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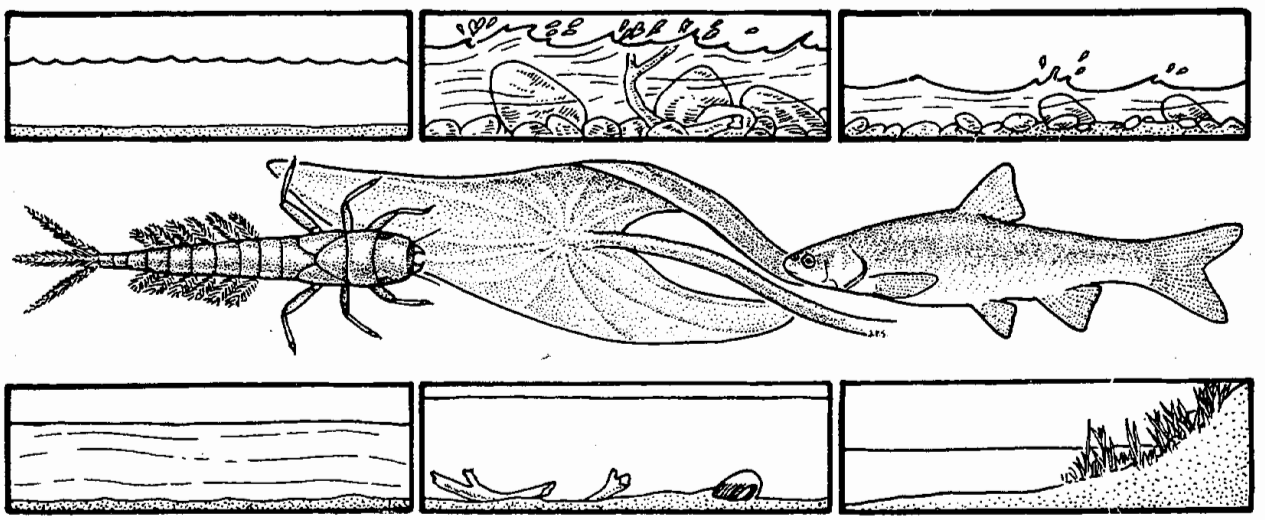
The Fishes of the Rio Grande between Velarde and Elephant Butte Reservoir and their Habitat Associations



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EXECUTIVE SUMMARY

The Middle Rio Grande historically supported a fish fauna comprised of at least 16 species, of which four were endemic to the basin. Two non-endemic species, shovelnose sturgeon and American eel, were large, wide-ranging taxa thought to have disappeared from the New Mexico portion of the Rio Grande during the early 1900s concurrent with the construction of mainstem dams. Since 1949, four mainstem cyprinid species have been extirpated from the Rio Grande in New Mexico. Of the four Rio Grande endemics, only Rio Grande silvery minnow remains in the New Mexico portion of the drainage. This fish, which historically occurred in the Rio Grande from Abiquiu to Brownsville, Texas, presently occurs in less than 5% of its former range.

The fish fauna of the Middle Rio Grande is currently composed of at least 26 species of which nine are native to the drainage. Between 1987-1990, native fishes accounted for about 85% of the catch by number, with the two most abundant species, red shiner and Rio Grande silvery minnow, comprising 53% and 18% of the catch, respectively. While Rio Grande silvery minnow was numerically the second most abundant species, 99.9% were taken in the 50 collections made between Bernalillo and Elephant Butte Reservoir in 1987-1988. Only three additional Rio Grande silvery minnow were taken in the 56 collections made in the study area between 1989-1992. During that period, Rio Grande silvery minnow went from second to least abundant native species. This precipitous decline in abundance of the Rio Grande silvery minnow coincided with regional summer droughts (1987-1991) which left reaches of the Middle Rio Grande dry for prolonged periods.

The Middle Rio Grande is a highly regulated system operated to provide for the efficient transport of water to downstream users and ultimately to Elephant Butte Reservoir. Man-induced perturbations include numerous river maintenance activities and hydrologic manipulations. Maintenance activities generally result in modification of instream habitats and a decrease in habitat heterogeneity. Hydrologic activities can result in the de-watering of extensive reaches of the river and effective elimination of the aquatic community.

This study, initiated in 1987, was designed to determine the distribution and abundances of fishes and physical habitats in the Middle Rio Grande. In addition, an effort was made to determine species-habitat correlations which could, in turn, be used to direct mitigation of the effects of river maintenance activities. Correlations between species and habitats varied both seasonally and by life stage. The wide range of habitat variability and the absence of fish in many collections made during the habitat association portion of the study, restricted the characterizations of species-habitat correlations. Data from this study provided an important segment of the biotic and abiotic information required by the Bureau of Reclamation to conduct its mandated tasks.

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INTRODUCTION

Fish assemblages in most of the arid regions of North America have been affected by man-induced disturbances such as water development, habitat alteration, and the introduction of non-native species. Over half of the cyprinid taxa recently listed as endangered, threatened, or of special concern were from desert streams in the American Southwest or west (Williams et al. 1989). Included in that list were several taxa from the Rio Grande basin.

Despite the unique ichthyofaunal composition of this drainage, there is little historical or published information on the distribution, life history, and abundance of the fishes of the Rio Grande in New Mexico. Cope and Yarrow (1875) listed species captured at a single locality (San Ildefonso) and described Rio Grande shiner (Notropis jemezanus) and Rio Grande bluntnose shiner (Notropis simus simus). Koster (1957) presented cursory life history and abundance notes in his species accounts; Hatch (1985) produced a species checklist; Smith and Miller (1986) summarized the zoogeographic knowledge of the drainage based on the ichthyofauna, and Sublette et al. (1990) discussed previously published information and provided spot-distribution maps using pre-1985 records. Chernoff et al. (1982) addressed the distribution and taxonomic status of phantom shiner (Notropis orca) and Rio Grande bluntnose shiner, and Bestgen and Platania (1990) reviewed the decline, extirpation, and life history of these two taxa. Cook et al. (1992) reported on allozymic divergence and systematics of the Rio Grande silvery minnow (Hybognathus amarus) and Bestgen and Platania (1991) discussed its status and conservation. The reports by Propst et al. (1987) on fish in a 23-km reach of the Rio Grande between Caballo and Elephant Butte reservoirs and Platania (1991a) on the fishes of the Rio Chama and upper Rio Grande, New Mexico, are the only published accounts on the composition of the ichthyofaunal community in specific reaches of the Rio Grande in New Mexico.

