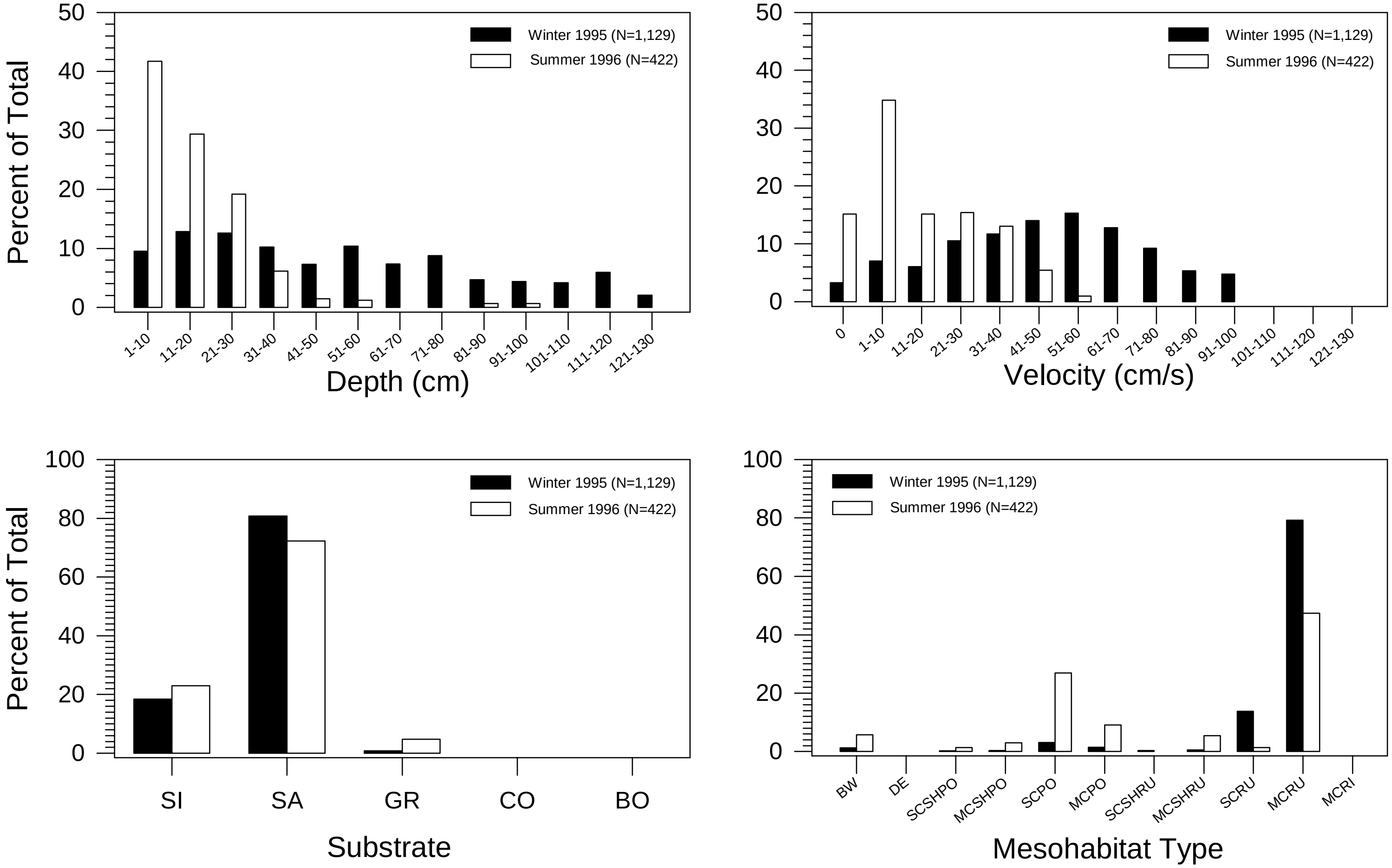


Figure 13. Habitat availability by season at the Socorro sampling locality in the Rio Grande.

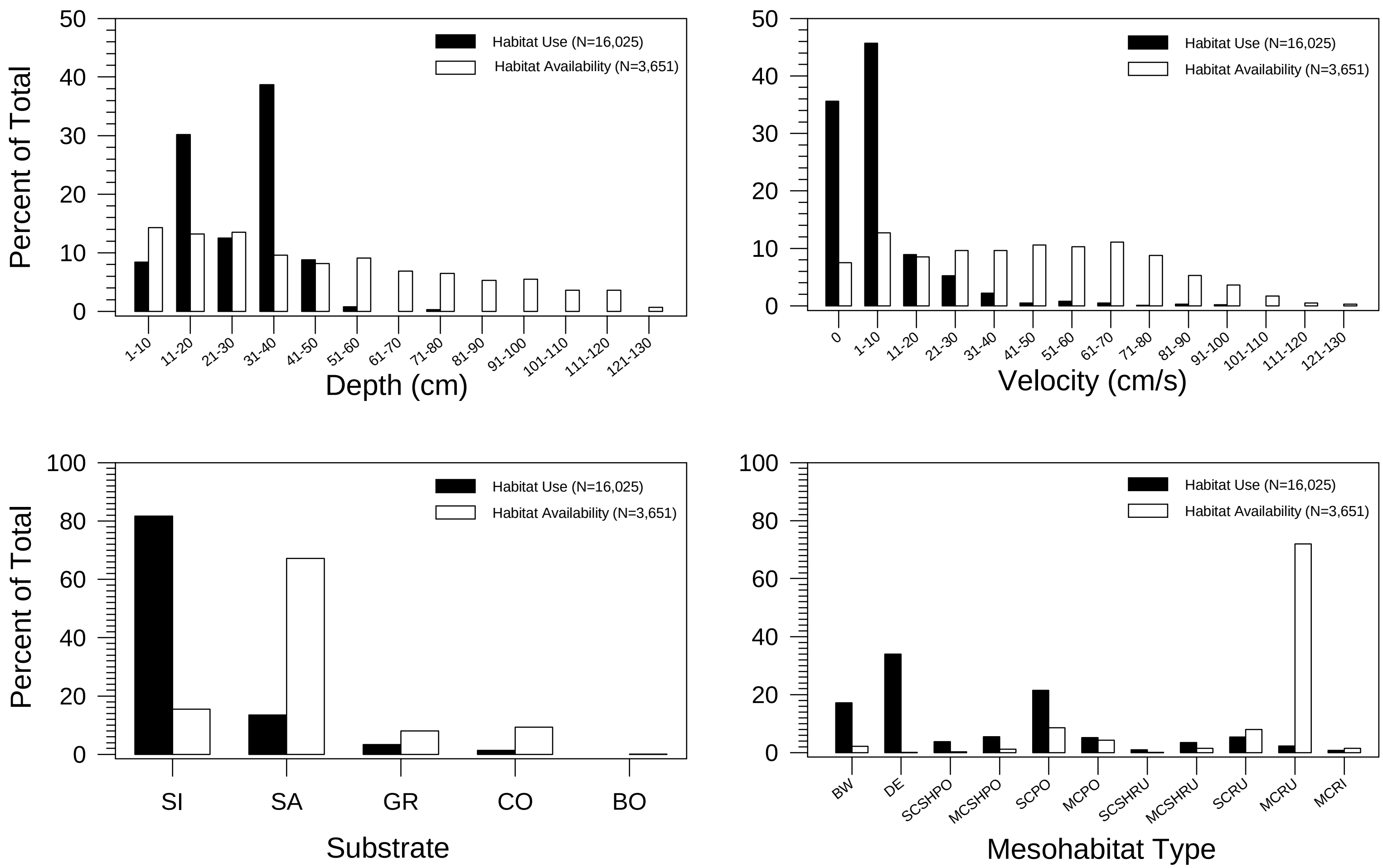


Figure 14. Comparison of mesohabitat availability and use by all fishes for both sampling localities in the Rio Grande.

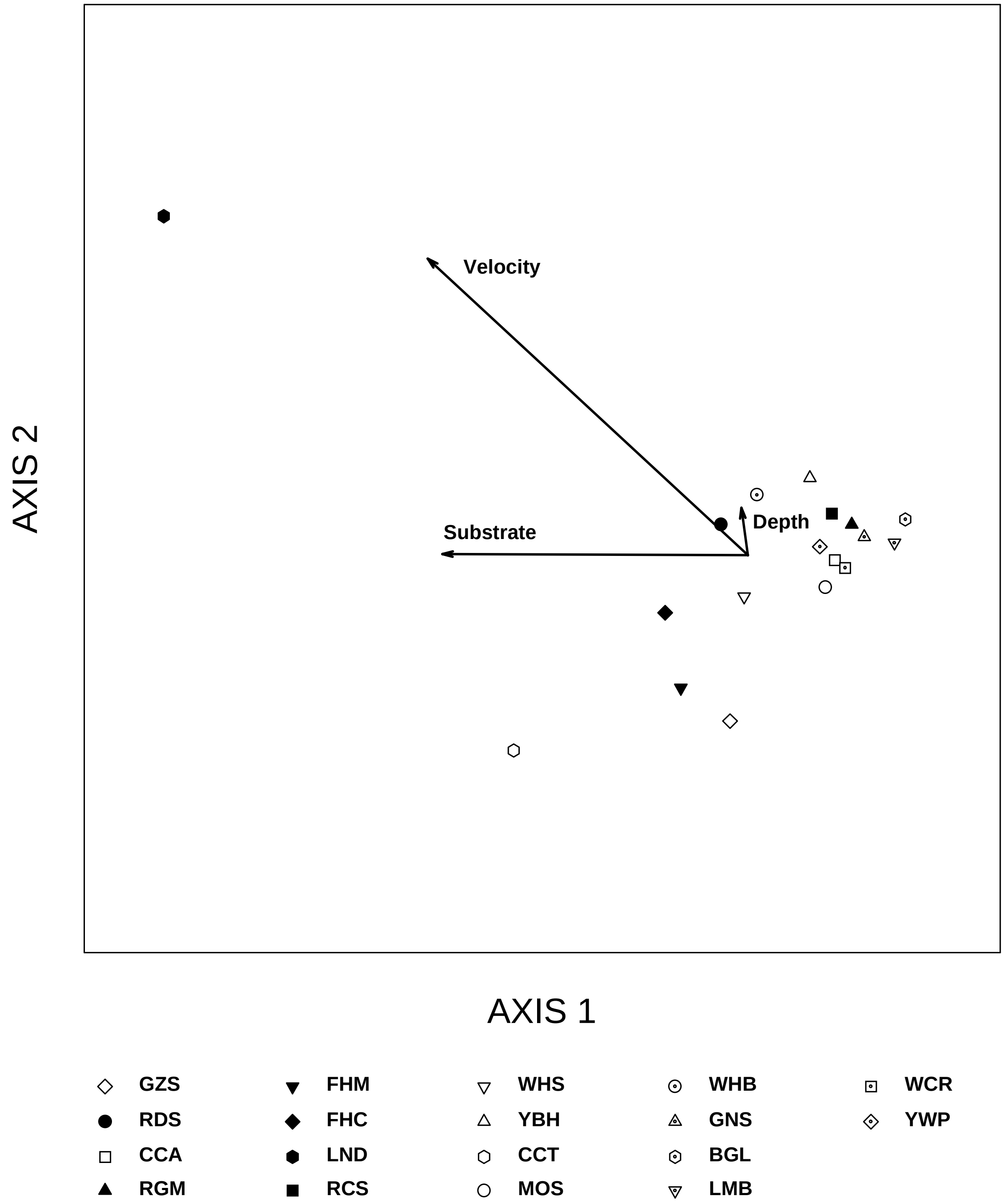


Figure 15. Canonical Correspondence Analysis diagram of habitats selected by all fishes for both sampling localities in the Rio Grande.

wise comparisons of depths and velocities, 13 depth ($p<0.05$) and 22 velocity comparisons ($p<0.05$) were different.

Longnose dace was widely separated from the rest of the community along the direction of the velocity and substrate gradient arrows indicating that it utilized high velocity habitats with large substrata more often than other species. In contrast, bluegill, largemouth bass and green sunfish were present in the opposite direction of the velocity and substrate gradient arrows indicative of their preference for lower velocity habitats. While channel catfish generally occupied moderate velocity habitats over sand or gravel substrata, they were only slightly segregated from the other species. This was primarily due to the presence, in a single seine haul at Rio Rancho, of numerous small channel catfish. They were taken in the winter in shallow, low-velocity water with associated instream debris and a cobble substrate. This collection drew the channel catfish CCA point back towards the origin. Rio Grande silvery minnow was in the center of the species array. This species was found to occupy habitats characterized by moderate-low water velocities over small substrata.

Site Comparisons

While there were differences in habitats occupied by the fish community at Rio Rancho and Socorro, (Figure 16) fish were generally taken at water depths <40 cm and water velocities <10 cm/s. Community members at both sites usually were found in low-velocity mesohabitats and appeared to avoid high velocity habitats. Fish at Rio Rancho occurred in higher water velocities more frequently than at Socorro ($p<0.01$). Another between site difference in community habitat use was that fish at Rio Rancho utilized areas with larger substrata more frequently than those at Socorro.

There was little species-specific habitat separation at Rio Rancho (Figure 17). The species-environment correlations for the axes were similar (r^2=0.758 [axis 1] and r^2=0.635 [axis 2]). Velocity was the strongest predictor of species segregation (r^2=0.968), but the only species exhibiting a divergence from the community was longnose dace. Although most separation between species was along axis 2, environmental variables were poorly correlated with this axis ($r^2<0.25$). There was moderate separation of species along the substrate gradient with channel catfish, fathead minnow and flathead chub occurring over larger substrata more often than white crappie, green sunfish, or bluegill . The weak predictive power of depth (r^2=0.008 [axis 1] and r^2=0.214 [axis 2]) was inadequate to make additional definitive statements about fish assemblage preferences.

While there was a greater spatial separation of species at the Socorro site than at Rio Rancho (Figure 18), the species-environment correlations were only moderately predictive at the former (r^2=0.540 [axis 1] and r^2=0.205 [axis 2]). Most of the species separation at Rio Rancho was due to water velocity (14 of 66 pairwise comparisons with $p<0.05$), while separation at Socorro was due to depth (12 of 66 pairwise comparisons with $p<0.05$). The depth gradient arrow at Socorro was strongly correlated with axis 2 (r^2=0.971) and indicated that species, such as longnose dace, common carp and yellow bullhead utilized shallower habitats than did largemouth bass or white crappie. Velocity and substrate at Socorro were both well correlated with axis 1 (r^2=0.523 and r^2=0.916 respectively). The species segregation along the velocity and substrate gradient arrows indicated that longnose dace, channel catfish, red shiner and flathead chub occupied high velocity and larger substrate habitats than did other species. There was a greater amount of native species spatial separation at Socorro than at Rio Rancho.

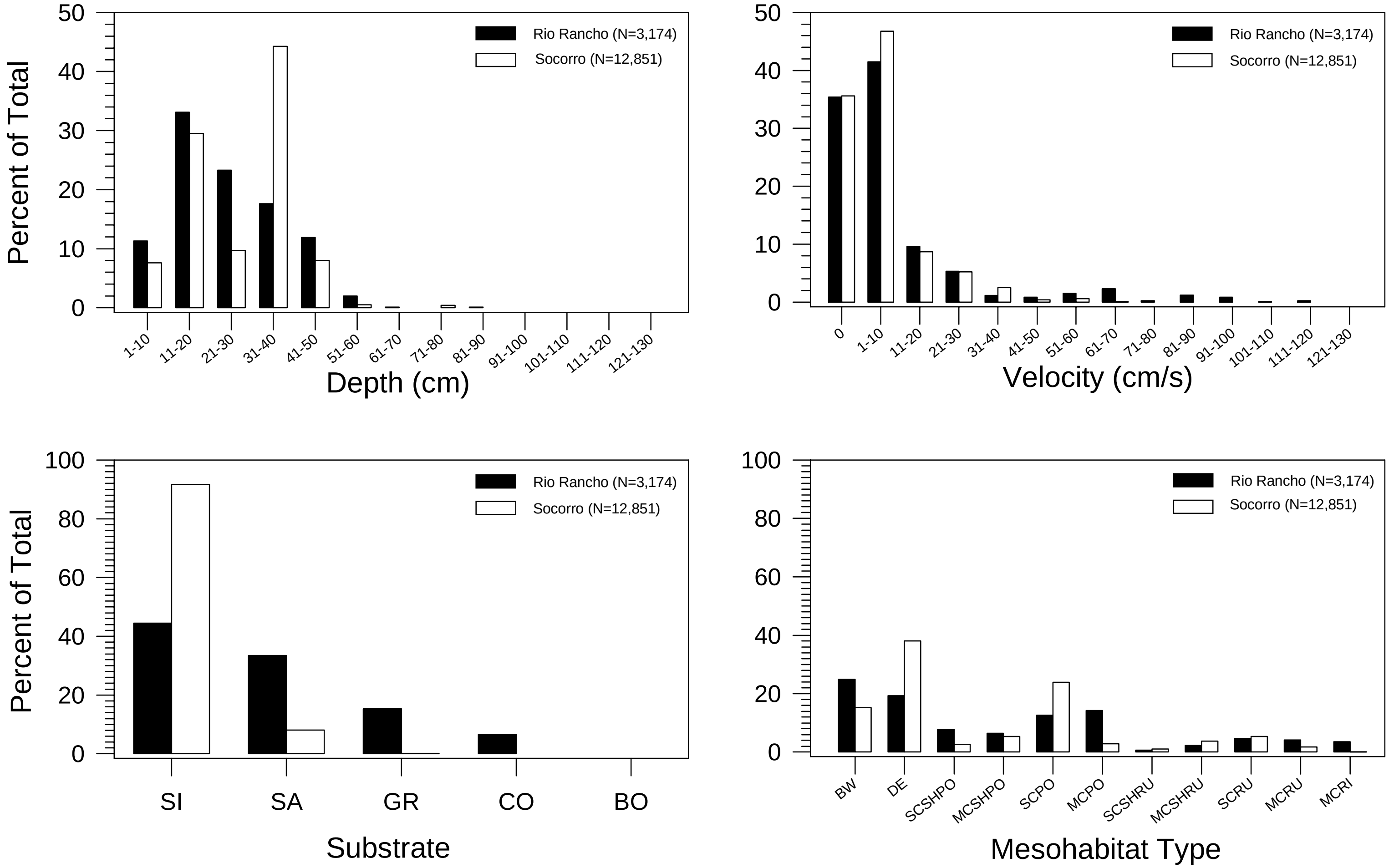


Figure 16. Comparison of mesohabitat use by all fishes broken down by sampling locality in the Rio Grande

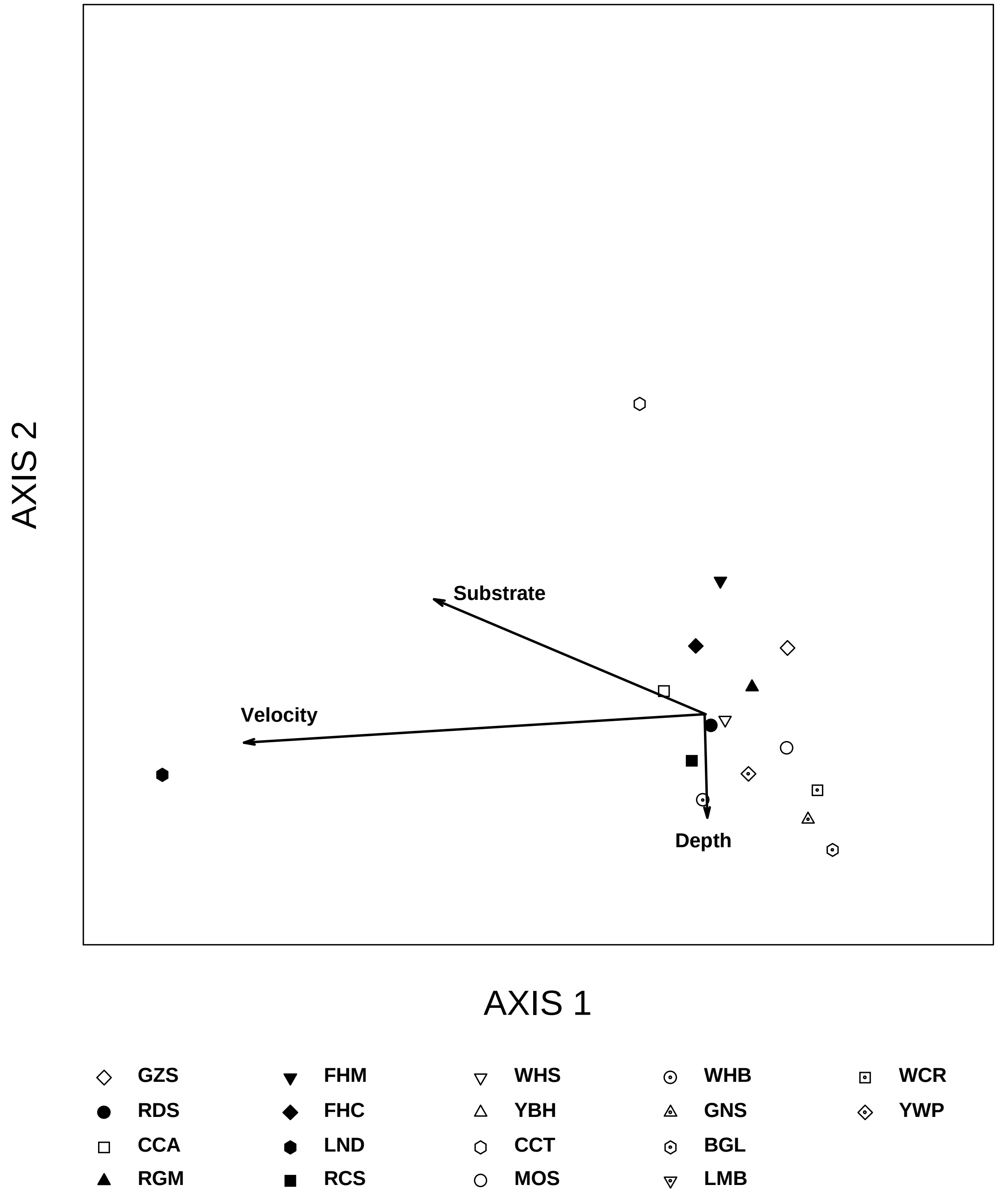


Figure 17. Canonical Correspondence Analysis diagram of habitats selected by all fishes at the Rio Rancho sampling locality in the Rio Grande.

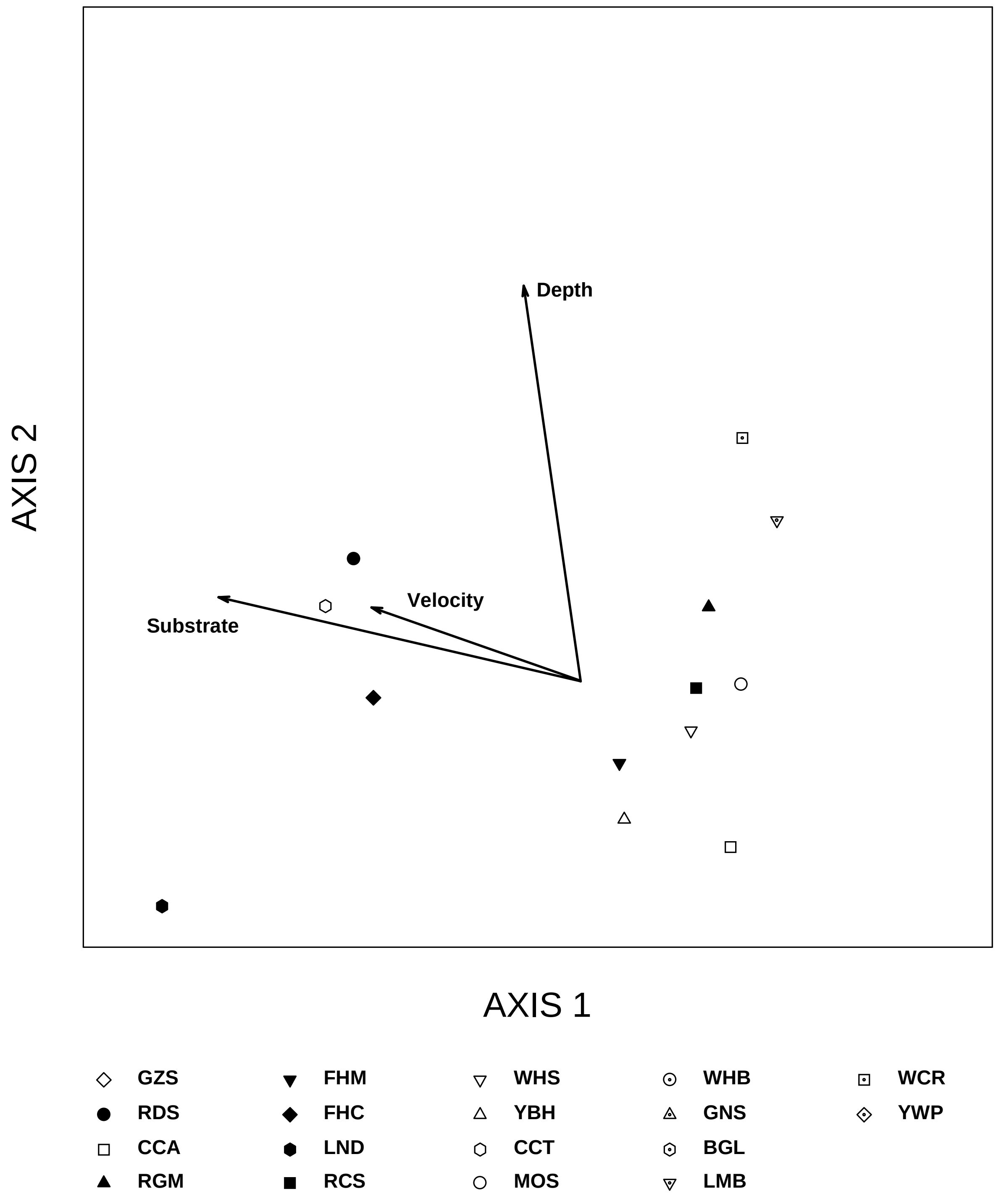


Figure 18. Canonical Correspondence Analysis diagram of habitats selected by all fishes at the Socorro sampling locality in the Rio Grande.

Seasonal Comparisons

Fish generally occupied lower velocity and deeper habitats in winter than in summer ($p<0.01$) (Figure 19). Most fish collected in summer were taken in habitats with mean water depths <20 cm (68.2%), but in winter the majority (69.1%) occupied depths 31-50 cm. Fish were most commonly found in habitats with little or no flow (<10 cm/s) in both summer (73.8%) and winter (86.0%). However, fish were nearly twice as abundant in higher velocity water (>20 cm/s) in summer as compared to winter. The transition to lower velocity water in the winter was also indicated by the substrata over which fish were found. A higher percentage of fish community was taken over gravel and cobble substrata (instead of silt) during the winter (7%) than summer (3%). The fish community was also found to occupy areas of cover (debris piles) much more frequently in winter (54%) than summer (2%).

Individual species showed little separation along the only strongly predictive gradient arrow (velocity; r^2=0.802 [axis 1] and r^2=0.797 [axis 2]) in winter (Figure 20). However, the correlation between species abundance and environmental variables was strong along both axes (r^2=0.805 [axis 1] and r^2=0.676 [axis 2]). Although there was some segregation between species along the substrate and depth gradient arrows, their predictive power was low along both axes. The limited predictive power from this CCA meant that the visual spatial separation of species along axis 2 had little meaning. The overall trend in winter was that all species except longnose dace appeared to occupy low-velocity habitats. This was supported by the fact that many species were taken syntopically (in the same seine haul) during winter sampling.

There was a higher degree of spatial segregation between species during the summer (Figure 21) than winter (Figure 20). However, species-environment correlations for both axes in summer were only moderately predictive (r^2=0.595 [axis 1] and r^2=0.319 [axis 2]). Substrate and velocity both strongly predicted variation along axis 1 (r^2=0.875 and r^2=0.799 respectively), but only velocity was a useful predictor of variation along axis 2 (r^2=0.514). Since depth was poorly correlated with both axes (r^2=0.017 [axis 1] and r^2=0.052 [axis 2]) it was not useful for making conclusions regarding summer fish habitat separation. Longnose dace and channel catfish were positively associated with increased water velocities and larger substrata, while the opposite was true for many species including the centrarchids.

Rio Grande silvery minnow

Habitats selected by Rio Grande silvery minnow were not those most commonly available (Figure 22). In addition, the mean depths and velocities occupied by this species differed significantly ($p<0.01$) from their availability. There was a bimodal distribution in the histogram plot of depth use by Rio Grande silvery minnow with individuals most commonly collected in habitats with depths <20 cm or 31-40 cm. Few individuals utilized areas with depths >50 cm.

Rio Grande silvery minnow was abundant (86.5%) in areas of little or no water velocity (<10 cm/s). Individuals were occasionally taken (11.0%) in areas of moderate velocity (11-30 cm/s) but rarely (0.8%) in habitats with water velocities >40 cm/s. Silt was the substrata over which most (91.3%) individuals were located. Sand was the second most common substrata

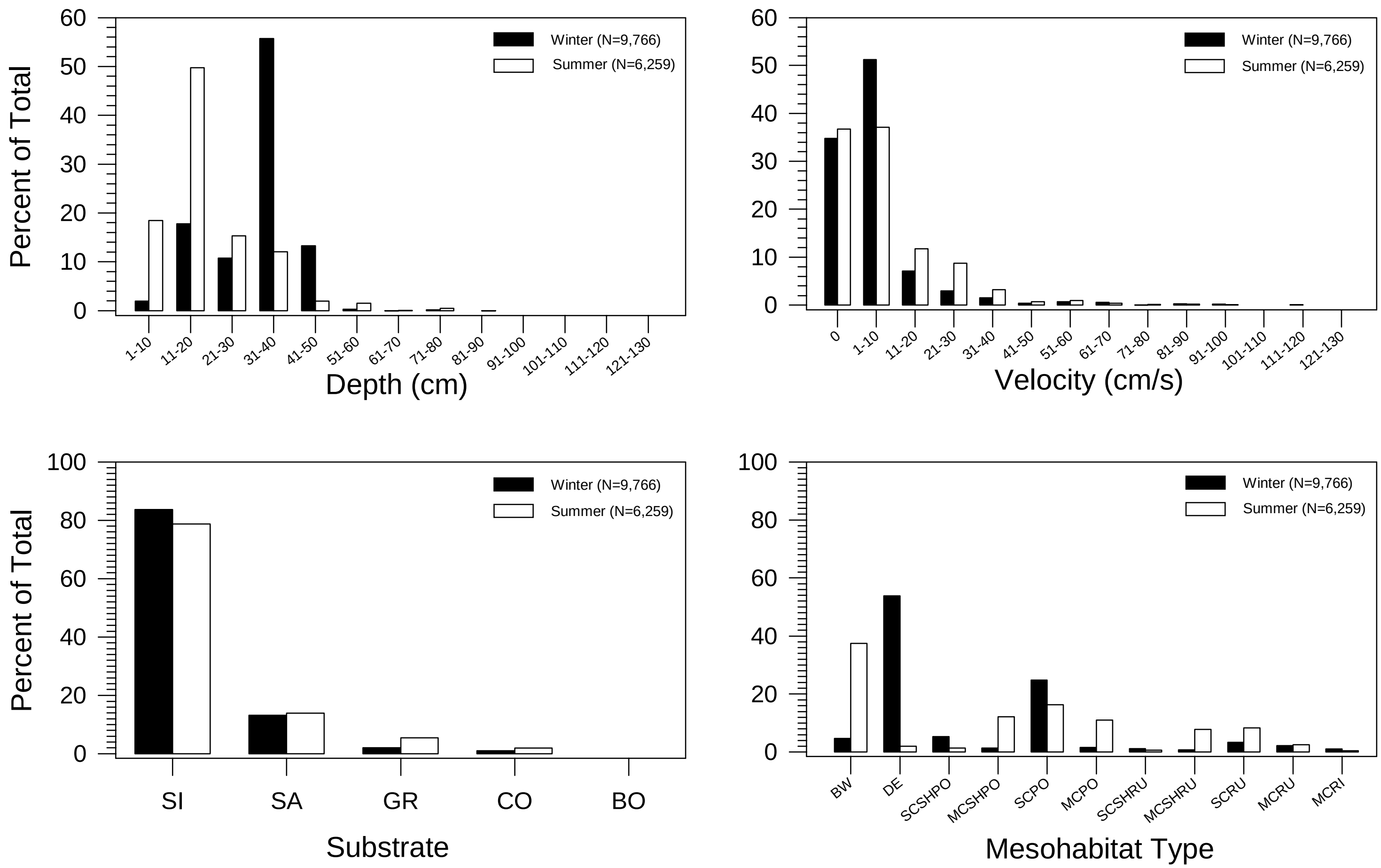


Figure 19. Comparison of mesohabitat use by all fishes broken down by season for both sampling localities in the Rio Grande.

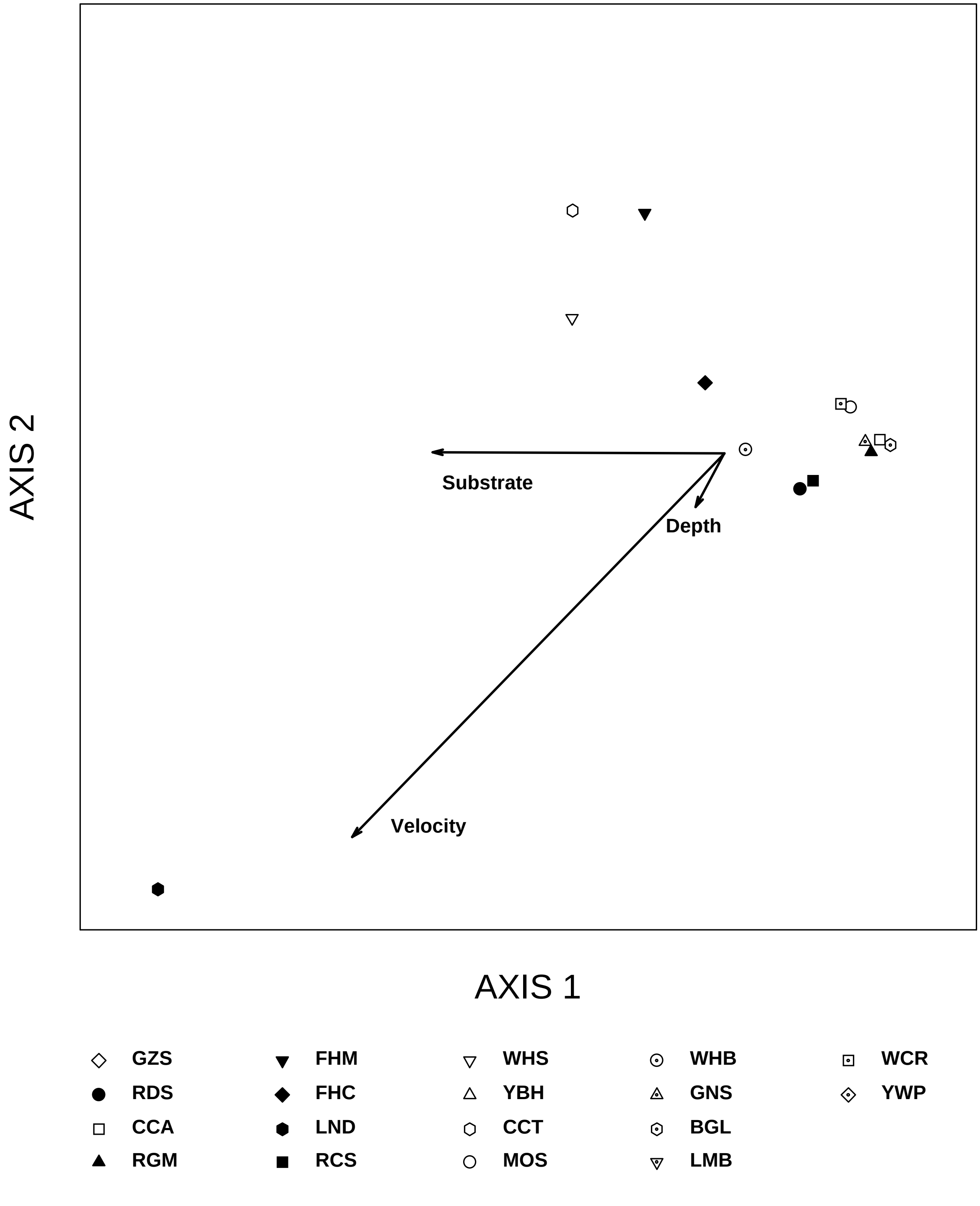


Figure 20. Canonical Correspondence Analysis diagram of habitats selected by all fishes during winter (October-March) for both sampling localities in the Rio Grande.

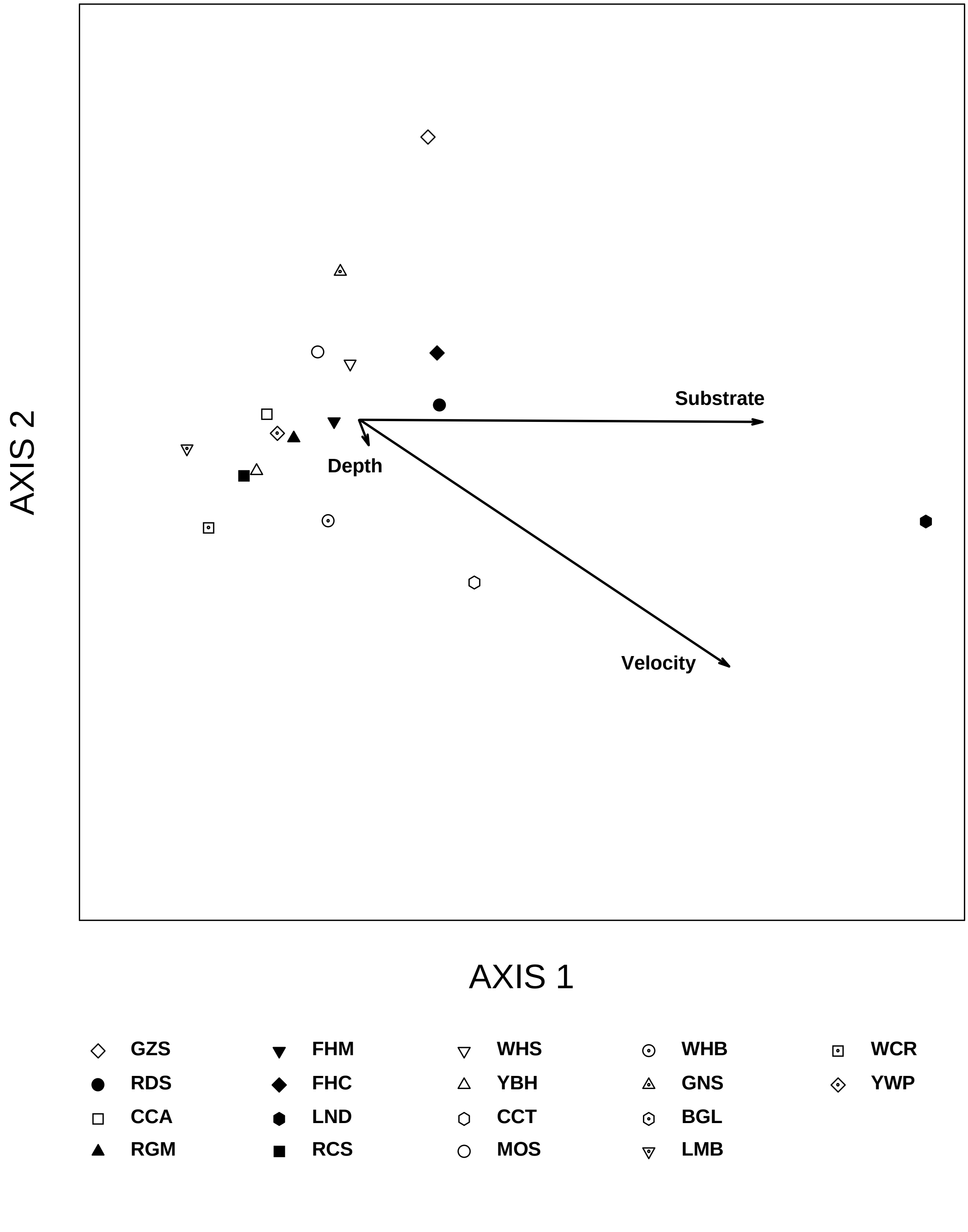


Figure 21. Canonical Correspondence Analysis diagram of habitats selected by all fishes during summer (April-September) for both sampling localities in the Rio Grande.