The native ichthyofauna of the New Mexico portion of the Rio Grande is believed to have consisted of between 16 and 27 species (Hatch 1985; Smith and Miller 1986; Propst et al. 1987), four of which were endemic to the basin. Of the latter, Rio Grande shiner, phantom shiner, and Rio Grande bluntnose shiner no longer occur in the New Mexico portion of the Rio Grande (Bestgen and Platania 1990). Rio Grande shiner was known from 81 specimens in eight collections in the Rio Grande in New Mexico and has not been taken there since 1949 (Platania 1991a). Phantom shiner and Rio Grande bluntnose shiner, both reported as extirpated (Chernoff et al. 1982; Bestgen and Platania 1990), were last collected in the Rio Grande in 1939 and 1964, respectively (Chernoff et al. 1982; Bestgen and Platania 1990). Rio Grande silvery minnow is the only endemic Rio Grande fish surviving in New Mexico and occurs in $<5\%$ of its total former range (Bestgen and Platania 1991).

The aforementioned four species comprised a guild of short-lived (3-5 years) mainstream cyprinids which were apparently especially susceptible to reduction and alteration of stream discharge. Changes in stream hydrology were most closely associated with construction of mainstream dams and irrigation withdrawals. Additional factors which were thought to have contributed to the decline and demise of the native Rio Grande fish fauna were channel modifications, municipal, agricultural, and industrial pollution, and the introduction of several non-native predaceous game fishes.

Non-endemic taxa extirpated from the Rio Grande in New Mexico were shovelnose sturgeon (Scaphirhynchus platorynchus), American eel (Anguilla rostrata), speckled chub (Macrhybopsis aestivalis), and blue catfish (Ictalurus furcatus). Shovelnose sturgeon was known from two specimens collected in the Rio Grande at Albuquerque in 1874 (Cope and Yarrow 1875). Toomey (1991) provided information on the apparent historic abundance of shovelnose sturgeon in the lower portion of the basin (Texas) based on the discovery of their remains, previously misidentified as gar (Lepisosteus sp.), at six Holocene archaeological sites in Amistad Reservoir region of Val Verde Co., Texas. Natural populations of American eel, a catadromous species, no longer occur because of mainstem dams which have blocked their migrations. Sporadic recent records (1986, Española; 1988, Cochiti Lake, MSB 6388) were thought to represent dispersing individuals from introductions in Colorado (Zuckerman 1983). Speckled chub was last collected in the Rio Grande in New Mexico in April 1964 at Radium Springs (near Las Cruces) and in October 1964 at Peña Blanca (just downstream of Cochiti Dam). While blue catfish occurred in Elephant Butte and Caballo reservoirs on the Rio Grande, these were believed to be introduced populations. There are no post-1949, non-reservoir, Rio Grande, New Mexico, records of this species.

Although numerous studies have been conducted on habitat associations of individual, native, non-game species of warmwater fishes (Wagner et al. 1989, James and Maughan 1989), relatively few have dealt with fish taxa from the American Southwest. There are no published fish assemblage habitat use studies from the Rio Grande basin and few from large, warmwater streams in North America (Lobb and Orth 1991).

There may be several reasons for the lack of habitat association studies from the Rio Grande basin. Most habitat studies, whether single species or community, employ electrofishing as the method of capture. Electrofishing is usually performed under conditions of good water visibility, allowing the investigator to document, with a relative reliability, the point of occurrence of the species or assemblage being collected. Habitat parameters are then measured from this visible point of capture. From Bernalillo downstream to Elephant Butte Reservoir, the Rio Grande carries a high suspended silt-load and visibility in the water column is frequently <2 cm, thereby restricting direct observations. In addition to limitations imposed by the turbid habitat, the prior lack of knowledge of the fish fauna has also hampered habitat association activities. Our attempt to determine habitat associations of the fish assemblage of the Rio Grande is the first that we are aware of for the basin, and one of only a few anywhere that attempts to determine community assemblage use in a large, warmwater system.

Anthropogenetic activities on the Rio Grande have produced both physical and hydrological modifications. River channel maintenance projects have included clearing of floodway vegetation, pilot channeling, bank stabilization, and construction of jetty jack fields. The primary purpose of river maintenance activities and altered flow pattern were to provide for efficient transport of water to Elephant Butte Reservoir. While alterations of aquatic habitats are usually deleterious to native fishes, it is possible that the level and extent of the impacts may be moderated or eliminated through changes in the design, timing, and duration of such modifying activities. Implementation of such actions requires more information than is presently available on the fishes of the Rio Grande basin.

The two principal purposes of this study were to determine the distribution and status of fishes in the Rio Grande between Velarde and Elephant Butte Reservoir and their habitat associations. The first charge was accomplished through systematical sampling of the fish fauna. Second, habitat association was determined through a series of physical measurements

and fish collections taken at preselected macrohabitat sites. Data obtained during the two phases of this study comprise an important segment of the information necessary to assist resource management agencies in conducting their mandated tasks.

STUDY AREA

This research project began as a four-year study (1987-1991) designed to determine the distribution, abundance, conservation status, and habitat associations of the fishes of the Rio Grande from the Interstate 40 bridge downstream to the upper end of Elephant Butte Reservoir. In 1989 the study was expanded to include the Rio Grande between Albuquerque and Velarde, thereby increasing the study area from Velarde to Elephant Butte Reservoir, a reach defined by the U.S. Bureau of Reclamation as the "Middle Rio Grande" (Figure 1). The study area was further subdivided into an "upper" reach between Velarde and Albuquerque and a "lower" reach between Albuquerque and Elephant Butte Reservoir.

The Rio Grande originated in the San Juan Mountains in southern Colorado and flowed south through New Mexico for approximately 750 km. The Rio Chama, which emptied into the Rio Grande in the vicinity of Española, was the only major tributary in New Mexico. These rivers were fed primarily by melting snowpack from high elevations in northern New Mexico and southern Colorado and were supplemented by transmontane diversions from the San Juan River drainage (Colorado River basin). Historically, highest flows usually succeeded spring snowpack melt and lowest flows occurred in late summer and fall during the irrigation season. Localized summer thunderstorms, when present, ameliorated low flows in discrete reaches. Precipitation in the region was low, averaging <25 cm/year (Gold and Denis 1985).

During the course of this study, the Middle Rio Grande exhibited considerable physical change through its 364-km length. At high elevations, the Rio Grande may be characterized as a narrow, canyon-bound cold river with large substrate particles and a salmonid-dominated fish community, while downstream reaches were 50-250 m wide, sand-bottomed, and supported warmwater fish communities.

In the upper section, the Rio Grande emerged from a relatively narrow canyon about 5 km upstream of Velarde. It was then confined to a relatively slender channel where water velocity was high (> 1 m/second), substrate was primarily boulder or cobble, and habitat heterogeneity was low. Within 8 km of Velarde, there were at least five diversion dams which divided the river. Mud and silt-bottomed pools formed above diversions while boulders and rip-rap were located directly below the spillways in higher velocity water. Water-depth in the main channel was frequently >2 m.