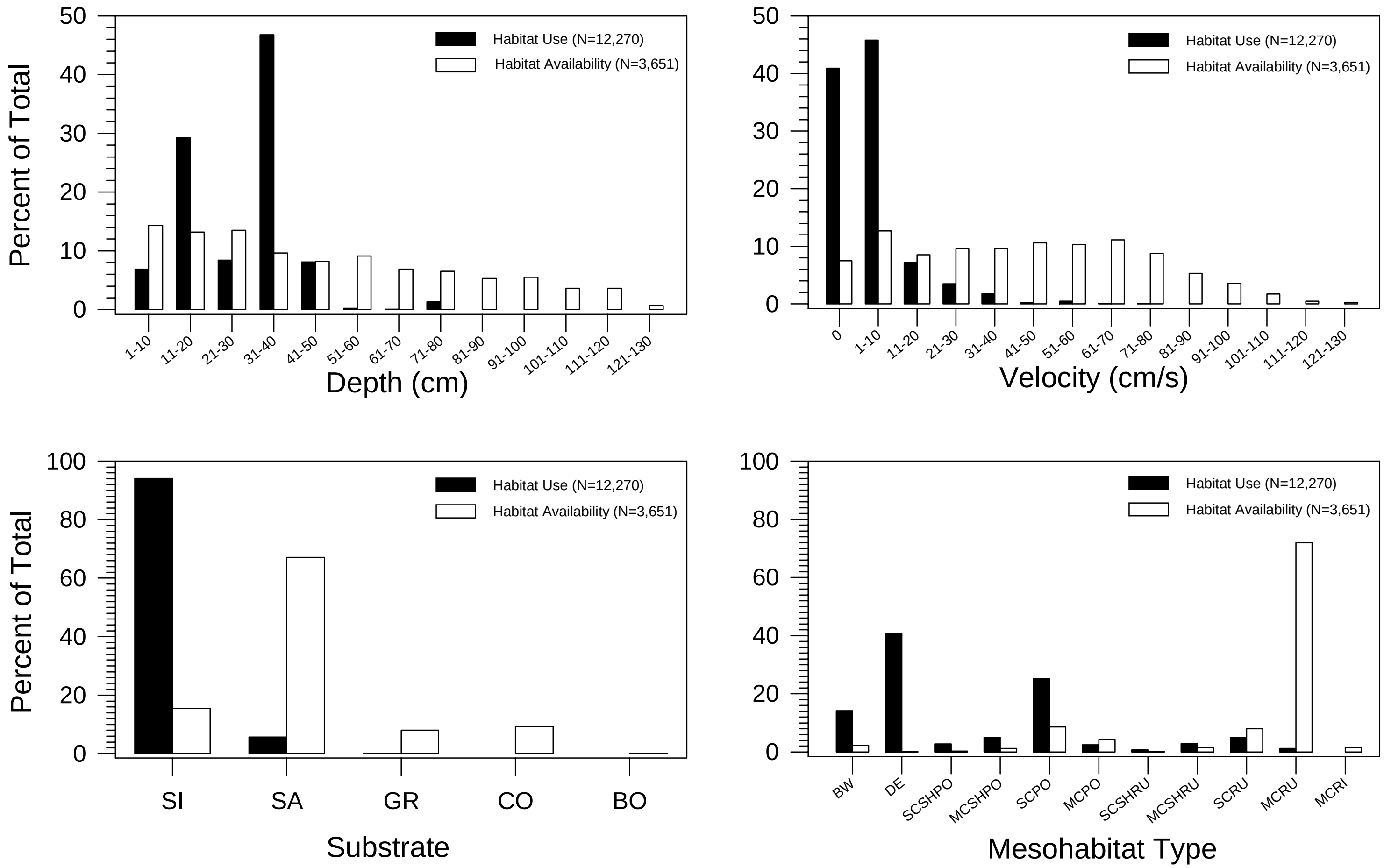


Figure 22. Comparison of mesohabitat availability and use by Rio Grande silvery minnow for both sampling localities in the Rio Grande.

associated with Rio Grande silvery minnow occurrence (8.1%), while gravel and cobble collectively accounted for <1% of the substrata over which silvery minnow were taken. Mesohabitat types selected by individual Rio Grande silvery minnow largely reflected their preference for low-velocity areas. The most frequently selected mesohabitat types were debris piles (40.5%), pools (35.9%) and backwaters (13.8%). Main channel runs were generally avoided by Rio Grande silvery minnow as only 1.3% were taken in this most abundant habitat.

Ontogenetic Comparisons

Various size-classes of Rio Grande silvery minnow exhibited notable differences in their selection of habitats (Figure 23). Depth, velocity and substrate were virtually equal in their predictive power of variation in habitat use between size-classes. Most spatial separation between size groups was apparent along the direction of the depth and velocity gradient arrows. Velocity was the strongest predictor of size-class habitat use along axis 2 (r^2=0.759) and overall. Depth was also well correlated with axis 2 (r^2=0.572). Because of the correlation between depth and velocity, it was difficult to ascertain how much of the size-class variation was attributable to each factor. The smallest size-class (11-20 mm SL) was greatly separated from the other groups in the opposite direction to depth and velocity gradient arrows indicating its use of very shallow and low-velocity habitats. The next three larger size-classes (21-30, 31-40 and 41-50 mm SL) were closely grouped in a location indicative of their increased use of greater depths and velocities compared to the smallest size-class. This shift into slightly deeper and higher velocity habitats continued as fish increased in length. The largest size-classes (71-80 and 81-90 mm SL) were at the opposite end of the gradient utilizing the fastest and deepest areas compared to smaller size classes. There was some separation of size-classes along the substrate gradient arrow and larger individuals (51-60, and 61-70 mm SL) were collected over the largest substrata. However, the range of substrata over which Rio Grande silvery minnow was found was so constrictive that the difference between the groups was minimal (i.e., smaller size-classes over silt and larger size-classes over silt and sand).

Examination of the habitats selected by each 10 mm SL size-class revealed the extent of ontogenetic shifts (Figures 24-30) and the overall trends (Figure 31). The smallest individuals (11-20 mm SL) used shallow habitats (=14.9 cm) and were never taken in water depths >30 cm. Although the range of depths used by a single size-class did not vary considerably (all used depths <50 cm), larger individuals were found in deeper areas. This shift occurred over a narrow range of depths (range=14.9 to 34.8 cm). There was an overall difference ($p<0.05$) in the depths occupied by all size-classes and three of fifteen pair-wise comparisons (mostly larger vs. smaller) were different ($p<0.05$).

The ontogenetic shift in water velocities selected by different size-classes of Rio Grande silvery minnow was not as pronounced as that for depth. The only discernable break for water-velocity size-classes was 60 mm SL. Rio Grande silvery minnow that were <60 mm SL were taken in slightly lower water velocities (range=4.01 to 4.63 cm/s) than those fish >60 mm SL (range=7.6 to 8.4 cm/s). The majority of all individuals in all size-classes were taken in water velocities < 10 cm/s. Although there was a cumulative difference ($p<0.01$) in velocities selected by size-classes, only one of fifteen pair-wise comparisons (70 mm versus 40 mm SL) was statistically different ($p<0.05$).

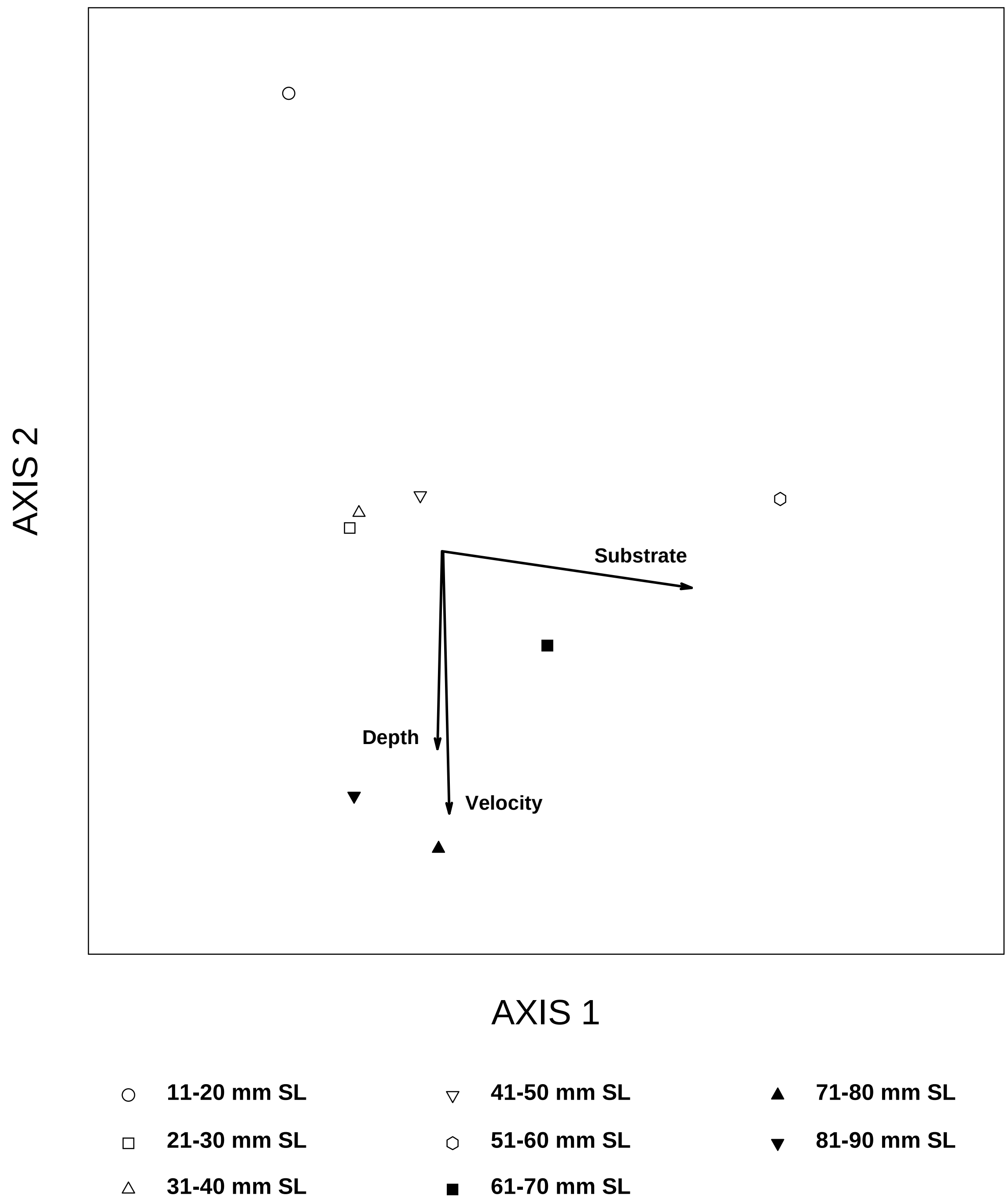


Figure 23. Canonical Correspondence Analysis diagram of habitats selected by Rio Grande silvery minnow for both sampling localities in the Rio Grande.

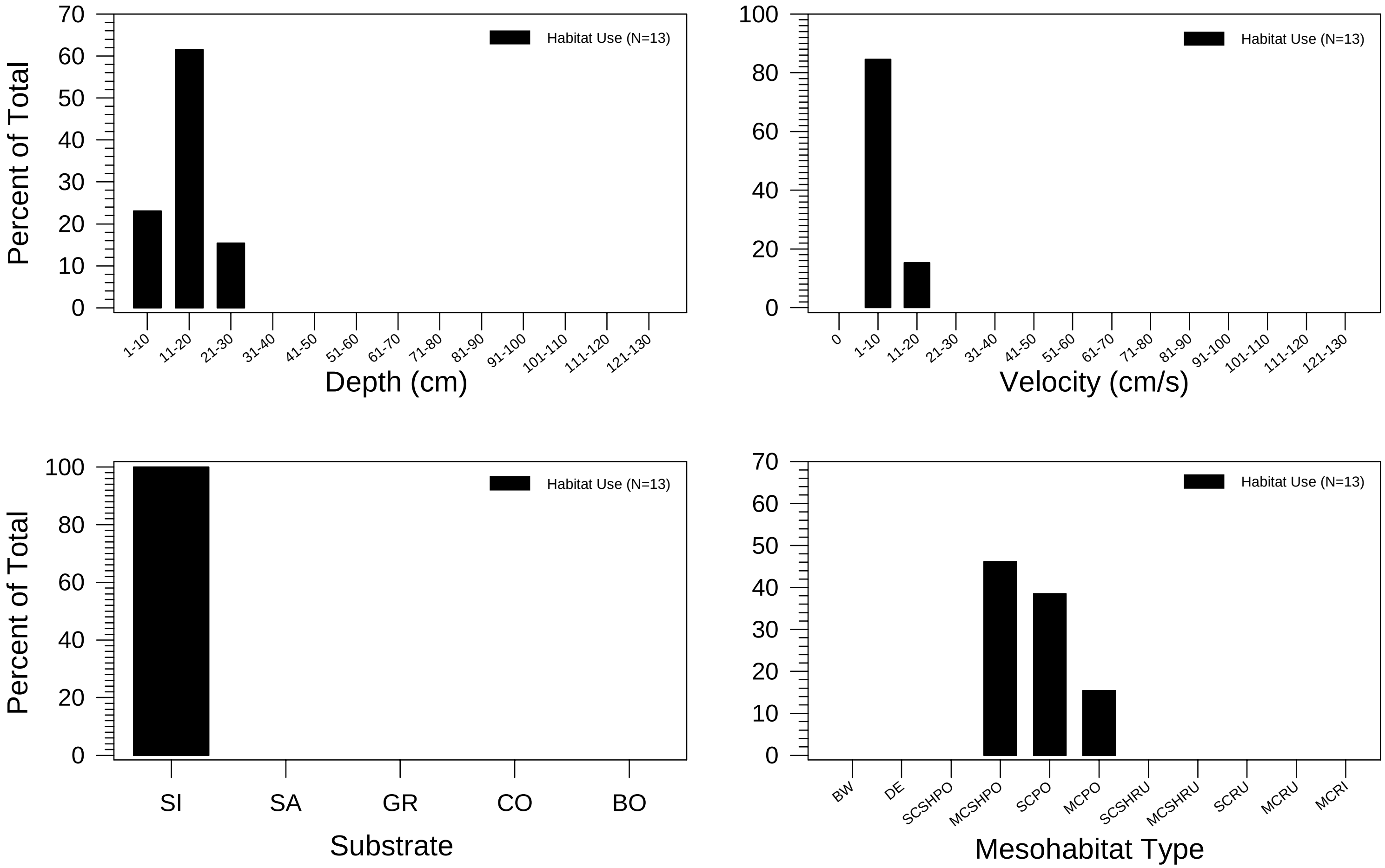


Figure 24. Habitat use by Rio Grande silvery minnow (11-20 mm SL) for both sampling localities in the Rio Grande.

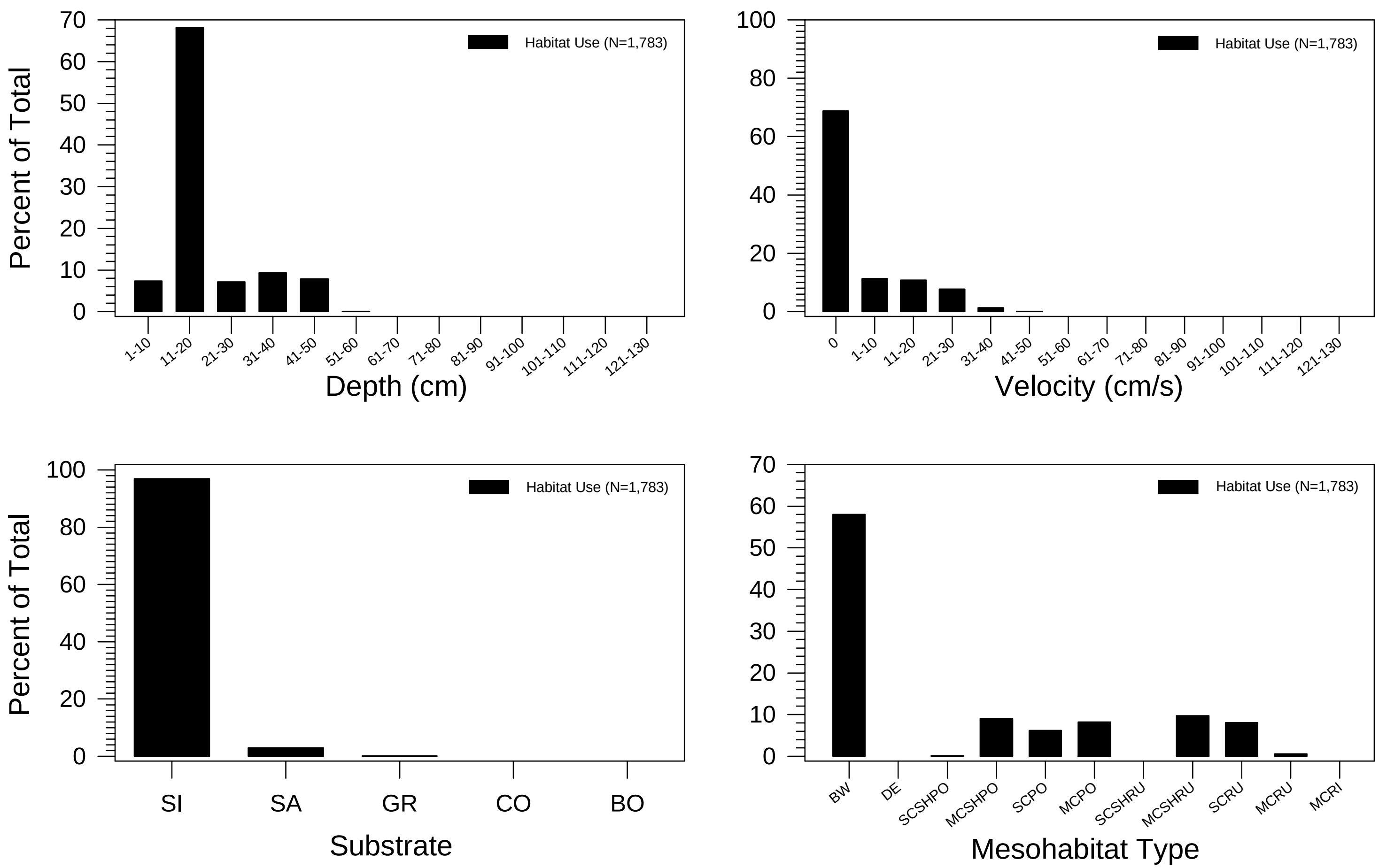


Figure 25. Habitat use by Rio Grande silvery minnow (21-30 mm SL) for both sampling localities in the Rio Grande.

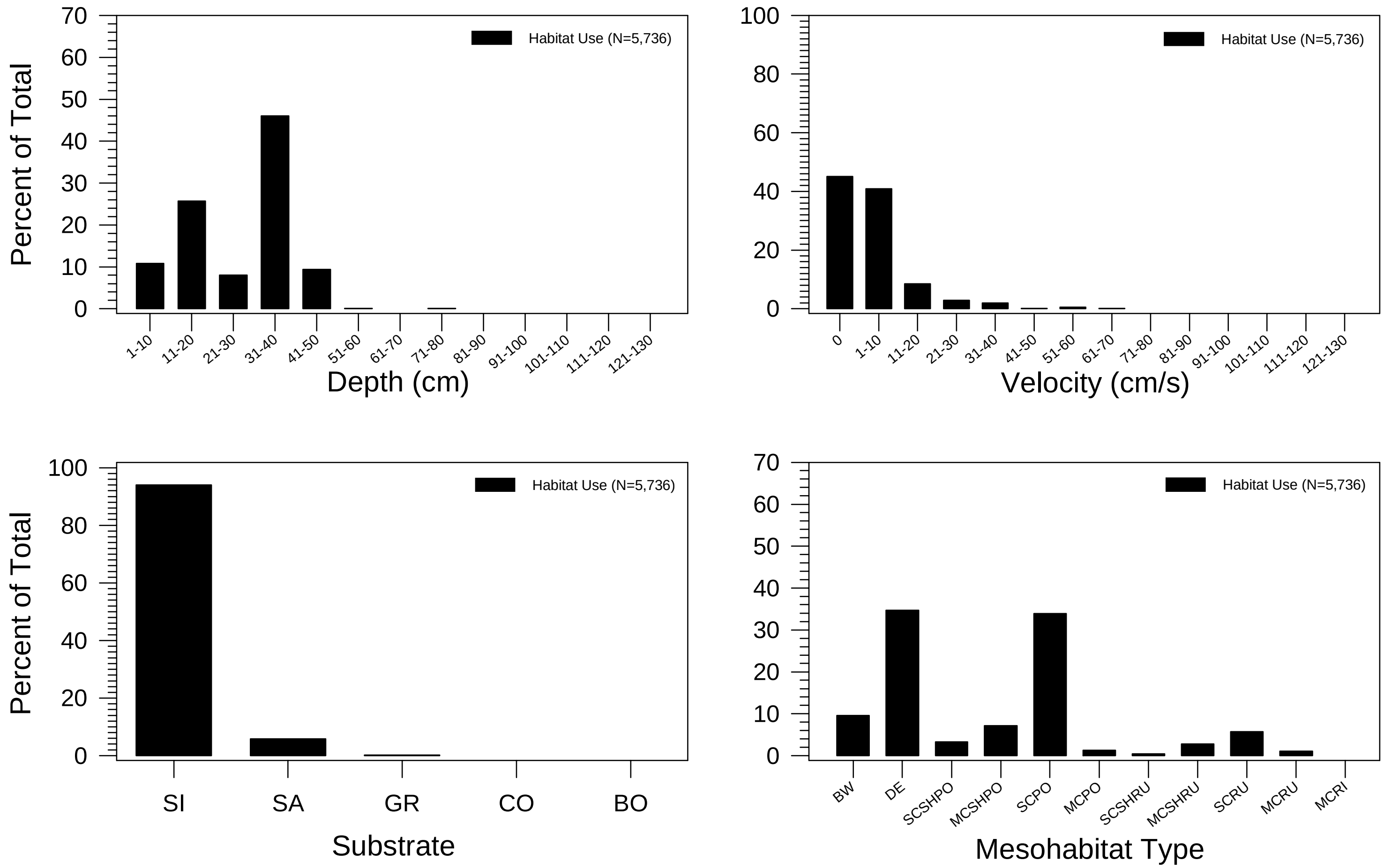


Figure 26. Habitat use by Rio Grande silvery minnow (31-40 mm SL) for both sampling localities in the Rio Grande.