Between the mouth of the Rio Chama and the upper reach of White Rock Canyon (site 5), the Rio Grande was still relatively narrow (50 m) and confined to one or two main channels over a cobble-gravel substrate. The river coursed through a broad, shallow flood-plain and, in many places, a vertical water rise of 1 m would cause flooding. It flowed about 5 km through San Juan and Santa Clara pueblos before reaching Española, the largest municipality in this reach. San Ildefonso Pueblo, just downstream of Española, was the upper boundary of the 34 km White Rock Canyon reach which terminated at Cochiti Reservoir, the largest mainstem Rio Grande impoundment in the study area.

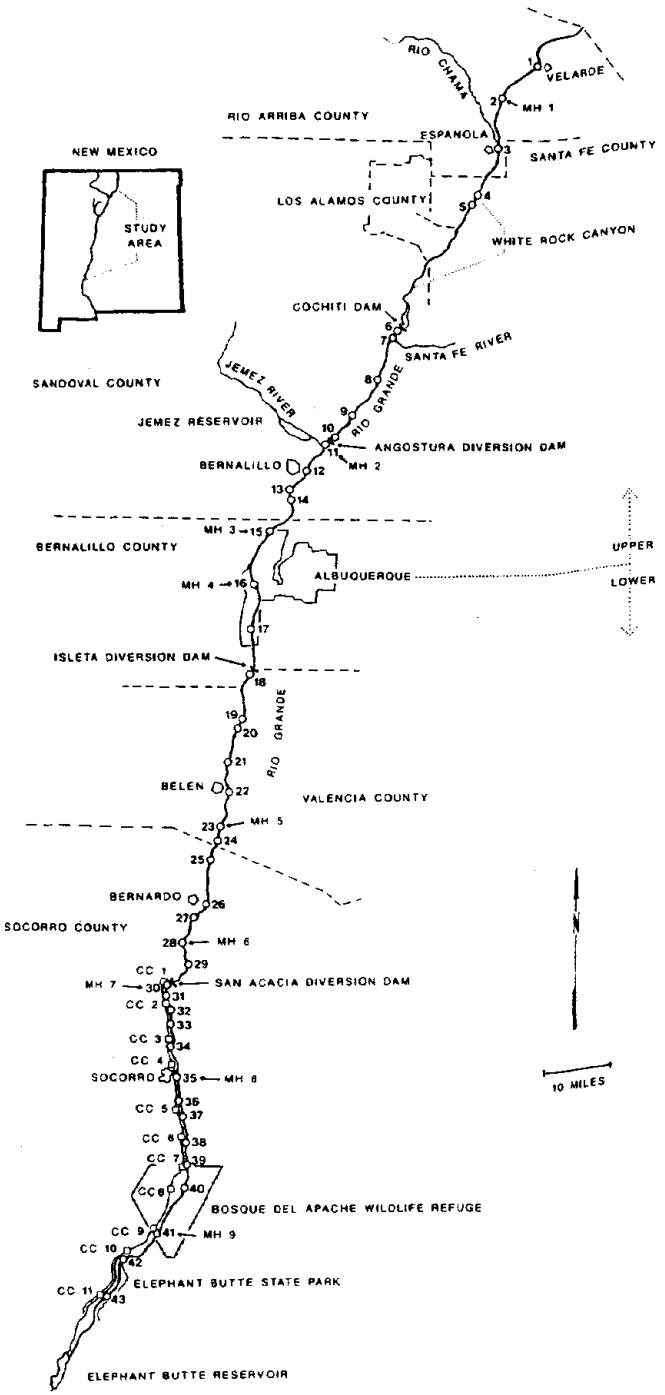

Figure 1. Map of Middle Rio Grande study area. Open circles (○) indicate collecting localities. "MH" refers to macrohabitat sites and "CC" refers to Low-Flow Conveyance Canal sites.

Between Cochiti Dam and Angostura Diversion Dam, the Rio Grande was again confined primarily to a single channel with a cobble-gravel substrate as it passed through Cochiti, Santo Domingo, and San Felipe pueblos. Low-water levels frequently resulted in drying of secondary channels and a reduction in backwater habitats. Water depth in the main-channel rarely exceeded 2 m and velocity was dependent on reservoir discharge. The Santa Fe River, which contributed a relatively minor volume of water, was the largest natural tributary in this reach.

The stretch from Angostura Diversion Dam to Bernalillo was a transition zone where the river channel became more braided, the flood-plain widened, and the substrate was comprised primarily of sand and silt. At Bernalillo the river exceeded 200 m in width, water depth was usually < 1 m, and velocity was reduced. Riverine habitat from Bernalillo downstream to Albuquerque was very similar and was composed of primary or secondary channel runs between 0.25 and 1 m deep. Backwaters were more abundant in this reach than in between Cochiti and Angostura and substrate particles larger than sand were rare.

Downstream of Albuquerque, the Rio Grande was an ephemeral and wide meandering river with predominantly sand substrate, high silt load, low-velocity, and a variety of habitats. The mainstem channel was generally broad (100-200 m), < 1 m deep, and had a current velocity of < 1 m/second. Pools were uncommon and usually existed only near vegetated banks, on the downstream side of the confluence of two channels, and around bridge abutments. From the Bosque del Apache National Wildlife Refuge to Elephant Butte Reservoir, the river channel was generally less than 50 m.

Howe and Knopf (1991) reported that Fremont cottonwoods (Populus fremontii var. wislizenii) accounted for 93% of the canopy trees between Española and Bernardo. Peach-leaf (Salix amygdaloides) and Goodding (Salix gooddingii) willows comprised the remainder of the canopy. Predominant under-story shrubs in the cottonwood habitats were coyote willow (Salix exigua), Russian olive (Elaeagnus angustifolia), salt cedar (Tamarix chinensis), seepwillow (Baccharis salicina), false indigobush (Amorpha fruticosa), and New Mexican olive (Forestiera neomexicana) (Howe and Knopf 1991).

The lower Rio Grande meandered between vegetated banks in several channels during low flow periods, alternately eroding and aggrading mid-stream and near-shore bars. Habitat consisted mainly of homogenous, moderate velocity runs. Substrate particles larger than sand were rare; they occurred only in the vicinity of Albuquerque (sites 16-17), directly downstream of Isleta and San Acacia diversion dams (sites 18 and 30, respectively) and where ephemeral arroyos deposited wedges of large substrate particles (site 28).

Diel and seasonal discharge varied greatly both historically and during this study. There was a general trend of lower flow at downstream locations than upstream. Since 1973, flow in the Rio Grande was dictated largely by releases from Cochiti Dam as well as by diversions for irrigation. Highest flow during this study occurred in the spring and early summer (April-July) as a result of snow-melt and irrigation water releases. Lowest flow occurred late in the irrigation season (September-October), when most of the available stream flow was diverted.

Downstream of Isleta, the Rio Grande was sometimes ephemeral; in 1987 we observed disjunct desiccated reaches up to 20 km long. We do not know the length of time these areas were dry, but the periods were presumably days to weeks. Throughout the study area, irrigation water which discharged back into the Rio Grande through the 15 ditch-return outfalls sometimes provided the only surface riverine flow during summer and autumn.

The Low-Flow Conveyance Canal originated at San Acacia Diversion Dam and flowed south paralleling the natural river channel until it emptied into Elephant Butte Reservoir. The canal was designed and constructed to carry all of the water of the Rio Grande (< 63 m^3/second) with the express purpose of providing efficient water delivery to Elephant Butte Reservoir. The general plan was for the mainstem Rio Grande (referred to as the "Rio Grande floodway" in annual U.S. Geological Survey Water Resources Data Books) to carry water that exceeded the capacity of the Low-Flow Conveyance Canal. Thus, flows bypass the mainstream in the river during all but the highest flow periods. The canal has been used sparingly over the last 10-15 years due to operational difficulties and high water levels in Elephant Butte Reservoir.

During the study, the Low-Flow Conveyance Canal was uniformly wide (ca. 20 m) and substrate was primarily sand. Instream and bank vegetation were sometimes extensive and subjected to mechanical removal. Discharge in the canal historically varied from 0 to 62 m^3/second, but during this study was low. No water was diverted into the Low-Flow Conveyance Canal at the San Acacia Diversion Dam during our study and flows in the upper few kms were negligible. Irrigation return and groundwater influx progressively increased discharge in the downstream portion of the canal to 5-14 m^3/second near Elephant Butte Reservoir. At flows > 5 m^3/second fish habitat in the canal was limited as water depth exceeded 1 m and velocity was > 1 m/second throughout the canal.

Flow in the Rio Grande was regulated by five mainstream reservoirs on the rios Chama and Grande and numerous smaller irrigation diversion dams throughout the drainage. The complex system of ditches, drains, and conveyance canals provided for extensive irrigated agriculture in the Rio Grande Valley. Cochiti Reservoir, located 66 km above Albuquerque and operational in 1973, was the primary flood control reservoir on the mainstem of the Rio Grande. In addition, there were several irrigation diversions that impounded and diverted water and may have been barriers to upstream fish dispersal.

Rio Grande flow data were obtained from six U.S. Geological Survey (USGS) gauging stations between Embudo and San Marcial and were selected because of their proximity to sampling sites, (Tables 1 and 2). Discharge was high throughout 1986 and most of 1988. In 1987, discharge was also high through July, but by September several dry reaches (10-20 km) were observed between Isleta and Elephant Butte Reservoir. These same reaches were also frequently dry during the macrohabitat phase of this study (October 1989-March 1992).

MACROHABITAT SITE AND DESCRIPTION

Sites were selected throughout the previously described reaches for further fish and habitat study. The following is an annotated listing of the macrohabitat sites, their location, and dates sampled. The methods section provides additional detail on the macrohabitat phase of this project.

Macrohabitat site 1 (Inventory site 2): NM: Rio Arriba County, Rio Grande ca. 1.6 km upstream of State Hwy 74 Bridge Crossing.

This locality, approximately 0.8 km above the northern boundary of San Juan Indian Pueblo, was 180 m long and characterized by a relatively narrow channel, swift to moderate velocity water, and a substrate of cobble and gravel. In addition, a small irrigation-return

Table 1. Summary of U.S. Geological Survey flow records (cfs) during non-macrohabitat sampling (U.S. Geological Survey 1987, 1988, 1990).

DATE	EMBUDO (08279500)	SAN FELIPE (08319000)	ALBUQUERQUE (08330000)	BERNARDO (08332010)	SAN ACACIA (08354900)	SAN MARCIAL (08358400)
09 SEP 87	319	686	341	111	36	55
10 SEP 87	317	684	344	112	24	40
11 SEP 87	313	688	345	130	21	0
16 SEP 87	298	691	333	151	18	0
17 SEP 87	288	697	331	140	106	0
04 APR 88	854	3460	3700	2950	3360	3140
23 MAY 88	739	2060	2210	2030	2030	1440
24 MAY 88	656	2170	2140	1880	1900	1320
25 MAY 88	604	2150	2100	1590	1830	1170
04 OCT 88	268	727	402	226	210	40
05 OCT 88	269	729	408	257	203	36
18 APR 90	683	1140	804	195	100	0
19 APR 90	688	1070	997	299	64	0
24 APR 90	807	1220	794	590	440	143
29 APR 90	666	975	916	1110	1070	667
06 SEP 90	293	840	363	0	32	29
09 SEP 90	318	1140	623	0	355	544
28 OCT 90	339	323	155	17	137	0
29 OCT 90	328	319	139	13	134	0
30 OCT 90	320	322	139	9.5	114	0

These USGS gauging stations corresponded with the following macrohabitat sites: Embudo = San Juan Pueblo (macrohabitat site 1); San Felipe = Angostura (macrohabitat site 2); Albuquerque = Alameda and Central Avenue bridges (macrohabitat sites 3 and 4); Bernardo = Turn and Arroyo los Alamo (macrohabitat sites 5 and 6); San Acacia = San Acacia and Socorro (macrohabitat sites 7 and 8); and San Marcial = Bosque del Apache (macrohabitat site 9).

Table 2. Summary of U.S. Geological Survey flow records (cfs) during macrohabitat sampling (U.S. Geological Survey 1989, 1990, 1991, 1992).

DATE	EMBUDO (08279500)	SAN FELIPE (08319000)	ALBUQUERQUE (08330000)	BERNARDO (08332010)	SAN ACACIA (08354900)	SAN MARCIAL (08358400)
14 OCT 89	383	558	707	*202	*453	101
15 OCT 89	379	626	592	305	538	*66
16 OCT 89	382	642	*550	298	582	57
17 OCT 89	372	569	487	*202	515	134
19 OCT 89	365	594	238	176	*341	77
20 APR 90	648	1050	*874	900	608	0
21 APR 90	645	1040	779	768	*691	0
22 APR 90	691	1050	791	*646	436	107
23 APR 90	774	1090	784	*591	*470	171
22 OCT 90	344	536	*256	44	178	13
23 OCT 90	347	499	276	30	*123	0
24 OCT 90	347	455	231	*32	123	0
25 OCT 90	346	536	186	*48	*97	0
18 SEP 91	*845	1310	1670	843	1020	293
19 SEP 91	756	*1250	1640	880	920	205
20 SEP 91	702	1220	*1460	868	938	142
31 JAN 92	542	920	*924	NA	1150	676
01 FEB 92	541	958	*1000	NA	1330	776
31 MAR 92	1630	*1750	1680	NA	1340	1050
02 APR 92	1600	2030	2050	*NA	1680	1280
04 APR 92	1640	2490	2490	NA	*1910	*1400
06 APR 92	*1680	2700	2250	*NA	2420	1830

* indicates dates of collections at the corresponding macrohabitat site.