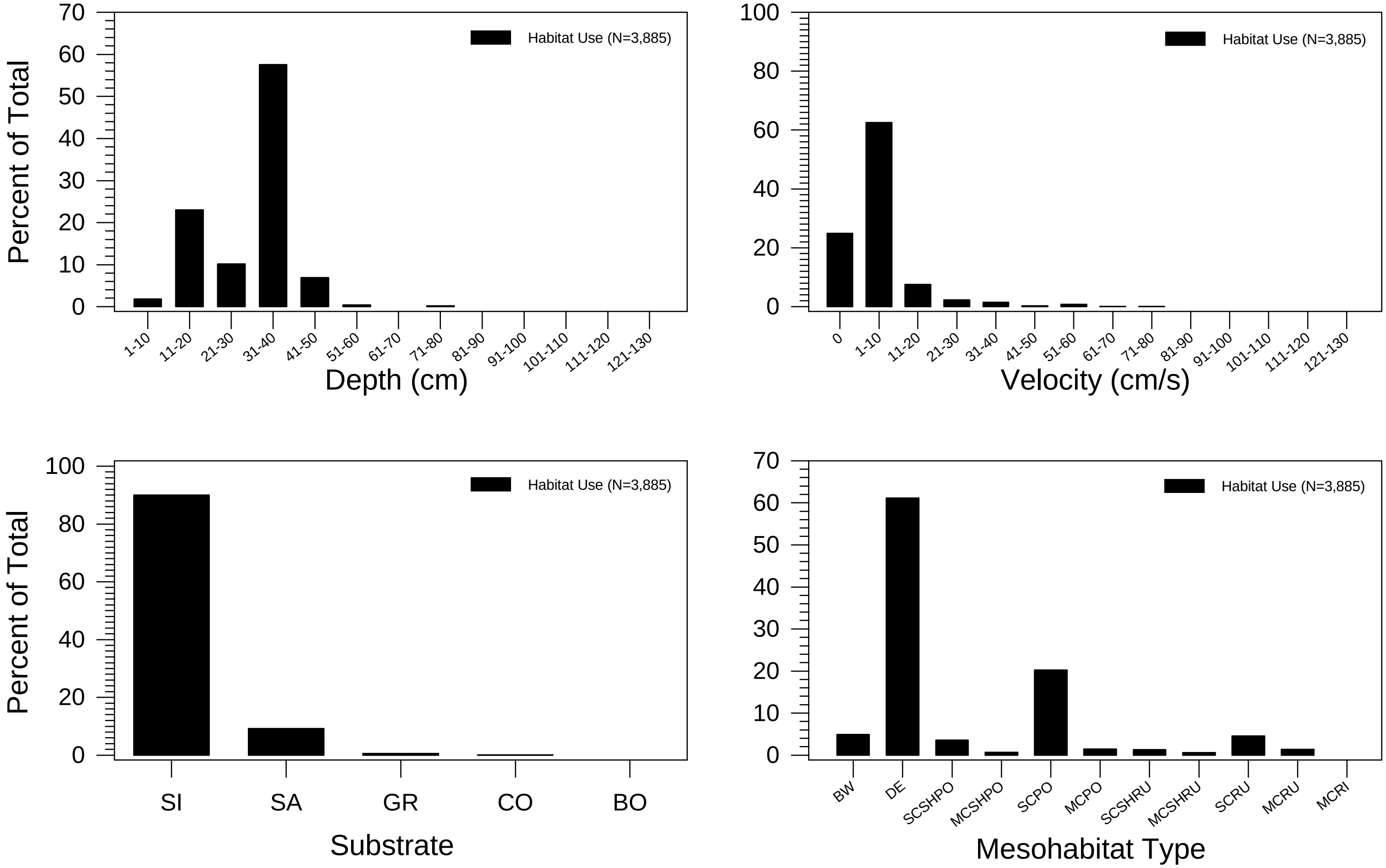


Figure 27. Habitat use by Rio Grande silvery minnow (41-50 mm SL) for both sampling localities in the Rio Grande.

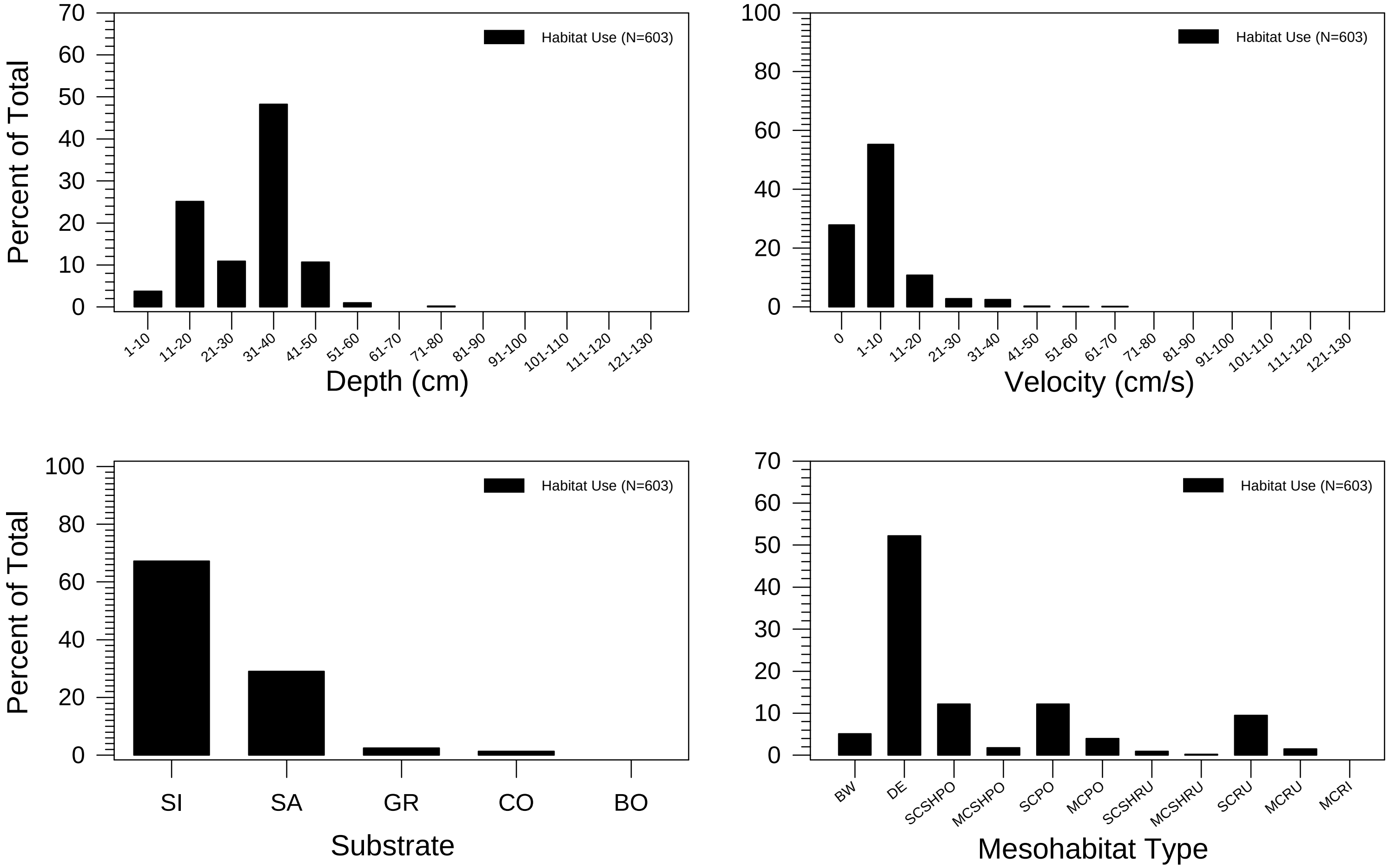


Figure 28. Habitat use by Rio Grande silvery minnow (51-60 mm SL) for both sampling localities in the Rio Grande.

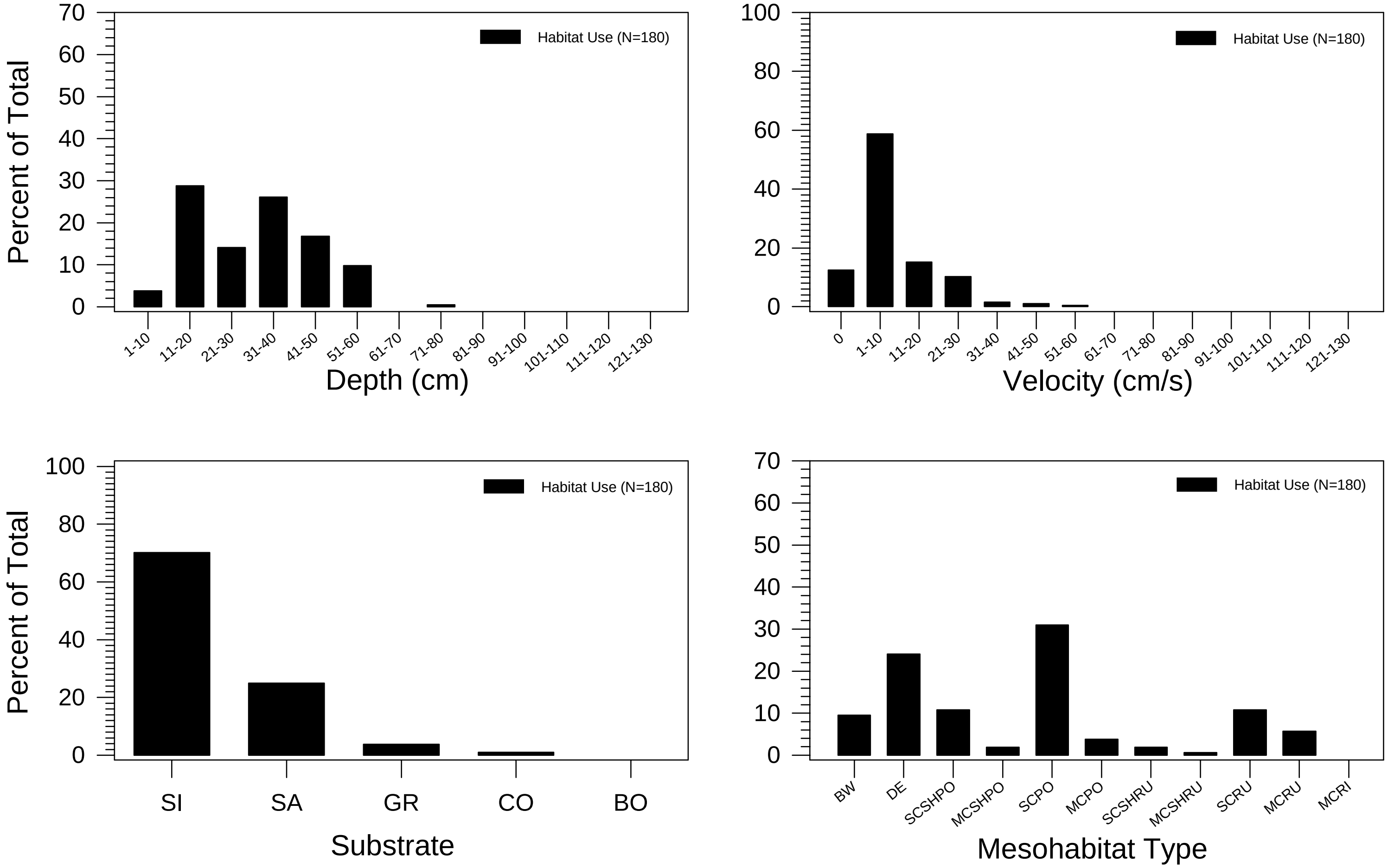


Figure 29. Habitat use by Rio Grande silvery minnow (61-70 mm SL) for both sampling localities in the Rio Grande.

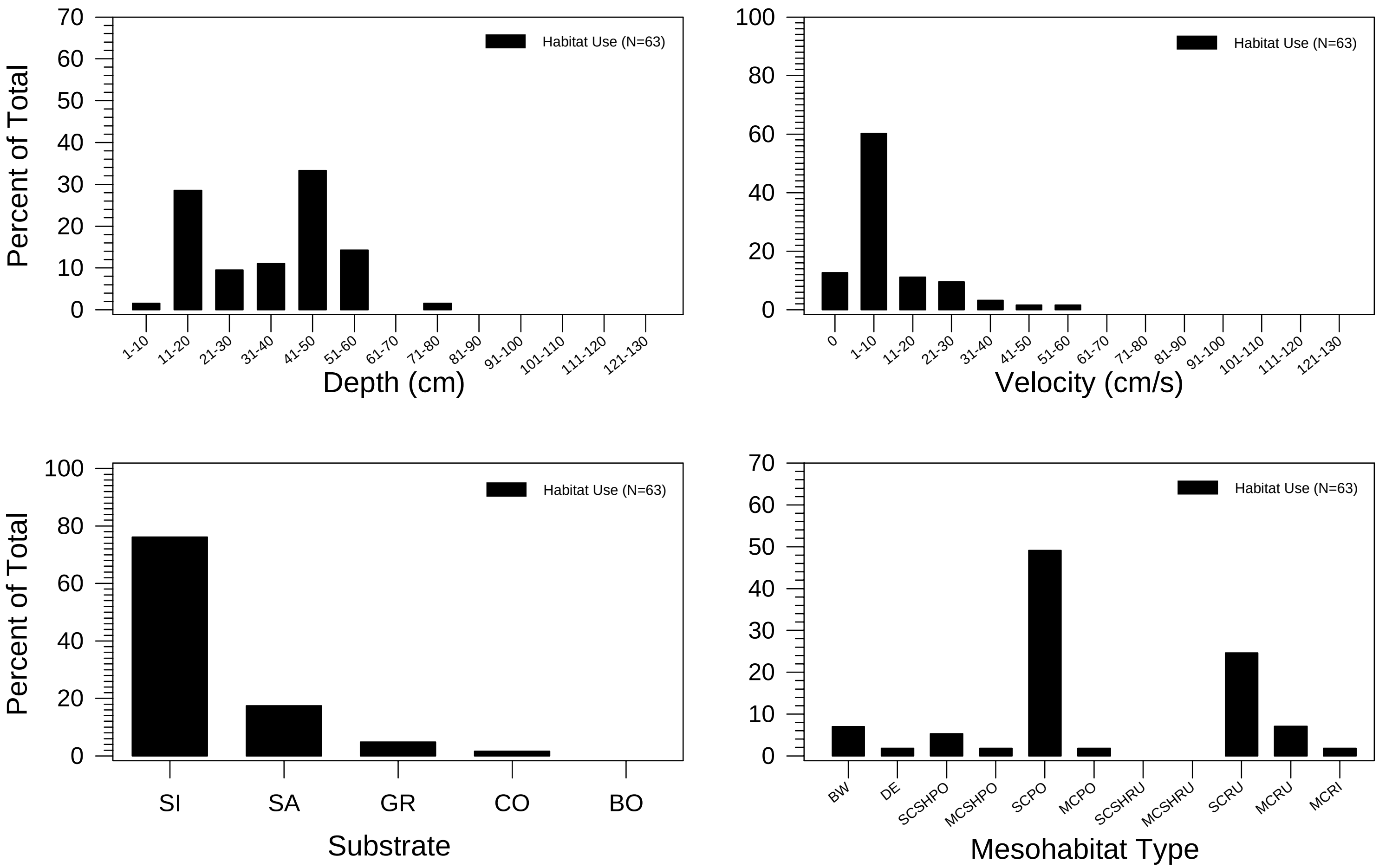


Figure 30. Habitat use by Rio Grande silvery minnow (71-80 mm SL) for both sampling localities in the Rio Grande.

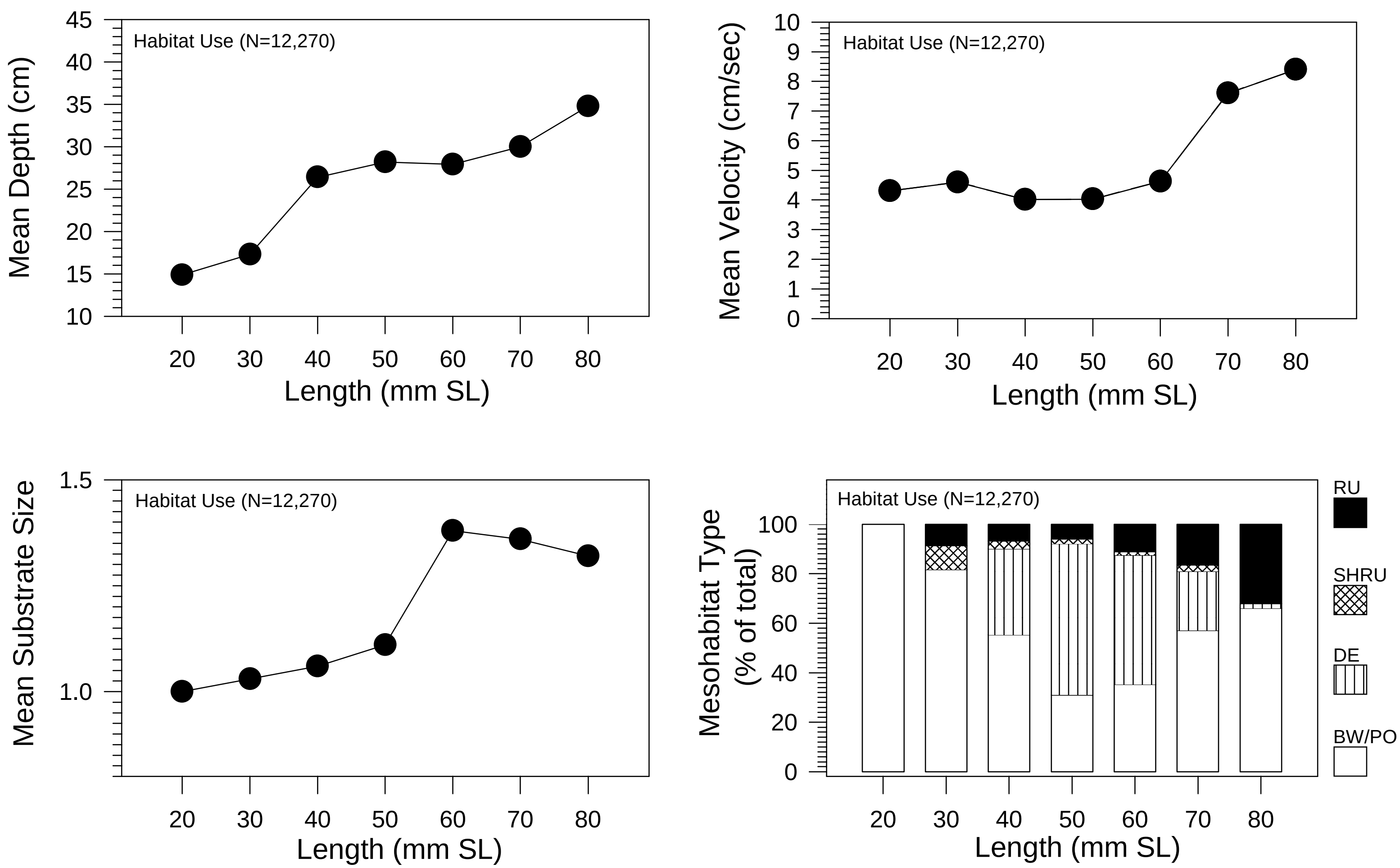


Figure 31. General trends in the ontogenetic shifts in habitat use by Rio Grande silvery minnow for both sampling localities in the Rio Grande.