These USGS gauging stations corresponded with the following macrohabitat sites: Embudo = San Juan Pueblo (macrohabitat site 1); San Felipe = Angostura (macrohabitat site 2); Albuquerque = Alameda and Central Avenue bridges (macrohabitat sites 3 and 4); Bernardo = Turn and Arroyo los Alamo (macrohabitat sites 5 and 6); San Acacia = San Acacia and Socorro (macrohabitat sites 7 and 8); and San Marcial = Bosque del Apache (macrohabitat site 9).

canal fed the Rio Grande and provided low-velocity habitat. Fish and habitat were sampled at this site during the summer (18 September 1991) and winter collecting trips (6 April 1992).

Macrohabitat site 2 (Inventory site 11): NM: Sandoval County, Rio Grande directly downstream of the Angostura Diversion Dam, Angostura.

Angostura Diversion Dam was located on private land at the southern end of San Felipe Indian Pueblo. Although fish at this site were surveyed only once during the inventory phase (summer), they were sampled just upstream of the diversion (site 10, Algodones) during the winter collecting period (April 1990). This area of the river represented the transition zone between the cool, high-velocity water and cobble substrate characteristic of the upper section of the Middle Rio Grande and the warm, slow velocity water and sand-silt substrate common in the lower end of the study area. Macrohabitat samples were taken in a 180-m reach at this locality on 19 September 1991 and 31 March 1992.

Macrohabitat site 3 (Inventory site 15): NM: Bernalillo County, Rio Grande at Alameda Avenue Bridge, State Hwy 46, Corrales.

At this locality, the river flood-plain was wide (up to 200 m), water velocity and temperatures were elevated compared to upstream sites, and substrate particles larger than sand were rare. The Upper Corrales Riverside Drain emptied into the Rio Grande on the west bank just upstream of the bridge. Fish and habitat were sampled in a 270-m reach at this locality on 20 September 1991 and 1 February 1992.

Macrohabitat site 4 (Inventory site 16): NM: Bernalillo County, Rio Grande at Central Avenue Bridge, U.S. Hwy 66, Albuquerque.

This 270-m site had a representative array of habitat types characteristic of the lower Rio Grande such as high turbidity, braided channel, moderate gradient, and sand substrate. Sampling at this site occurred on four occasions: 16 October 1989, 20 April 1990, 22 October 1990, and 31 January 1992.

Macrohabitat site 5 (Inventory site 23): NM: Valencia County, Rio Grande 4.4 km upstream of State Hwy 346 Bridge, Turn.

Habitat at this site was typical of the Rio Grande between Isleta and San Acacia. The river channel was broad and meandered over a sand substrate. Habitat consisted primarily of runs, with pools occurring at low flows near channel margins and under overhanging vegetation. Fish and habitat were sampled in a 270-m reach at this site on 14 October 1989, 22 April 1990, 24 October 1990, and 6 April 1992.

Macrohabitat site 6 (Inventory site 28): NM: Socorro County, Rio Grande southwest of La Joya at Arroyo los Alamos.

Input of particulate materials from Arroyo los Alamos produced a diverse array of macrohabitats (pools, riffles, and runs) and variety of substrate types (cobble and gravel) that were not typical for this reach of the Rio Grande. The study site, 180 m long, was sampled on 17 October 1989, 23 April 1990, 25 October 1990, and 2 April 1992.

Macrohabitat site 7 (Inventory site 30): NM: Socorro County, Rio Grande below San Acacia Diversion Dam, San Acacia.

This site was located just below the point of diversion of the Low-Flow Conveyance Canal. The dam extended across the entire river and produced scouring cascades which removed most fine particle substrate material and created pools. There was a wide assortment of artificially produced macrohabitats such as cobble and gravel runs and riffles not present elsewhere in the lower reach of the Rio Grande. Fish and habitat samples were collected in a 270-m reach at this locality on 19 October 1989, 23 April 1990, and 23 October 1990. An additional survey was to be conducted in winter 1992 (March-April), but high water levels prevented us from performing that work.

Macrohabitat site 8 (Inventory site 35): NM: Socorro County, Rio Grande directly east (and upstream) of the Socorro sewage treatment plant, Socorro.

This 180-m site was characterized by habitats typical of the lower reaches of the study area; wide floodplain, braided channel, low velocity water, and sand substrate. This site was located in a reach of the river where flow is periodically reduced or eliminated. This is also the site of levee construction work done by the U.S. Army Corps of Engineers in 1986. Samples were taken on 14 October 1989, 21 April 1990, 25 October 1990, and 4 April 1992.

Macrohabitat site 9 (Inventory site 41): NM: Socorro County, Rio Grande at the southern boundary of the Bosque del Apache National Wildlife Refuge.

This 90-m site was characterized by an extremely restricted channel and frequent periods without flow. Data gathered from this site may provide insight into the fish that use such ephemeral habitats as well as information on population abundance and biomass levels in ephemeral reaches. An attempt was made to sample habitat and fish at this site on four occasions: 15 October 1989, 21 April 1990, 25 October 1990, and 4 April 1992. However, during two sampling forays (21 April and 25 October 1990), the river channel was dry.

METHODS

This study was divided into two major phases, inventory and habitat association. The first stage of work was to determine the distribution, abundance, and conservation status of the fishes of the Rio Grande and "associated habitats." ("Associated habitats" is not analogous with habitat association). The study area was divided into 8-km intervals to afford sampling of the different physiographic reaches and to discern physical and biotic longitudinal patterns. "Associated habitats" were initially identified in the work contract as canals, drains, and ponds along the river. Upon re-examination, a single associated habitat, the Low-Flow Conveyance Canal, was defined. The other "associated habitats" were eliminated because of their ephemeral nature (most canals) or general absence (ponds) in the study area.

Inventory

Inventory sampling was conducted in both warm (summer) and cold (winter) seasons. These periods were arbitrarily designated as 1 June to 31 October (warm) and 1 November to 31 May (cold). An agreement with the U.S. Bureau of Reclamation allowed summer sampling for year-1 to include collections made in September 1987. The Low-Flow Conveyance Canal was sampled once and without regard to season (Table 3).