The substrata over which different size-class Rio Grande silvery minnow were collected changed only moderately for larger individuals and seemed a function of the weak ontogenetic shift into slightly higher velocity habitats. The smallest size-class was found exclusively over a silt substrata. The next larger size-classes (21-30 mm SL and 31-40 mm SL) were predominantly collected over silt (96.9% and 94.0% respectively), but were occasionally located over sand or gravel. All other size-classes were taken, to varying degrees, over silt, sand, gravel and cobble. Individuals <50 mm SL primarily used habitats with silt substrata whereas individuals >50 mm SL were mostly taken over sand (i.e., slightly higher velocity habitats). No individuals were associated with boulder substrata.

The overall ontogenetic shifts in depth, velocity and substrate by Rio Grande silvery minnow was supported by mesohabitat use shifts from low to moderate velocity areas. Small size-classes were collected almost exclusively in backwaters, pools and along shoreline habitats. Larger individuals were found in a broader spectrum of habitats which included areas of current such as main and side channel runs. The decline, as Rio Grande silvery minnow grew, in the percent of individuals that occupied lower velocity habitats (debris piles and shoreline habitats) suggested their movement to higher-velocity habitats. Despite notable shifts in mesohabitat use, the majority of all size-classes were found in low-velocity habitats. Moderate sized fish (30-70 mm SL) were found to occupy debris piles (this was primarily a winter phenomena).

Site Comparisons

Rio Grande silvery minnow utilized similar habitats at the Rio Rancho and Socorro sites (Figures 32 and 33) despite significant differences in habitat availability between sites. Three-dimensional graphs display the landscape of depth-velocity relationships for habitat use and availability by site (Figures 34 and 35). The range of depths occupied by individuals was the same at both sites (<70 cm). There was a bimodal distribution of depth use at Socorro (peaks at 11-20 cm and 31-40 cm) and a unimodal "mesa" distribution of depth use at Rio Rancho (21-40 cm). It was uncommon at either site to collect fish in depths <10 or in depths >50 cm. The majority of individuals taken at both sites selected low-velocity areas (<10 cm/s). Some individuals at both sites (mostly larger size-classes) occupied areas of moderate current (>10 cm/s), although this was observed more frequently at Rio Rancho than Socorro. Few individuals from either site selected higher water velocity (>40 cm/s) areas.

When differences in the size distributions of Rio Grande silvery minnow between Rio Rancho and Socorro were accounted for (using size as a covariate in ANCOVA), there were no overall differences ($p<0.05$) in the depths or velocities selected. This was despite considerable differences in habitat availability between sites. The substrata over which individuals were collected seemed correlated with its relative availability. There was an increased presence of gravel and cobble substrata at Rio Rancho, even in low-moderate velocity habitats, and fish were associated with these substrata more than at Socorro. At both sites, Rio Grande silvery minnow selected silt substrata more than would be predicted from its availability.

There were few between site differences in mesohabitat type selected by Rio Grande silvery minnow. Individuals were most abundant in low-velocity mesohabitats (debris piles, backwaters and pools) and rarest in high velocity habitats (runs and riffles). While there were some shifts between sites in the exact mesohabitat occupied (i.e., side channel versus main

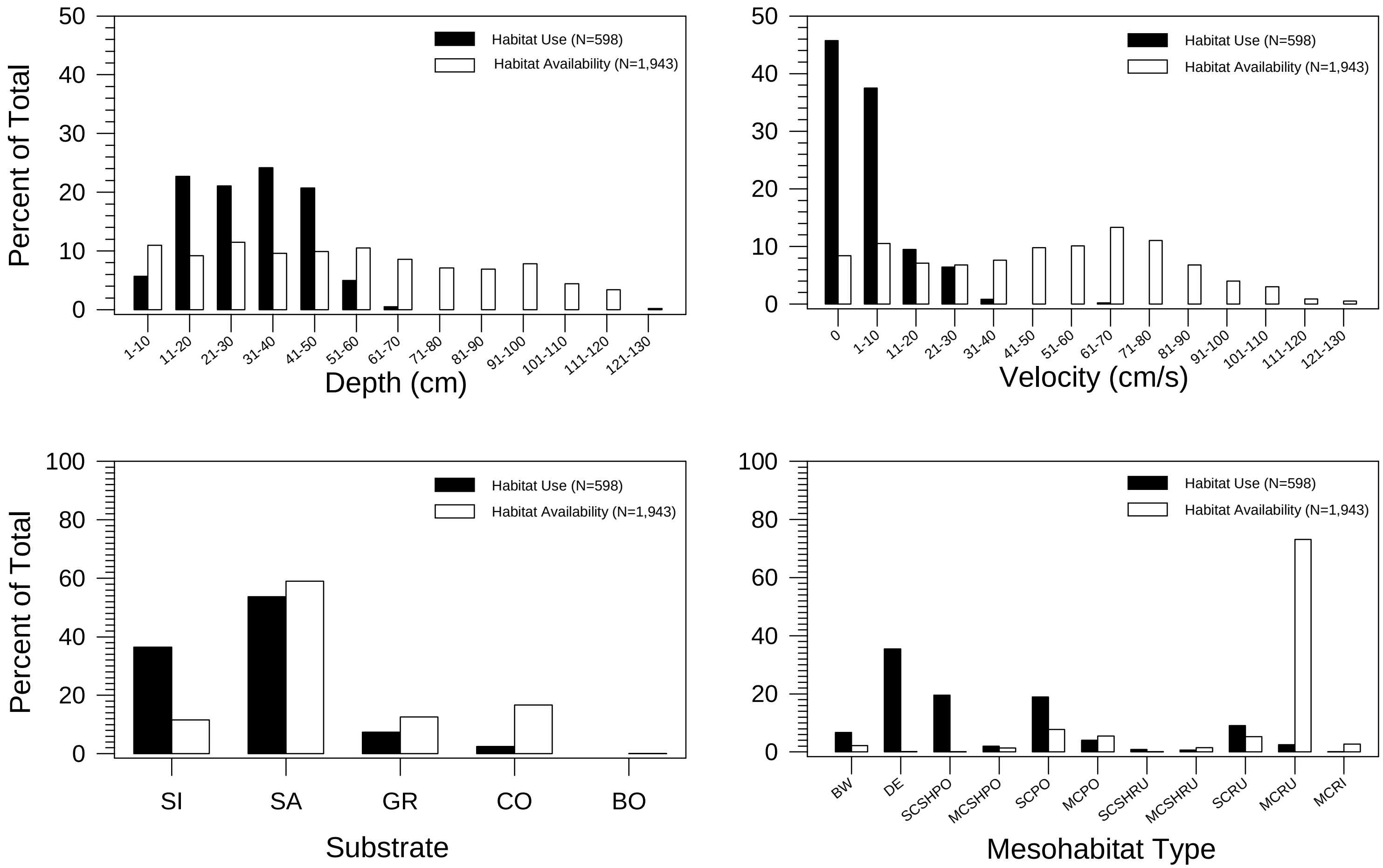


Figure 32. Comparison of mesohabitat availability and use by Rio Grande silvery minnow at the Rio Rancho sampling locality in the Rio Grande.

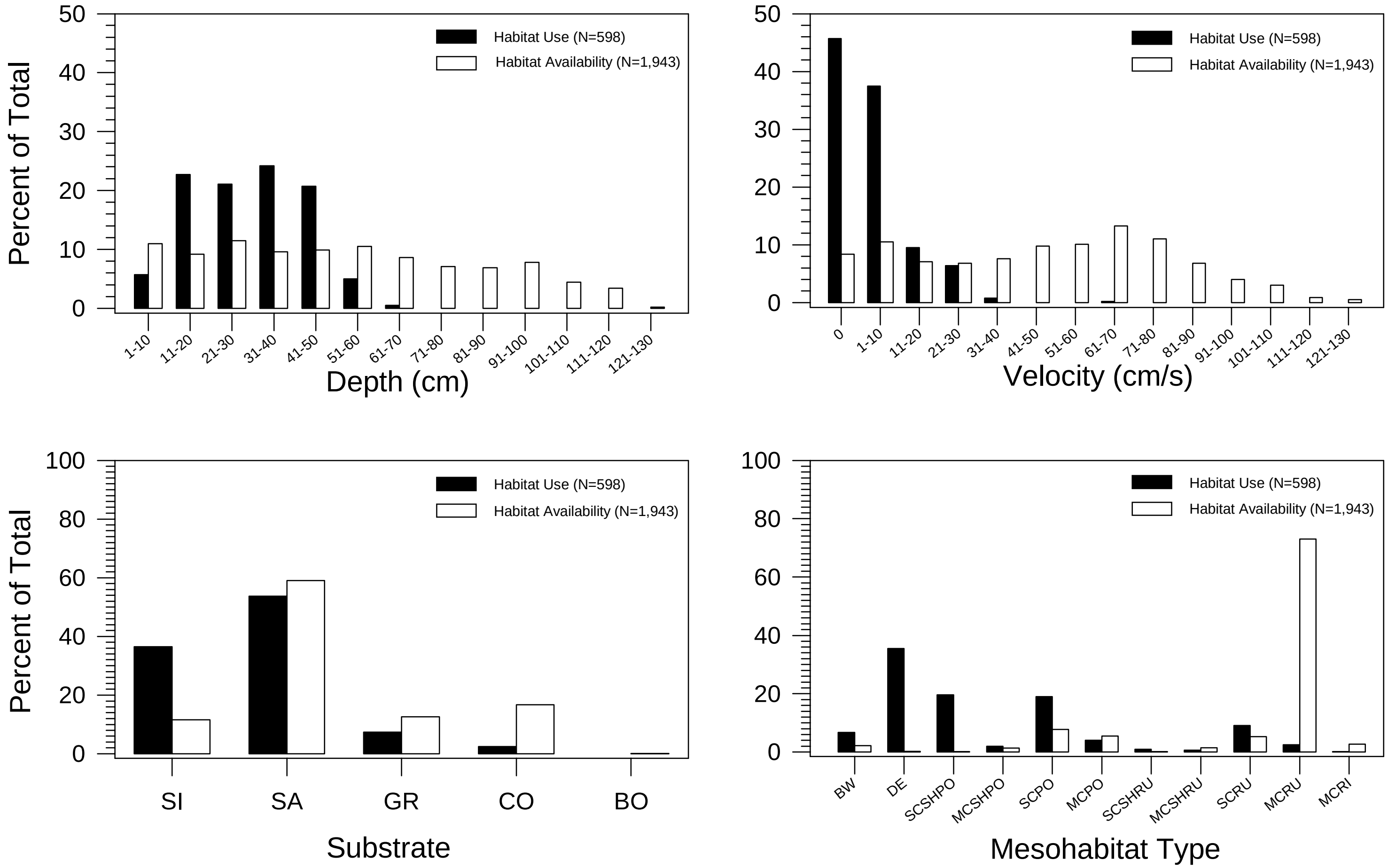


Figure 33. Comparison of mesohabitat availability and use by Rio Grande silvery minnow at the Socorro sampling locality in the Rio Grande.

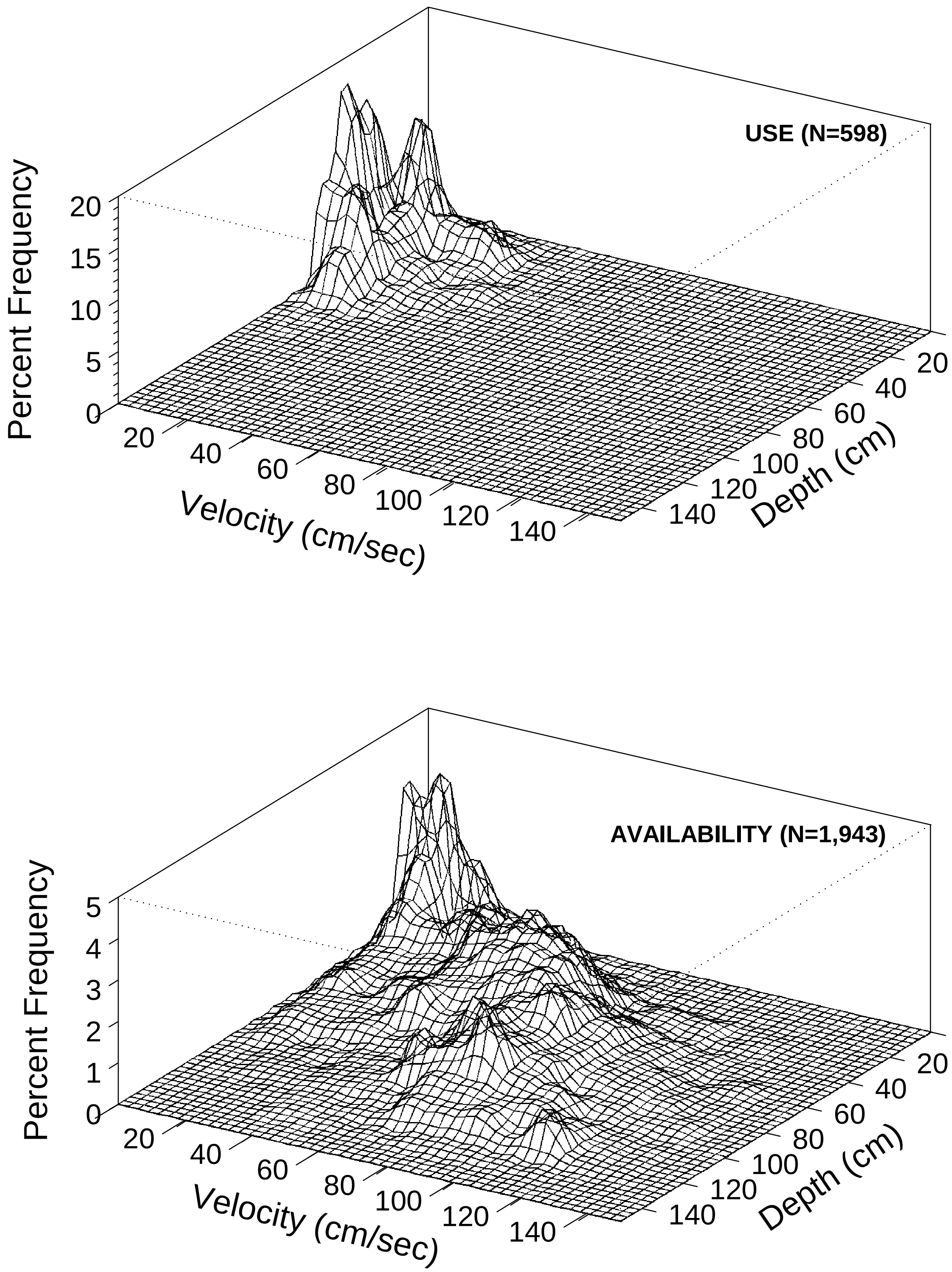
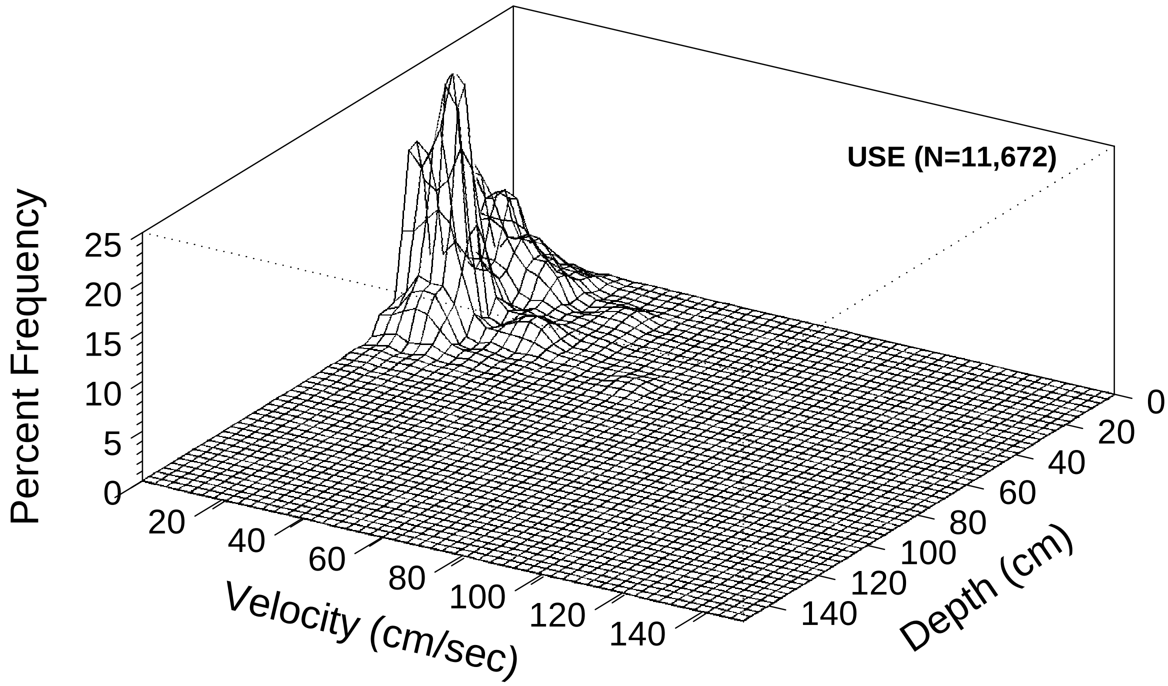


Figure 34. Comparison of depth-velocity availability and use by Rio Grande silvery minnow at the Rio Rancho sampling locality in the Rio Grande.



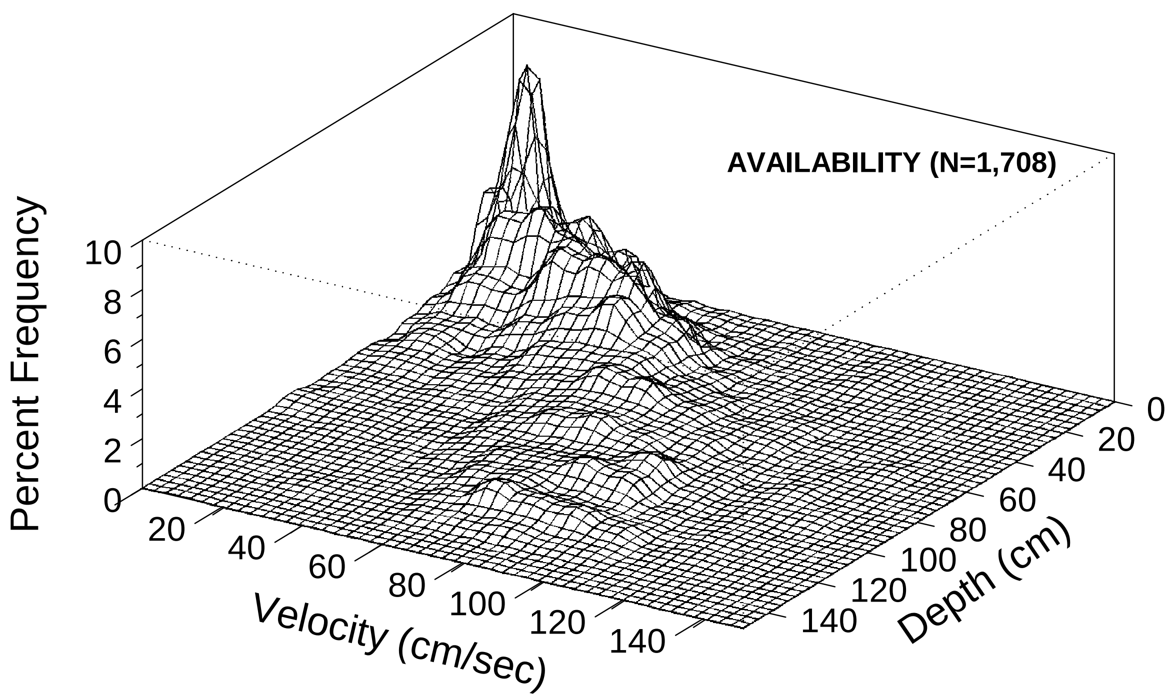


Figure 35. Comparison of depth-velocity availability and use by Rio Grande silvery minnow at the Socorro sampling locality in the Rio Grande.

channel or shoreline versus open water) the overall trend in habitat selection was virtually unchanged.