Table 3. Schedule of inventory and macrohabitat sampling in the Middle Rio Grande.

	Inventory			Macrohabitat	
DATE	Lower	Upper	LFCC[1]	Lower	Upper
summer 1987	▮				
winter 1987-1988	▮		▮		
summer 1988	▮		▮		
winter 1988-1989					
summer 1989				▮	
winter 1989-1990		▮		▮	
summer 1990		▮		▮	
winter 1990-1991					
summer 1991					▮
winter 1991-1992				▮	▮

[1] LFCC= Low Flow Conveyance Canal

For the inventory study, fish were captured with small mesh seines of various lengths. Collection efforts were generally intense with 10-40 seine hauls per site and all habitat types sampled. Benthic species were sampled by placing the seine perpendicular to fast velocity water and agitating the substrate upstream of the seine. Dislodged specimens were swept by the current into the seine. Specimens were fixed in 10% formalin immediately upon capture and returned to the laboratory for processing. Retained fish were sorted, identified, enumerated, and curated in the fish division of the Museum of Southwestern Biology (MSB), Department of Biology, at the University of New Mexico. Most specimens greater than 250 mm TL (total length) were identified, counted, and released.

A total of 54 sites was sampled for the inventory phase of this study. Of those, 40 lower Rio Grande and Low-Flow Conveyance Canal sites were surveyed between 9 September 1987 and 5 October 1988. There were 29 sites (which included two [sites 12 and 16] in the "upper reach") and 50 samples from the Rio Grande and 11 sites and 11 samples from the Low-Flow Conveyance Canal (see Figure 1).

Fish in the upper segment of the study area were sampled between 18 April-30 October 1990. A total of 16 sites in the upper portion of the Middle Rio Grande were surveyed producing 27 samples. There was overlap between the upper and lower inventory stations as sites 12 (Bernalillo) and 16 (Albuquerque) were sampled four times; twice during the inventories in each of the two reaches.

Macrohabitat

The second phase of this study assessed habitat availability and habitat preference of fish. Macrohabitat sites were selected following the completion of the inventory phase of each segment of the project. Those sites were selected based on three criteria: 1) both the habitat and associated fish fauna were to be characteristic (representative) of that reach of the Rio Grande, 2) the physical characteristics could not preclude our ability to adequately perform macrohabitat measurements (water depth >2 m) and, 3) we had to be assured of continuous accessibility to the study site. While many of the sampling locations on Native American Lands met the first two requirements, the potential for lack of continuous access eliminated those sites as macrohabitat study locations. Substrate types were taken from the literature while macrohabitat types and corresponding definitions were developed for this project (Table 4, Figure 2).

A total of nine macrohabitat study sites was ultimately selected in the upper and lower reaches. Macrohabitat work in the upper reach of the Middle Rio Grande was conducted at three sites for six months over two seasons (September 1991-February 1992), and data were gathered from six macrohabitat sites in the lower reach for 2.5 years over four seasons (October 1989-April 1992). The Low-Flow Conveyance Canal was not included in the macrohabitat phase of the program.

Macrohabitat work on the lower sites was scheduled to be completed during the 1991 cold season. However, unusually high water levels in the Rio Grande occurred during that period, postponing the second and final cold season sampling of the lower reach until winter-1992. The 1992 cold season was the only period in which both upper and lower sites were surveyed concurrently. San Acacia was not sampled in 1992 due to the dangerous nature of the Rio Grande directly downstream of the dam caused by large water releases.

Table 4. Macrohabitat and substrate types, codes, and definitions used in the Middle Rio Grande, New Mexico.

Primary Habitat	
MC	**Main channel**-the section of the river which carries the majority of the flow; where the thalweg is located; there can only be one main channel.
SC	**Secondary channel**-all channels not designated as the main channel; may carry appreciable flow or be low velocity habitat; there can be none or several secondary channels at a site.
BW	**Backwater**-a body of water, connected to the main or a secondary channel, with no appreciable flow; often created by a drop in flow which partially isolates a former secondary channel.
DE	**Debris**-an instream structure which provides some level of cover and refuge from surrounding habitats; can be permanent or ephemeral (i.e. tumbleweed) but must be at least temporarily stationary.
IS	**Island**-a parcel of land surrounded by water.
ISPO	**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.
Secondary Habitat	
ED	**Eddy**-a pool with current moving opposite to that in the channel.
FL	**Flats**-a region of relatively uniform depth, moderate velocity, and sand substrate; a flat is determined by the character of the substrate and recognized by the small standing waves it creates.
RA	**Rapids**-a relatively deep and fast velocity reach characterized by very turbulent water.
RI	**Riffle**-a shallow and slow velocity rapids in open river where waters 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-turbulent surface.
PO	**Pool**-the portion in the river that is deep and with relatively little velocity compared to the channel.
SH	**Shoreline**-shallow, negligible-to-low velocity waters, adjacent to the shore.

Table 4. continued.

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 (from Cummins 1962).

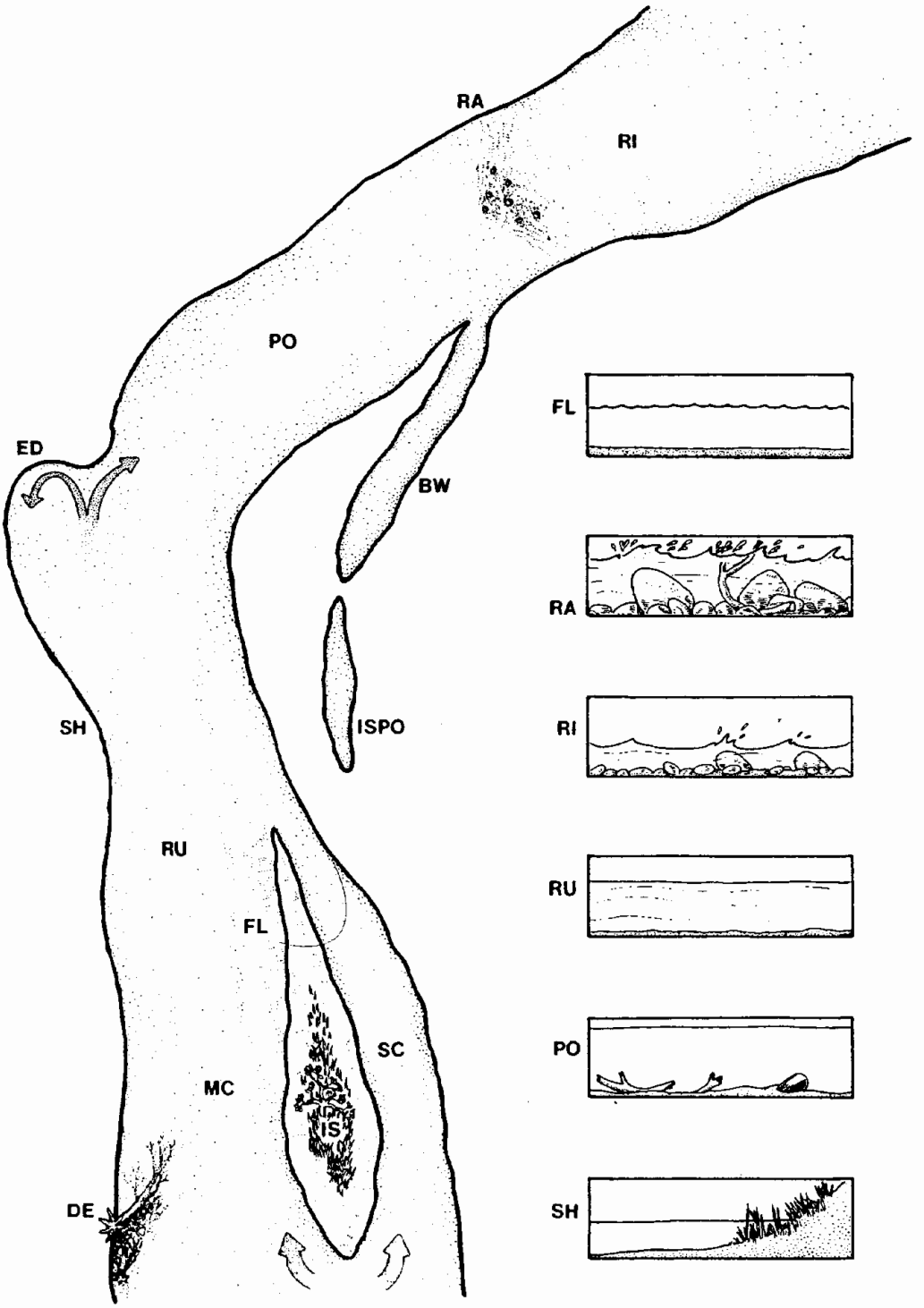

Figure 2. Illustration of macrohabitat types identified in the Middle Rio Grande. Codes for macrohabitat types listed and defined in Table 4.

The macrohabitat survey was subdivided into two stages. The first assessed habitat availability by measuring macrohabitat information at 100 points at each site. Study site lengths were either 90, 180, or 270 m depending upon the presence, diversity, and lengths of macrohabitat types and remained unchanged on subsequent visits. Once the length of each macrohabitat study site was determined, 10 transects, separated by equal distances and perpendicular to the river channel, were surveyed. After the length of each transect was measured, the starting point along the transverse survey line was determined by calculating 5% of the length of the transect and moving that distance from the bank. The remaining nine macrohabitat points were separated by a distance equal to 10% of the length of the transect. Macrohabitat type, depth, velocity, and substrate were recorded at the 10 equi-distant survey points along each of the 10 transect lines (Figure 3).

The second portion of the macrohabitat study, conducted at each site and on each visit, was the collection of fish and quantification of habitat associations. Fish were collected with a 10 foot-long x 6 foot-deep x 3/8 inch-mesh seine, providing a representative sample of the ichthyofaunal community at each site.

Individual seine hauls were taken in each of the discrete macrohabitat types observed within each macrohabitat study site. An attempt was made to sample only a single macrohabitat type per seine haul. At the completion of each seine haul, fish taken were preserved and given a unique field number. Following seining activities, habitat measurements were taken to quantify the physical characteristics in the areas of the seine hauls. Macrohabitat data taken at each of the seine sites consisted of site length, presence or absence of cover, macrohabitat type, depth, velocity, and substrate. The latter three measurements were taken three times for each seine haul, at the upper, middle, and lower end of the area seined (=discrete macrohabitat). The number of seine hauls per site ranged from 6 (macrohabitat site 9; Bosque del Apache) to 21 (macrohabitat site 4; Central Avenue Bridge) and depended upon the variety of macrohabitat types available. Physico-chemical parameters (water temperature, dissolved oxygen, conductivity, and salinity) were measured at macrohabitat sites during 1989 but subsequently discontinued because of its negligible value and the availability of similar information from USGS gauging stations.

Macrohabitat fish collections and inventory samples from macrohabitat sites were subjected to a Wilcoxon Rank Sums test, a non-parametric two-sample comparison, to test for differences between samples from the same sites. This is a robust test that can be used with individual samples of different sizes. Macrohabitat samples ($N=2$-4) from a single site were combined, as were inventory samples ($N=1$-4). When $p>0.05$, the rank abundance of species between the two types of samples were not statistically distinguishable.

Multiple non-independent tests (ANOVA) performed on data collected during species-habitat association studies required Bonferroni corrections reducing the α level from 0.05 to 0.001. ANOVA was used to test for differences in the mean number of individuals of a given species according to habitat, depth, velocity, and substrate; it could not, however, be used to determine correlation between species occurrence and specific habitat, depths, velocities, or substrate types. For those that were significant ($p \leq 0.001$), a multiple comparison test (Duncan's new multiple range test) was used, subsequent to the ANOVA, to determine differences between means of specific habitat parameters. Information from Duncan's new multiple range test allowed qualitative description of species-habitat associations.