Analysis of habitats used by specific size-classes revealed similar ontogenetic shifts at both sites (Figures 36 and 37). Substrate and velocity were strong predictors of size-class spatial separation. At Rio Rancho, velocity was strongly correlated with both axes (r^2=0.746 [axis 1] and r^2=0.495 [axis 2]) and substrate was correlated with axis 2 (r^2=0.687). Depth was not predictive along either axis (r^2=0.146 [axis 1] and r^2=0.039 [axis 2]). At Socorro, all three environmental variables were well correlated with axis 2. Depth was a stronger predictor of size-specific habitat use variation at Socorro than Rio Rancho. The main separation of size-classes at Rio Rancho was between smaller fish (<60 mm SL) and larger fish (>60 mm SL) along the velocity gradient arrow. There was some partitioning between size-classes by substrate, but no clear patterns emerged and most separation seemed due to minor differences (i.e., found over silt versus sand). The main divisions of size-classes at Socorro were between smallest (<20 mm SL), moderate (21-70 mm SL), and largest (71-80 mm SL) size-classes. The smallest size-class was separated primarily along the depth gradient arrow (indicating preference of shallow areas). In addition, there was strong separation of this size-class along the substrate and velocity gradient arrows indicating preference for low velocities and small substrata. The largest size-class segregated from the average size-class along the velocity variable which suggests preference for higher velocity habitats.

Seasonal Comparisons

Habitats selected by Rio Grande silvery minnow differed between winter and summer (Figure 38). Rio Grande silvery minnow were collected in significantly deeper waters in the winter than summer ($p<0.01$). Median depth occupied by Rio Grande silvery minnow shifted from 11-20 cm during summer to 31-40 cm in winter. Although individuals used deeper waters in winter, these areas were generally typified by lower water velocities. A higher percentage of the total catch of Rio Grande silvery minnow utilized lower water velocities (<10 cm/s) in winter than summer. Despite this redistribution of fishes within stream habitats between seasons, the range of water velocities occupied by Rio Grande silvery minnow was similar in summer (0-70 cm/s) and winter (0-80 cm/s). Individuals were found almost exclusively over silt and sand substrata in winter and summer. All substrate classes were utilized to some degree in the summer and winter with the exception of boulders. The percent of individuals found in higher velocity mesohabitats (main and side channel runs) was higher in summer than winter. There also was a dramatic shift of individuals from pool and backwater habitats in summer to habitats with instream debris piles in winter. The majority of individuals collected in the winter were in or adjacent to instream debris: debris accounted for 0.1% of the available habitats.

Similar shifts in seasonal habitat use were noted even when the data set were parsed by site (Figures 39 and 40). In winter, individuals at both Socorro and Rio Rancho were more commonly located in deeper and lower velocities water and mesohabitats than in summer. There was a movement to debris in winter at both sites. There were seasonal differences in the substrate over which Rio Grande silvery minnow were located at Rio Rancho but not at Socorro. At Rio Rancho in winter, individuals were more common over sand and less common over silt, gravel and cobble than in summer. At Socorro, individuals were found over silt, sand and gravel in almost equal proportions during both seasons.

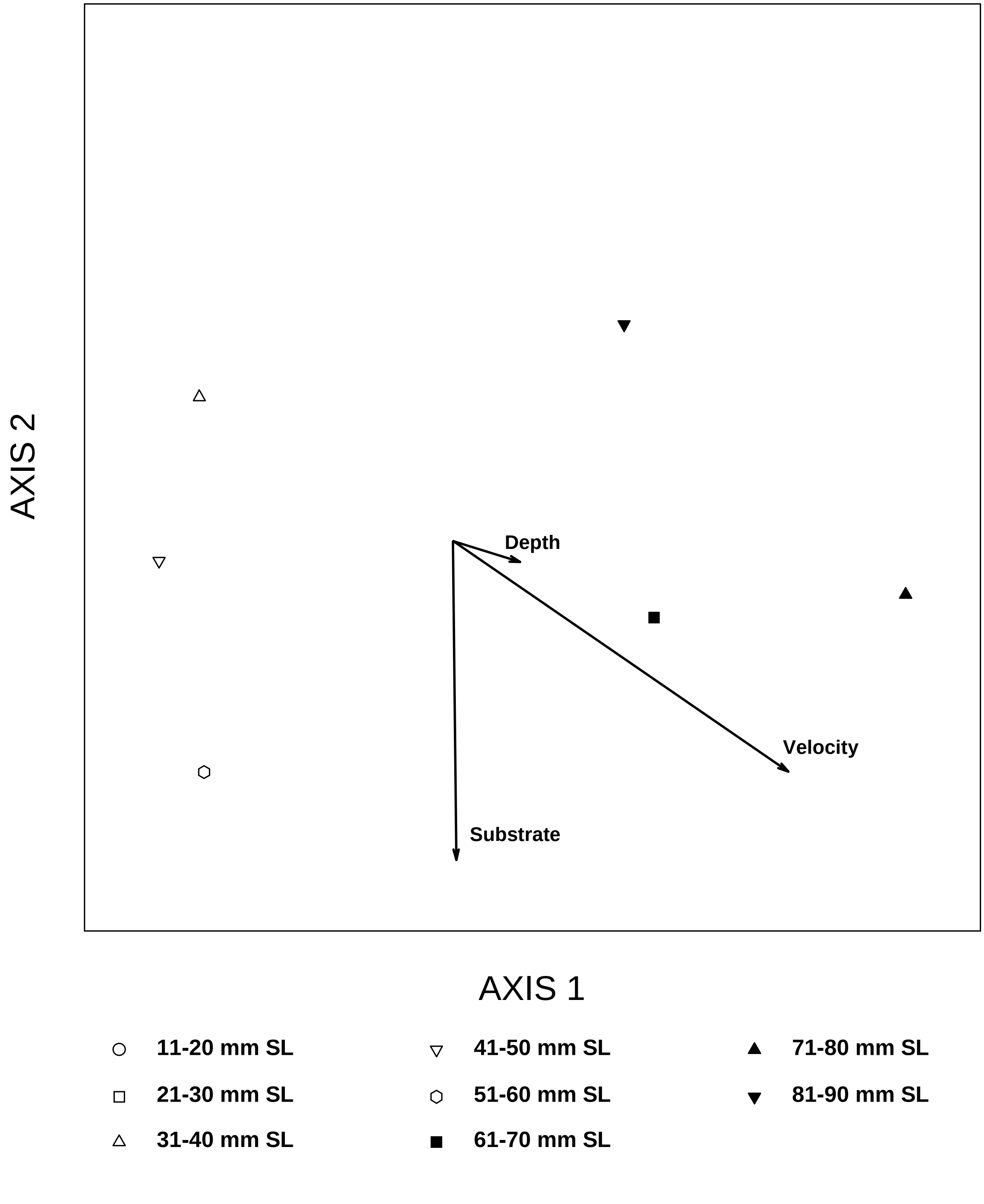


Figure 36. Canonical Correspondence Analysis diagram of habitats selected by Rio Grande silvery minnow at the Rio Rancho sampling locality in the Rio Grande.

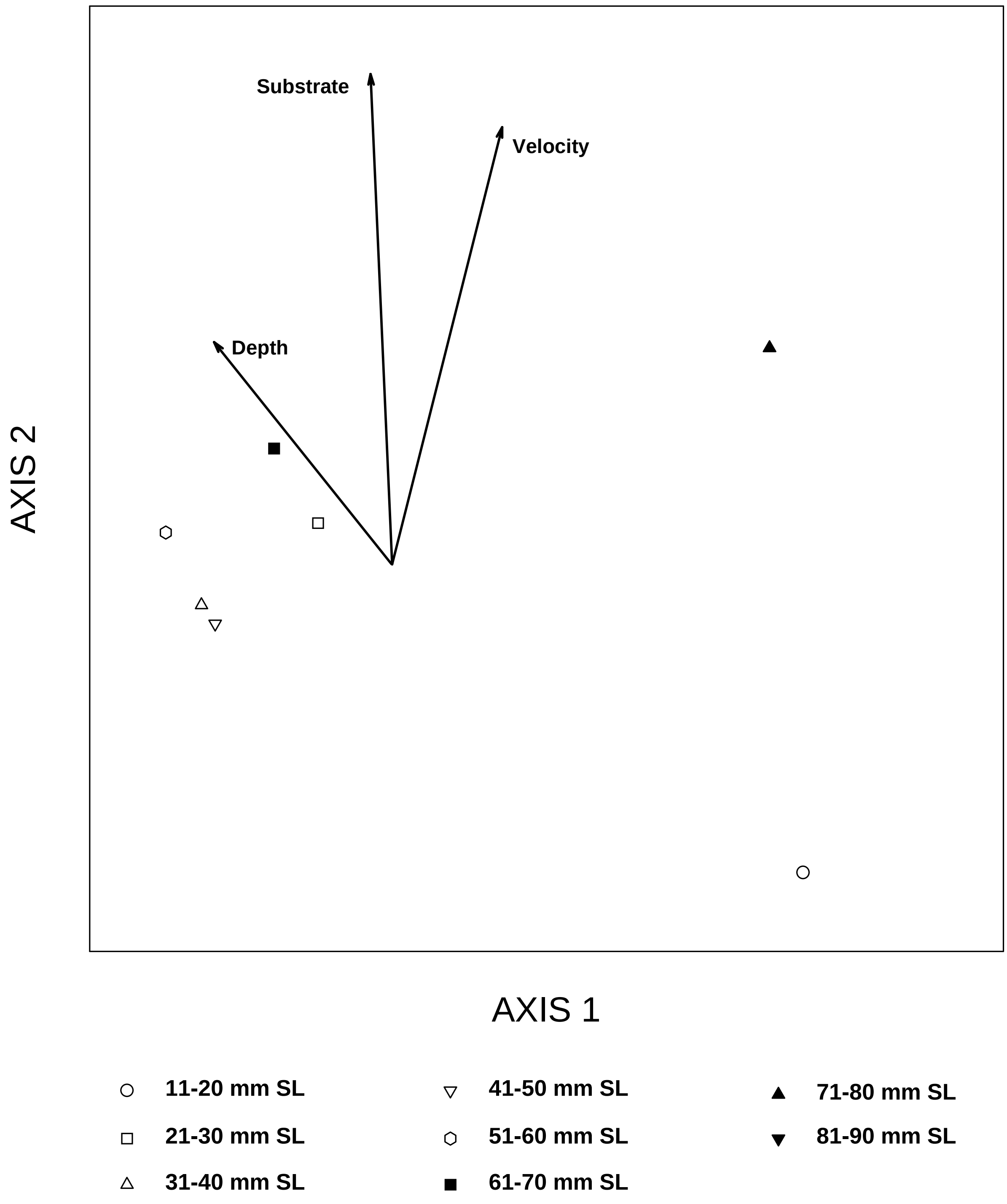


Figure 37. Canonical Correspondence Analysis diagram of habitats selected by Rio Grande silvery minnow at the Socorro sampling locality in the Rio Grande.

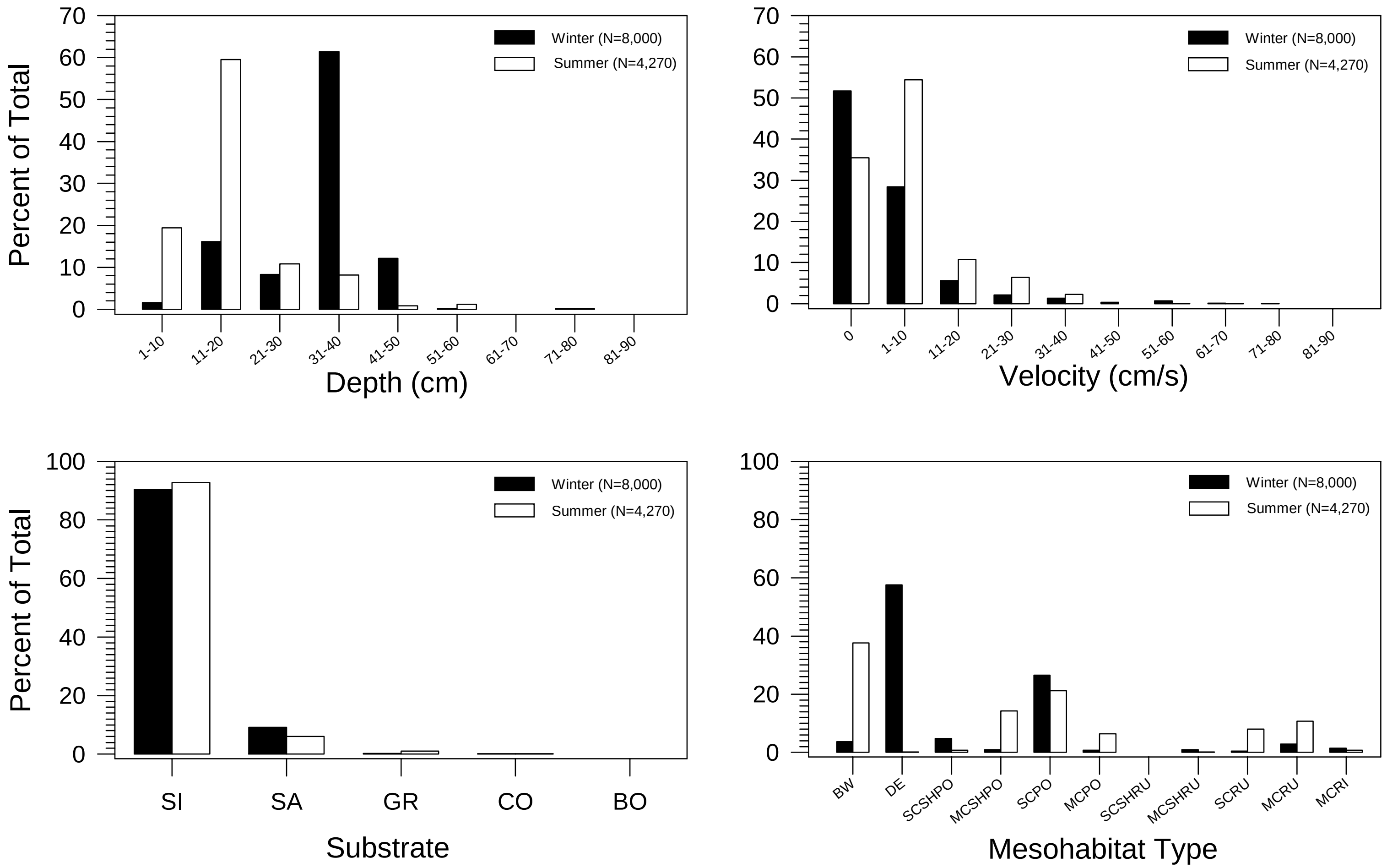


Figure 38. Comparison of mesohabitat use by Rio Grande silvery minnow broken down by season for both sampling localities in the Rio Grande.

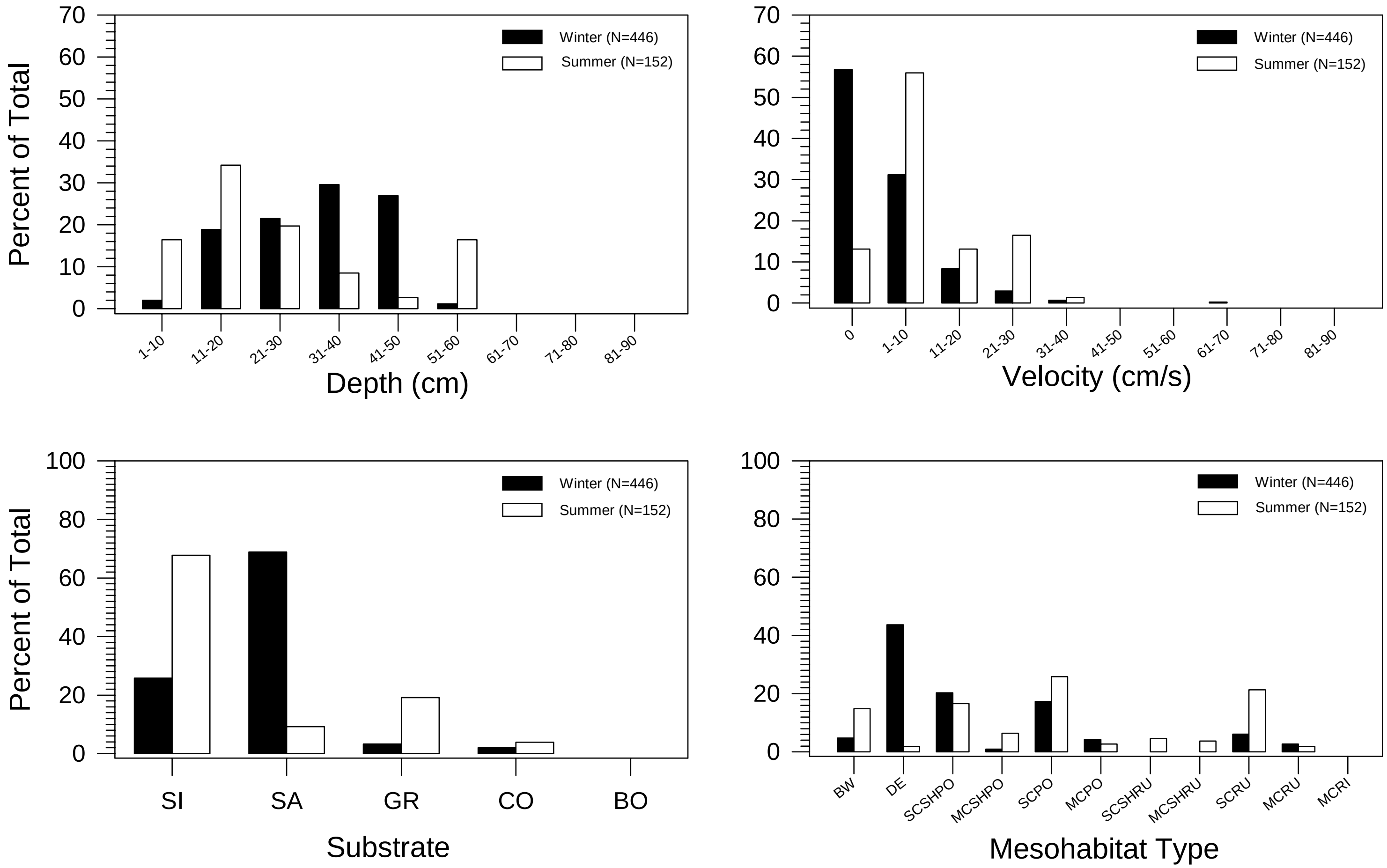


Figure 39. Comparison of mesohabitat use by Rio Grande silvery minnow broken down by season at the Rio Rancho sampling locality in the Rio Grande.

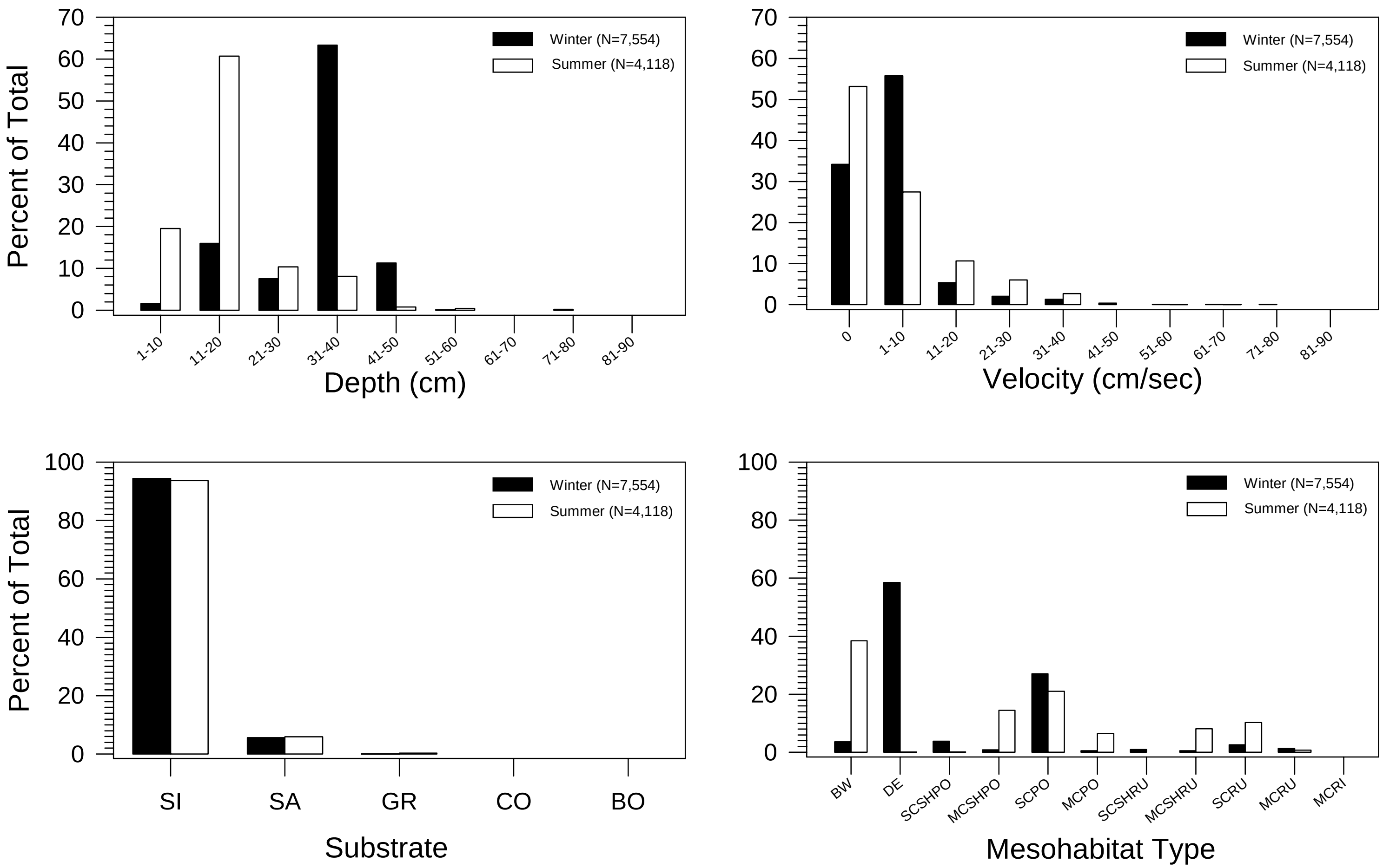


Figure 40. Comparison of mesohabitat use by Rio Grande silvery minnow broken down by season at the Socorro sampling locality in the Rio Grande.

There were size-specific habitat use differences between winter (Figure 41) and summer (Figure 42). All three habitat variables (depth, velocity and substrate) were strong predictors of size-specific differences in habitat use for both seasons (r^2>0.5). In winter, substrate strongly correlated with the first axis (r^2=0.836) while depth and velocity correlated with axis 2 (r^2=0.739 and r^2=0.688 respectively). In summer, the variables were also well correlated with at least one axis. The trend in ontogenetic shifts in habitat use was the same for both seasons. There was also a broad seasonal separation between size-classes in the direction of the velocity and depth gradient arrows. However, there was more separation of sizes along the substrate gradient arrow in the summer than winter. Most differences along the substrate gradient arrow were due to moderate-sized individuals (41-70 mm SL) occupying areas over slightly larger substrata (sand and occasionally gravel).

DISCUSSION

Understanding the current distribution and abundance of Rio Grande silvery minnow requires the integration of ecological data on this taxon with hydrologic information from the study reach. While the chronology of post-1900 water development in the Middle Rio Grande had been relatively well documented, it was only recently that sufficient information was accumulated on the distribution, abundance, and life history of Rio Grande silvery minnow to allow the production of a cogent theory. The synthesis of Rio Grande silvery minnow life history information and the hydrologic history of the region provided the background necessary for more thorough understanding of current patterns of fish habitat use.

Rio Grande silvery minnow is a member of a guild of fishes that evolved reproductive and early life history strategies for living in aquatic ecosystems in arid lands of the Great Plains region of the west-central United States. Rio Grande silvery minnow is a small (100 mm TL), short-lived and herbivorous fish that grows rapidly during its first year with few individuals surviving to age-2. Spawning occurs during spring runoff (May-June), with the reproducing population being numerically dominated by age-1 fish and with few age-2 individuals (<5%).

Rio Grande silvery minnow is a pelagic spawner that produces from hundreds to several thousand semi-buoyant, nonadhesive eggs during a spawning event. Members of this reproductive guild appear to spawn in microhabitats with moderate to high velocities thereby allowing their eggs to remain suspended in the water column during development. Increases in flow, typical of spring runoff or summer rainstorms, is the principal spawning stimulus (Platania and Altenbach, in press). Numerous individuals congregate during spawning and these events may continue over several days or weeks.

Development and hatching of Rio Grande silvery minnow eggs are correlated with water temperature. Egg hatching-time decreased with increasing temperature and hatching generally occurred in 24-48 hours. Recently-hatched larval Rio Grande silvery minnow remained part of the drift by swimming vertically (swim-up stage) in the water column. About three days after hatching, development of the gas bladder was completed, their yolk-sac was absorbed, and protolarvae began feeding. These physiological developments corresponded with a shift in

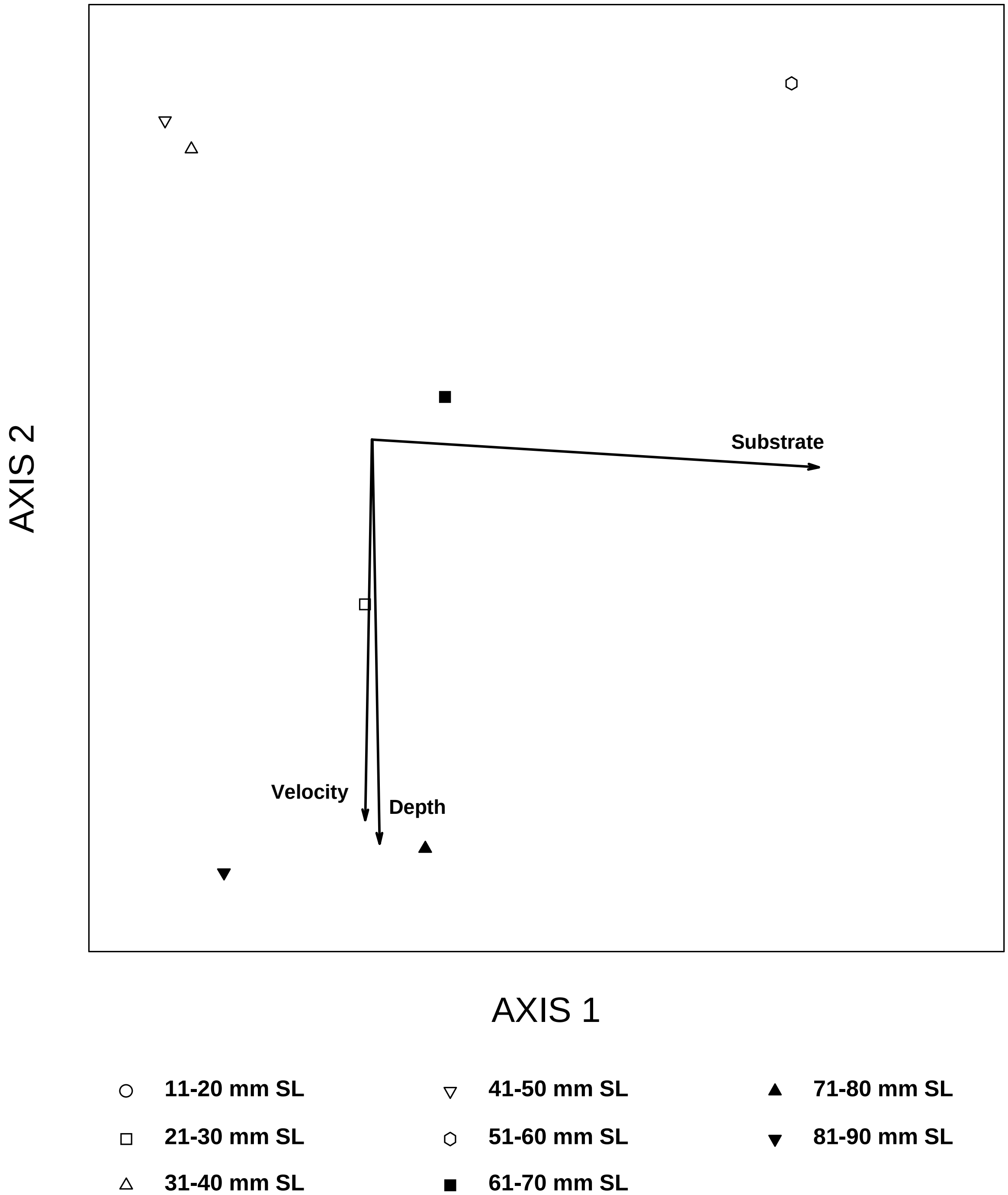


Figure 41. Canonical Correspondence Analysis diagram of habitats selected by Rio Grande silvery minnow during winter (October-March) for both sampling localities in the Rio Grande.

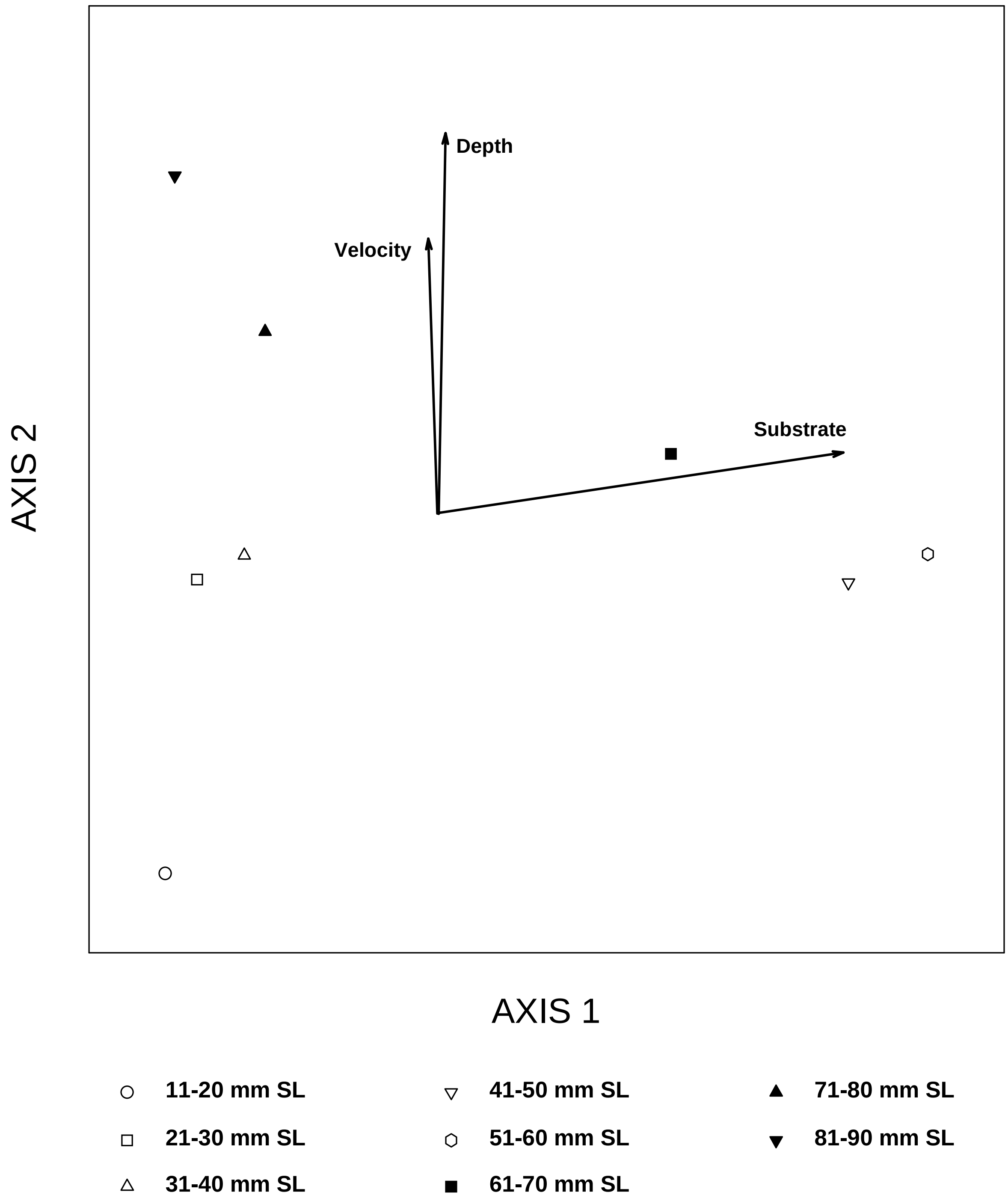


Figure 42. Canonical Correspondence Analysis diagram of habitats selected by Rio Grande silvery minnow during summer (April-September) for both sampling localities in the Rio Grande.

swimming behavior as protolarvae ended their swim-up period, moved horizontally, and appeared to actively seek low-velocity habitats.

Shallow, low-velocity habitats are characterized by high water temperatures and elevated levels of primary productivity. This combination of warm water temperatures and abundant food likely result in accelerated growth of larval fish. The elapsed time that an egg and early protolarvae remained a component of drift, was about five days. The rapid development and hatching of eggs are likely strategies necessary for survival of fish in plains or desert ecosystems.

The downstream transport of eggs and larvae was, historically, likely beneficial to Rio Grande silvery minnow populations. This phenomena was a mechanism to recolonize downstream reaches impacted during periods of natural drought. The tendency of fish and other aquatic organisms to move upstream toward more permanent sources of water potentially would concentrate reduced populations and allow for staging prior to annual runoff events. Increased temperature and flow would stimulate spawning, resulting in redistribution of eggs and larvae throughout recently de-watered or impacted reaches. However, a crucial component of that scenario is the ability of fish to move upstream to reaches of sustained flow.

There have been at least five mainstream impoundments or diversions that affected the aquatic ecosystem in the study area. Between 1925 and 1935, the MRGCD (Middle Rio Grande Conservancy District) constructed Cochiti and Angostura Diversion Dams whose main purpose was to pool water for diversion into irrigation canals (MRGCD, 1980). The first large-scale water project in the region was the completion of Jemez Canyon Dam in 1954. The next large project was Abiquiu Dam, which was completed in 1963 and impounded the Chama River, the largest Middle Rio Grande tributary. The final and most important project on the Middle Rio Grande was the construction of Cochiti Dam (1965-1973) which was built at the site of the former Cochiti Diversion Dam.

There are currently three structures between Cochiti Dam and Elephant Butte Reservoir that are barriers to upstream movement of fishes (Angostura Diversion Dam, Isleta Diversion Dam, and San Acacia Diversion Dam). These diversion dams effectively divide the Middle Rio Grande of New Mexico into four discrete reaches: Cochiti to Angostura, 35.5 km; Angostura to Isleta, 65.2 km; Isleta to San Acacia, 85.5 km; and San Acacia to Elephant Butte Reservoir, 90.4 km.

Mainstream impoundments are barriers to longitudinal movement of aquatic biota, modify physical habitat and morphology of the river and result in alteration of the shape of the historic annual flow regime (Zwick, 1992; Martinez et al., 1994; Stanford et al., 1996). Manipulating flows with dams has been employed throughout the American Southwest (e.g., Colorado River Basin) in an attempt to improve the status of imperiled aquatic organisms. In the absence of the immense amount of empirical information necessary to accurately predict flow needed for species and ecosystem recovery, one strategy is to attempt to mimic the natural (historic) flow regime. Changes in the abundance or distribution of a species following the return to a more natural flow regime may not be immediate as there are additional factors (e.g., barriers to upstream movement, physicochemical conditions and nonnative species) that often impede recovery to pre-impoundment population levels.

The extent of the impacts of man-induced habitat alterations within the Rio Grande could not be determined until habitat use and requirements of its fishes were better understood. Currently, the amount and availability of aquatic habitats in the Middle Rio Grande is an indirect artifact of the laws that govern water distribution, use, and river management practices. The principal goals of river management and maintenance are to prevent flooding, ensure the efficient transport of water, and protect the 1450+ km of irrigation canals. A detailed review of the evolution of these laws and history of hydrology in the Middle Rio Grande was provided by Bullard and Wells (1992).

The construction of the main channel and tributary dams in the Middle Rio Grande Valley have modified the historic flow pattern. Highest pre-dam discharge in the Middle Rio Grande occurred from April through August. There was also considerable seasonal variation in the annual historic flow regime.

Flooding downstream of Cochiti Dam was virtually eliminated by regulation of spring flow (Bullard and Wells, 1992). Summer flooding from intense thunderstorm spates has also generally been eliminated from the mainstem of the Rio Grande. This includes large discharges that formerly were important channel shaping and sediment transporting events. Variable flows were needed to create and maintain habitats under historic conditions. In reaches of the river where the channel was relatively wide, high flow reconnected secondary channels and pools and resulted in an increase in the number or size of low-velocity habitats. Areas where the river overbanked during high water provided habitats protected from current. While localized flooding still occurs in the rios Puerco and Salado and other smaller tributaries, Bullard and Wells (1992) stated that dams on the Rio Grande and its tributaries have dampened this broad variation in discharge.

Concerns about the effects of alterations to historic hydrologic patterns (i.e., reduction in low-velocity mesohabitats) to the ichthyofaunal community of Middle Rio Grande are supported by information on their early life history and subsequent ontogenetic shifts in habitat use. Rio Grande silvery minnow (eggs and drifting protolarvae) are likely transported downstream from one reach to another but are unable to return upstream past these barriers. The downstream transport rate of reproductive products has probably increased since constriction of the river channel of the Rio Grande by construction of levees. Additionally, water velocity is at its maximum rate during the putative spawning period of Rio Grande silvery minnow. Given the reproductive ecology of Rio Grande silvery minnow (spawning behavior, egg type, and early life history traits), it is not surprising that this species is least common in the uppermost section and most common in the lowermost reach of its current range. Rio Grande silvery minnow has on occasion been very abundant in several reaches of the Middle Rio Grande during the last 10 years, indicating that environmental and habitat conditions were at times suitable to its survival. The mesohabitats utilized by most Rio Grande YOY fishes, including Rio Grande silvery minnow, were relatively shallow areas of low or no water velocity over fine particulate substrata. The preference for a narrow range of physical habitat conditions by these early life stages meant that large numbers of individuals of multiple species were congregated into small areas within the river. These conditions most commonly occur in backwaters and secondary channel pools that were not directly associated with the main river channel. The only main channel habitats that had shallow and slow-velocity water were along the shoreline in areas where stream edges were not eroded. Low-velocity mesohabitats often had water temperatures that were higher than those in areas having current, especially in summer. Warmer water temperatures and corresponding increased primary productivity appear to increase the survival and growth rate of larval fishes. A potential population bottleneck for Rio Grande silvery minnow appears to be the survival of larval fish through summer and autumn into their first winter. It is during this period that individuals either grow to an adequate size to survive the reduced water temperatures and aquatic productivity of winter or perish.

Ontogenetic shifts in habitat use by Rio Grande silvery minnow occurred over a relatively narrow range of habitat conditions, but did lead to spacial separation of size-classes. Most of the variation between developmental stages was due to segregation of individuals into different depths and velocities. The smallest size-class (11-20 mm SL) was comprised of larval individuals that were widely separated from all other stages because of their exclusive use of very shallow and low-velocity habitats. Larval Rio Grande silvery minnow were only found in pools over a silt bottom. Individuals between 21-60 mm SL, classified as juveniles, occupied habitats with moderate depths and velocities. While the 51-60 mm SL size-class was found over sand, gravel and cobble more frequently than other juveniles, this difference is probably attributable to its occasional occupation of habitats with increased water velocities (e.g., runs). Increased water velocities seemed to correlate directly to the presence of larger substrates at both sites, but especially at Rio Rancho where larger substrata (i.e., gravel and cobble) was more common. The three largest size-classes (61-70, 71-80 and 81-90 mm SL) were spatially separated from smaller individuals because they were more frequently found in moderately deeper and faster water. The mesohabitats selected by larger individuals were primarily in backwaters and pools, but included main and side channel runs.

General trends in habitats occupied by Rio Grande silvery minnow through their various life-stages did not vary notably between sampling localities. The smallest individuals were spatially separated from larger individuals primarily along the velocity gradient in CCA analysis. The smallest size-class (11-20 mm SL) was only collected at the Socorro sampling locality and was strongly separated from all other size-classes along the depth and velocity gradients. The separation in CCA space between other size-classes (21-70 mm SL) at Socorro was probably minimized by the notably different habitats occupied by the smallest and largest (71-80 mm SL) size-classes. This contrasts to Rio Rancho where moderate differences in habitat use between size-classes were more easily visualized in CCA space because of the lack of outliers (i.e., size-classes which occupied very low or moderately high water velocities).

Ontogenetic shifts in habitat use occur in many species of fish and are often accompanied by or are a result of changes in diet (Mol, 1995; Putman et al., 1995; Wainwright, 1996). Morphological changes, such as increased mouth size and larger jaw muscles, directly affect which foods are consumed most efficiently and is a cost-benefit trade-off (Mol, 1995; Wainwright, 1996). Rio Grande silvery minnow are known to consume plankton during their larval stages and switch to a herbivorous diet as they mature. It is probable that certain prey items are more abundant in certain mesohabitats. It is also possible that while very shallow and low water velocity areas may provide the best growing conditions for all size-classes of Rio Grande silvery minnow, only the smallest size-classes can readily access these areas.

Habitats selected by fishes are a trade-off between abiotic, biotic, and behavioral constraints and continually change with their reproductive and morphological development (Leveque, 1995). Interspecific interactions can largely dictate the habitats occupied by smaller individuals. Shallow and low-velocity mesohabitats may provide larval Rio Grande silvery with protection from larger predators that cannot easily access these areas in addition to favorable conditions for growth.

Seasonal shifts in habitat use by fishes are well documented in lotic systems (Facey and Grossman, 1992; Rincon and Loboncervia, 1993; Cunjak, 1996). The habitat selection and behavior of fishes during winter is largely dictated by energetic constraints and avoidance of deleterious physico-chemical conditions (Riehle and Griffith, 1993; Baras, 1995; Cunjak, 1996). There are negative bioenergetic consequences to fishes if they maintain their position in the water column during winter because of decreases in metabolic benefits and decreases in swimming ability (Facey and Grossman, 1990; Facey and Grossman, 1992; Rincon and Loboncervia, 1993). Daily activity budgets have also been significantly correlated to water temperature and may be a mechanism to maintain thermal homeostasis over the seasons (Baras, 1995). Fish often seek areas of cover during winter because of the reduced water velocities and protection afforded by these areas. This is a critical factor, especially in winter when fish are relatively inactive and rarely feed, as the costs of maintaining position in the water column are greatly reduced in lower water velocities.

Rio Grande silvery minnow and the rest of the ichthyofaunal community shifted their habitat use between summer and winter. Most changes in habitat use corresponded with the seasonal decrease in water temperatures. Water temperatures began to decline in autumn or winter and did not increase until late spring or summer. The most notable trend in seasonal habitat associations at both sampling localities was the fish community selection of habitats with instream debris in winter. There was also a shift of individuals out of areas with current (main and side channel runs). Rio Grande silvery minnow was found less frequently in areas with water velocities >10 cm/sec in winter than in summer. Water velocities within debris piles were notably less than those immediately outside of these structures. For example, a debris pile might be present within a main channel run, but have very low water velocities within its protected boundaries. Debris piles were often located along eroded shoreline habitats where moderate depths were encountered. The shift of individuals in winter into deeper water may largely be the consequence of the location of debris piles within the stream channel.

Rio Grande silvery minnow size-classes were segregated in their habitat utilization primarily along the depth and velocity axes in winter and summer. In winter, most individuals were found in low-velocity habitats. The lack of segregation along the substrate gradient between size-classes in winter was probably due to the increased presence of Rio Grande silvery minnow of all size-classes in low-velocity habitats with a silt substrata. Size-classes were separated along all environmental gradients in summer indicative of their broader range of habitat use in warmer water.

Elevated winter water releases can displace instream debris and result in a decreased abundance of low-velocity habitats. During periods of high flow, areas with debris were one of the few available and suitable low-velocity habitats. Fish were abundant in instream debris piles despite the extreme rarity of this mesohabitat. In a study commissioned by the Army Corps of Engineers to examine the winter mesohabitat of Rio Grande silvery minnow, Dudley and Platania (1996) found that over 70% of individuals selected debris piles.

The primary between-site difference in habitat use was of increased species spatial separation (CCA graphs) at Socorro compared to Rio Rancho. This trend was particularly true for native species which were clumped along the highly predictive velocity and substrate gradients at Rio Rancho, but were segregated along all physical habitat gradients at Socorro. The occupation of riffle mesohabitats with very high water velocities and large substrata by longnose dace resulted in this being the only species at Rio Rancho that was widely separated in CCA space from other community members. With the exception of longnose dace, the majority of the fish community occupied habitats similar to those selected by Rio Grande silvery minnow. The extreme difference between longnose dace and the group of other species probably, in part, minimized the CCA spatial differences in habitat use within the group. In contrast, the few longnose dace collected at Socorro occupied only moderately-high velocity habitats because riffle mesohabitats were not available. Thus, the CCA spatial separation between longnose dace and the rest of the fish community at Socorro was much less than at Rio Rancho. Even when longnose dace was excluded from the analysis of between site differences in habitat use, species were more segregated at Socorro than at Rio Rancho.

Increased species segregation at Socorro was most likely due to differences in habitat availability between sites. The Rio Rancho site was typified by a greater proportion of high velocity mesohabitats with large substrates than were found at the Socorro site. Socorro had an increased abundance of moderate to low-velocity mesohabitats (e.g., side channels) and shallow areas. These trends held even during periods of high flow (e.g., spring run-off in 1994 and 1995) and the dramatic decline in flow at Socorro during the spring-summer (April-June) of 1996. The increased availability and diversity of lower velocity mesohabitats at Socorro may have allowed species habitat use preferences to be more clearly illustrated. Species-specific differences in habitat use at Socorro were also evidenced by the broader array of mesohabitats and larger stream area from which fish taken. This was in contrast to Rio Rancho where almost all species were clumped together along the margins of the river or in other rarely available low-velocity mesohabitats.

The differences in available habitats between sites may have resulted in the variable composition and abundance of the fish communities at Rio Rancho and Socorro. Although species present at both sites were almost the same, the number of individuals per species varied greatly. Nonnative fishes comprised a much greater proportion of the ichthyofaunal community at Rio Rancho (45%) than at Socorro (2%). Most of this difference was due to increased abundance of percid game fish and white sucker at Rio Rancho. It is possible that warmer water temperatures or the dearth of appropriate spawning habitats prevented the proliferation of these nonnative species at Socorro. Longnose dace and flathead chub, which prefer higher velocity mesohabitats and cooler water temperatures, were more abundant at Rio Rancho than at Socorro. The habitat selected by same-sized Rio Grande silvery minnow was similar at Socorro and Rio Rancho. The differences that were apparent between sampling localities, such as substrate use, were probably due to confounding factors such as season. Several large collections of Rio Grande silvery minnow were made at Socorro in winter and this appears to have slightly skewed the overall habitat use patterns (i.e., more individuals in debris piles and over silt substrata). When accounting for differences in size-class composition and seasonal abundance, the habitats occupied by Rio Grande silvery minnow were nearly identical between sampling localities. This was despite differences in the composition of the fish community and the relative availability of mesohabitats between sites. The strong selection by Rio Grande silvery minnow for certain mesohabitats may influence their localized distribution within the stream channel more than abiotic or biotic differences between sampling localities.

Analysis of depth-velocity use (i.e., the depth and velocity at points where fish were collected) revealed that individuals utilized a broader range of water velocities at shallower depths than they did in deeper areas. While Rio Grande silvery minnow occupied a broad range of depths (e.g., deep or shallow pools and backwaters), deep areas with moderate water velocities were generally avoided. Velocity appeared to be a more important factor dictating the location of this species than depth.

Species morphology is a strong predictor of habitat use patterns (Douglas and Matthews, 1992; Wood and Bain, 1995). The similar overall morphology (compressed body form and short pectoral fins) and behavior (non-benthic) of many Rio Grande species, including Rio Grande silvery minnow, may explain why they were often collected in comparable low-velocity mesohabitats. In contrast, the physiological (reduced swim bladder), morphological (depressed body shape and extended pectoral fins), and behavioral characteristics of the longnose dace allowed it to occupy high velocity mesohabitats without expending much energy (Gee, 1968). Longnose dace occupied interstitial spaces of large substrata where water velocity is less than the mean of the water column. Even in experimental flow chambers with no substrata, longnose dace were able to maintain position at high water velocities without incurring a metabolic cost by inclining forward so that the tail was elevated and the extended pectoral fins forced the individual to the bottom (Facey and Grossman, 1990). This species was the only member of the fish community that consistently occupied high velocity waters. Two other species that frequently utilized higher velocity habitats were flathead chub and channel catfish. Like longnose dace, both have a somewhat depressed body form and extended pectoral fins. Despite species-specific differences in habitat use, the Middle Rio Grande fish assemblage was generally absent from the most common available mesohabitat (main channel runs with no debris).

The 1994-1996 habitat study demonstrated that fishes in the Middle Rio Grande occupy only a small portion of available aquatic habitats. This concurs with the conclusions of a previous investigation of fish habitat use in this reach (Platania, 1993). Decreases in the range and abundance of native fishes throughout the American Southwest, including the Rio Grande silvery minnow, occurred most frequently in areas where instream habitats have been modified by severe reductions or augmentations of flow (Platania, 1993; Martinez et al., 1994; Propst and Stefferud, 1994). The reduction of low-velocity mesohabitats associated with channel width narrowing and periodic high flow (at inappropriate times) have reduced the number and extent of habitats suitable to Rio Grande silvery minnow. This loss of habitat may most severely impact smaller size-classes of cyprinids which require low-velocity, shallow areas as nursery habitats and as potential protection from predation (Copp, 1992). The smallest Rio Grande silvery minnow size-class almost exclusively selected shallow low-velocity mesohabitats. As most low-velocity habitats are lost during periods of high flow, larval fish moved to river margins which were the only available low-velocity habitats. The primary change to the Rio Grande during periods of high flow was decreased availability of low-velocity habitats.

Post-construction changes to the morphology and physical habitat of the Rio Grande downstream of Cochiti Dam were well documented by Lagasse (1980, 1981). Rio Grande flows in the upper reaches are perennial largely because of the operation of Cochiti Dam. Regulation of spring flow at Cochiti Dam resulted in reduced peak discharges, but had little effect on average annual discharge. The trapping of sediments by the reservoir and release of sediment-free water resulted in degrading of the riverbed below the dam. The finer river-bed material was removed by hydraulic scouring and transported downstream resulting in a riverbed armored with coarse bed materials. Lagasse (1980, 1981) reported that degradation and armoring of the Rio Grande had achieved stability throughout the Cochiti Reach by 1979. The high sediment load carried by arroyos and tributaries, in conjunction with reduced and regulated post-dam flows, has prevented the stability purported by Lagasse (1980) from being attained in the Rio Grande downstream of the Jemez River confluence.

It is difficult to separate the effects of physical structures (dams and diversions) from hydrologic impacts. The post-dam change in habitat included clearer and colder discharge compared to pre-dam flows. The scouring effects of dam outflow had an important and negative impact on riverine habitat. Conversely, the cooler and clearer water was beneficial for numerous nonnative game fish species that escape from Cochiti Reservoir during spring releases. This latter group of fishes are visual feeders and fare better under such conditions than the native cyprinid taxa that evolved under turbid stream conditions.

The paucity of Rio Grande silvery minnow in the Cochiti reach and upstream portions of the Angostura reach may be habitat related. Between Cochiti Dam and Bernalillo, the river was relatively confined, substrate consisted of large-sized material and low-velocity habitats were rare. These factors appear to negatively affect all life-history stages (especially drifting stages) of Rio Grande silvery minnow to some degree and ultimately limit its distribution and population size. In general, this species was more abundant in reaches where the river channel widens and low-velocity habitats were more numerous.

However, it is inappropriate to make specific correlations between habitat availability and Rio Grande silvery minnow abundance because of the complex confounding factors that influence this relationship (see Addendum). While the density of Rio Grande silvery minnow was different between sampling localities and over time during this study, explanations for these observations cannot be provided exclusively by data on their habitat selection. While population levels of this species are clearly affected by the availability of appropriate habitats, the impact of these differences on various life-stages (especially drifting eggs and larvae) has not been determined.

Modifications of the natural flow regime (e.g., reduced amplitude) are well-established as being deleterious to endemic fish populations. Radical reductions in stream flow often lead to declines in the distribution and abundance of fishes (Poff and Allan, 1995; Day et al., 1996; Marschall and Crowder, 1996). Drought conditions can isolate fishes and lead to increased competition or predation. Microhabitat preferences of fishes have also been shown to shift dramatically during periods of low flow (Shirvell, 1994). In arid regions where municipal and agricultural demands have increased, many drainages have been dammed and water diverted as needed. This practice often leads to dramatic changes in the flow regimes of these systems and, during periods of below average precipitation, has resulted in the complete drying of significant portions of rivers. Many streams throughout the American Southwest that historically flowed throughout the year are now intermittent, ephemeral or dry. The most damaging effects to populations of fish or any other aquatic organism is a complete loss of habitat as occurs when a stream dries.

The most critical period for Rio Grande silvery minnow, under the current operation of the river, appears to be between 1 July and 30 October. During this period the population is comprised almost exclusively of age-0 fish. By late July, over 90% of mature Rio Grande silvery minnow will have spawned and died leaving larval Rio Grande silvery minnow to perpetuate the species. For this and other species to survive, requires that flow be maintained in the river. Unfortunately, the period when age-0 Rio Grande silvery minnow are most numerous is also the period when all the water in the river at Isleta and San Acacia Diversion dams can and has been diverted to canals.

While there may be some disagreement as to the extent and magnitude of the effects of water management practices on the Middle Rio Grande fish fauna, there should be no debate that the most serious impact is the drying of vast reaches of the river channel. Large movements of water out of the Rio Grande and into diversion canals can lead to de-watering of significant downstream reaches of the river. In 1989 and 1990, extensive portions of the Rio Grande downstream of San Acacia Diversion Dam were completely de-watered. All fish remaining in those sections died. Even after flow resumed, sampling frequently failed to yield fish. It took at least two years for those populations to return to pre-1989 levels. In April and May 1996, extensive reaches of the Rio Grande in the San Acacia reach were again de-watered resulting in the loss of thousands of gravid Rio Grande silvery minnow females and other members of the fish community. Stream-bed drying results in a complete loss of the aquatic ichthyofaunal community and poses a serious threat to the continued persistence of Rio Grande silvery minnow.

Aquatic habitats in the Isleta reach of the Middle Rio Grande are probably the most adversely impacted, due to water diversions, of any of the reaches. At Isleta Diversion Dam, up to 1,070 cfs of water can be diverted to east and west bank channels. Diverted water generally remains in the 716 km of drains and canals in this reach as there are few points of return in the upper and middle segments. Many extensive portions of this reach (especially the upper section) of the river are frequently isolated during summer and autumn and eventually dry. Localized flooding of the rios Puerco and Salado and other smaller tributaries can provide significant flow in the lower 16 km of the Isleta reach.

Habitats in the San Acacia reach are also negatively impacted by water diversion from the Rio Grande. Main channel habitats in the San Acacia reach were somewhat unique because, prior to 1996, there was no point in this section where diverted water could be returned to the river. As opposed to the Cochiti and Angostura reaches which maintain perennial flow and the Isleta reach which has numerous downstream outfalls for irrigation water, none of the water in canals at San Acacia could be diverted back into the river. After its use, irrigation water from the Socorro Main Canal was moved into the low-flow conveyance channel and transported directly to Elephant Butte Reservoir. These diversions of water and subsequent changes in river channel morphology have had marked effects on habitat availability in this reach of the Middle Rio Grande.

In 1996, the U.S. Bureau of Reclamation connected the low-flow conveyance channel with the Rio Grande at a point about 15.3 km downstream of San Acacia Diversion Dam. The Bureau of Reclamation has the mechanical ability to control the amount of water being diverted from the low-flow conveyance channel back into the Rio Grande. This capability can help assure that segments of the Rio Grande downstream of the outfall remain wetted.

In other portions of the American Southwest (Colorado River Basin), monumental efforts are being undertaken to re-establish and increase abundances of threatened fish species. These efforts frequently involve significant modification of flow from major reservoirs (i.e., Hoover Dam) and releases, over a short-period of time, of more water than passes through Albuquerque in a typical year. It is difficult to assess the long range achievement of these releases as those fishes are long-lived (>10 years) and it is many years before researchers are able to determine the reproductive success of the respective cohort. With all of the other factors involved, it is difficult to ascribe the success or failure on the flow pattern as there will have been 10 years of interim effects. Effects of flow modifications on population levels of Rio Grande silvery minnow can be seen almost immediately. The level of flow manipulation required to maintain this fish community is minimal compared to those efforts in other regions of the American Southwest.

The cyprinids extirpated from the Middle Rio Grande (speckled chub, Macrhybopsis aestivalis, Rio Grande shiner, Notropis jemezanus, phantom shiner, Notropis orca, bluntnose shiner, Notropis simus) shared similar ecological attributes with Rio Grande silvery minnow. They were each short-lived minnows with a common reproductive strategy and egg type (Platania and Altenbach, in press). Moore (1944) first recognized the apparent advantage of this strategy suggesting that it was particularly well suited for the arid environment of Great Plains stream ecosystems. The current suite of conditions in the Middle Rio Grande are not conducive for the lasting survival of aquatic organisms and may lead to the extirpation of the last endemic mainstream cyprinid (Rio Grande silvery minnow). All of the above considerations must be addressed prior to discussion of means to optimize the preferred habitat of this species. Ensuring the survival of Rio Grande silvery minnow and the aquatic community that supports this species will initially require maintaining some level of flow in most of the Middle Rio Grande throughout the year.

ACKNOWLEDGEMENTS

Many people collaborated with us to make this project possible. We thank Chris S. Altenbach (MSB), Jason E. Davis (USFWS), John P. Larson (MSB), Gregory M. Lein (MSB) and John P. Sherrod (MSB) for assistance with field portions of the study. Gregory M. Lein helped initiate this project and subsequently assisted in the field and with the entry and organization of the data set. Vicky J. Meretsky (USFWS) and Owen T. Gorman (USFWS) provided valuable comments pertaining to the statistical analysis of the fish habitat use data. Linda V. Beal (USGS) provided discharge data for the Rio Grande. Much of the technical and logistical support for this project was provided by Jennifer Fowler-Propst (USFWS), David L. Propst (NMGF) and James E. Brooks (USFWS). David L. Propst (NMGF) and James P. Wilber (USBR) assisted in the initiation of this project and also provided valuable comments on this report. This project was performed under a cooperative agreement between USBR and NMGF (Contract # 4-FC-40-16030) and NMGF: ASIC (Contract # 95-516-30).

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ADDENDUM

It was impossible to determine how much differences in mesohabitat availability between sites have contributed to the decreased abundance of Rio Grande silvery minnow at Rio Rancho. The abundance of this species is dependent on such a multitude of abiotic and biotic factors that making population demographic predictions based strictly on habitat availability would be imprudent. For example, the magnitude and rate at which drifting reproductive products of Rio Grande silvery minnow are carried downstream has certainly been negatively impacted by changes in stream habitat and flow regime. Because this relationship has not been quantified with empirical data, predictions cannot be made about the number of reproductive products that are displaced downstream under various flows or what impact this would have on population demographics. Changes in the density of Rio Grande silvery minnow cannot be predicted solely from its habitat use as this data provides no quantified empirical insight into future or current trends in abundance.

Instream flow methods assume a correlation between various flows and the presence of certain habitats that, in turn, affect the abundance of fish. The strength or weakness of this correlation is related to ontogenetic, physiological and behavioral characteristics of the organism (Annear and Conder, 1984 etc.) and also depends on the stability of the river channel. There were no data to suggest that a definitive relationship existed between varying levels of flow and fish abundance in the Rio Grande through the course of this study at either sampling locality. This was perhaps due to the variable effect of flow on habitat availability at different river reaches. The presence of certain mesohabitats does not seem to follow a simplistic pattern, but appears dependent on a myriad of factors (e.g., channel width, stream substrata, season, channel morphology etc.). Some reaches increased in the absolute area of low-velocity habitats during periods of high flow (e.g., re-opening side channel, backwaters etc.), while other more confined reaches with large substrata lost all lower velocity areas except along the shoreline. The river at Rio Rancho was generally confined to a single channel at lower flows, but several larger side channels opened during moderate flows to provide new low-velocity habitats. However, none of these relationships were predictable even within the period of study at these two sites, especially Socorro, because the morphology of the stream channel changed between sampling forays. Since the river channel and its associated mesohabitats are constantly shifting due to the dominant small unstable substrata, a wealth of data at multiple sites over time would need to be collected before one could begin to predict how habitat availability is altered by discharge throughout the Middle Rio Grande. As there is no indication that intense habitat modeling (e.g., IFIM or PHABSIM) would provide significant insights into how to improve population levels of Rio Grande silvery minnow based on its reproductive strategy and the stochastic river channel it occupies, the utility of such models should be carefully questioned (Ken D. Bovee, pers. comm.).

Extremes in flow and their impact on habitat availability do appear to influence the abundance of Rio Grande silvery minnow. The release of large volumes of water seems to effectively eliminate low-velocity habitats in many reaches especially where the stream channel is confined. The reduction of low-velocity habitats during increased discharge leads to some and perhaps extensive displacement of Rio Grande silvery minnow, especially drifting egg and larval stages, below barriers. The other extreme in discharge is the absence of flow which has lead to the loss of significant numbers of Rio Grande silvery minnow. The second issue is certainly more concerning than the first as its impact is immediate and permanent. Hydrologic modeling should be focused on how to maintain flow through critical river reaches during periods of low precipitation and/or high irrigation demand. While the relationship between river discharge, habitat availability and fish abundance should be explored further, the prevention of river drying appears to be orders of magnitude more important to the current persistence of Rio Grande silvery minnow.