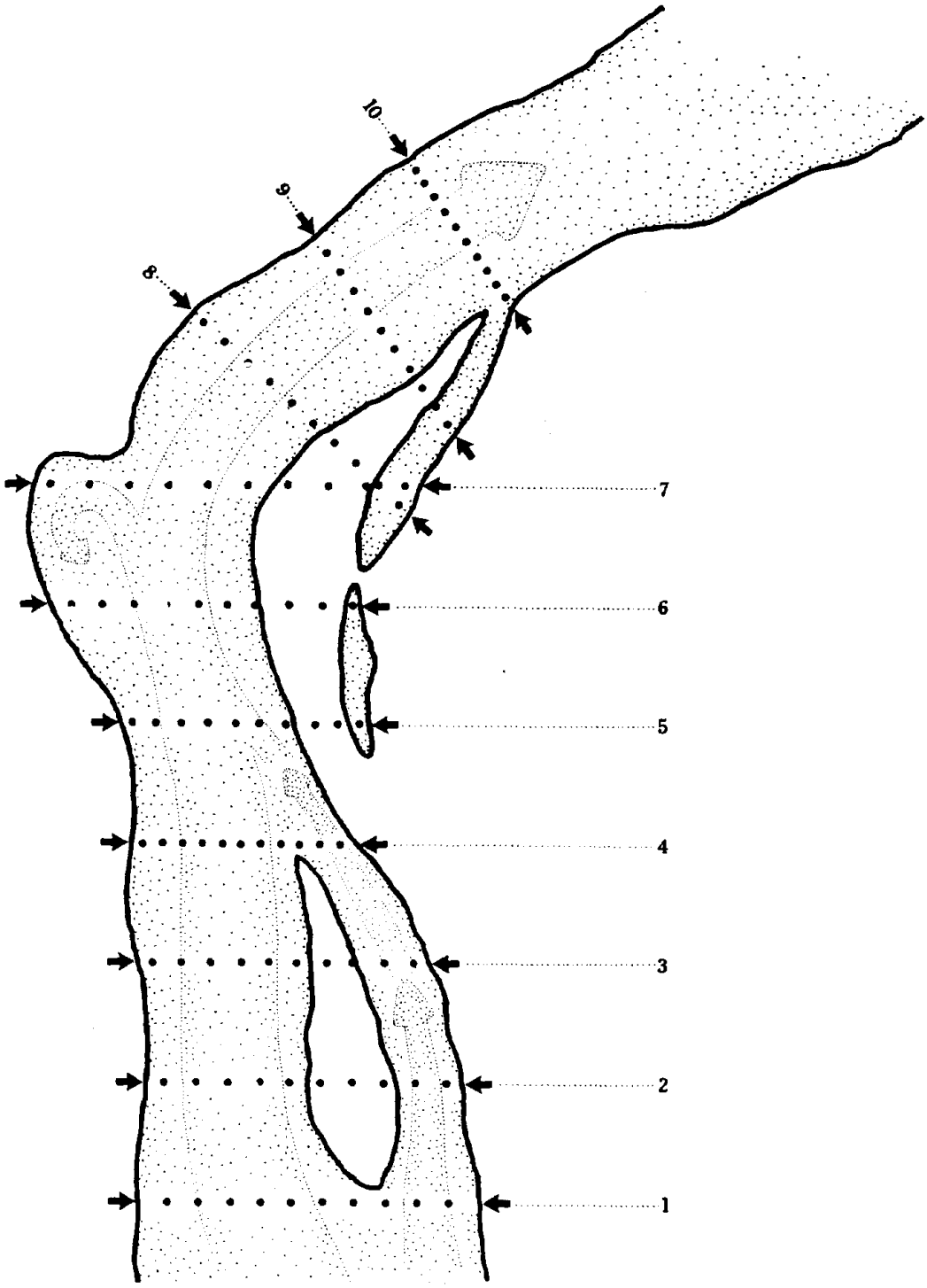

Figure 3. Diagram of hypothetical macrohabitat transect. Numbers refer to transects and ● indicates points at which macrohabitat variables (depth, velocity, and substrate) were measured.

Collection sites, dates of capture, field numbers, collectors, species and number of individual fish collected, and museum catalog number are presented in Appendix I for the inventory phase of this study and in Appendix II for the macrohabitat collections. Dot distribution maps of fishes taken in both phases of this study are presented in Appendix III.

Specific locations of the sites were derived from 1:24,000 U.S. Geological Survey 7.5-minute-series quadrangles of the region and plotted on a U.S. Geological Survey 1:500,000 state of New Mexico base map. The distribution map was traced from the latter map and photographically reduced to appear on a single page. The 43 Rio Grande inventory sites were ordered from upstream to downstream. The nine macrohabitat sites were also ordered from up to downstream and can be recognized by the presence of "MH" preceding the site number. The letters "CC" prior to a collection locality number signify Low-Flow Conveyance Canal collection sites (N=11). All symbols and numbers on the base map correspond to data in Appendices I-III.

Scientific and common names in this report generally followed Robins et al. (1991). Exceptions were the retention of the genera Pantosteus for Rio Grande sucker (after Minckley 1973) and Ictalurus, instead of Ameiurus, for bullhead catfishes. This latter decision was an attempt to avoid injecting unnecessary confusion into the report. Both scientific and common names were used the first time a taxon was mentioned in the text. Thereafter, only common names were used. Common names were used in tables and arranged in phylogenetic order.

Portions of the data contained in this report were previously presented in Bestgen and Platania (1989), Platania (1991b), and abbreviated interagency progress reports. Re-examination of specimens, modification in procedures, and review and correction of errors in the aforementioned reports have resulted in several changes to those databases. In an effort to avoid confusion, the reader should be aware that the data on which this report was based have been appended and supersede Bestgen and Platania (1989), Platania (1991b), and all other interim summary documents.

RESULTS

SYNOPSIS OF INVENTORY COLLECTIONS

A total of 31,699 specimens representing six orders, eight families, and 26 species (Table 5) was collected in the 88 inventory samples taken in the Rio Grande and Low-Flow Conveyance Canal in 1987-1990. Of the total catch, 1.17% of the fish were taken in the Low-Flow Conveyance Canal, 26.34% in the Rio Grande between Velarde and Albuquerque, and 72.49% in the Rio Grande between Bernalillo and Elephant Butte Reservoir (Figure 4). Native taxa (N=9) dominated the samples, comprising 85.1% of the total catch (Table 6; Figure 5). The number of individuals taken per native species ranged from two smallmouth buffalo (Ictiobus bubulas) to 16,670 red shiner (Cyprinella lutrensis).

Almost twice (1.8) as many introduced as native species were present but the former accounted for only 14.9% of the total numerical catch. Eight of the 17 (47%) non-native fish were represented by three or fewer specimens. Western mosquitofish (Gambusia affinis) and white sucker (Catostomus commersoni), the two most abundant non-native species, together accounted for 73% of the non-native catch (N=3,461).

Table 5. Scientific and common names and species abbreviations ( ) of fish collected from the Rio Grande (Velarde to Elephant Butte, NM) and Low-Flow Conveyance Canal (San Acacia to Elephant Butte, NM) 1987-1992.

SCIENTIFIC NAME	COMMON NAME AND ABBREVIATION	
Order Salmoniformes		
Family Salmonidae	salmon and trout	
Oncorhynchus mykiss	rainbow trout	(RBT)
Salmo trutta	brown trout	(BNT)
Order Clupeiformes		
Family Clupeidae	herrings	
Dorosoma cepedianum	gizzard shad	(GZS)
Order Cypriniformes		
Family Cyprinidae	carps and minnows	
Cyprinus carpio	common carp	(CCA)
Cyprinella lutrensis	red shiner	(RDS)
Gila pandora	Rio Grande chub	(RGC)
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)
Ictiobus bubulas	smallmouth buffalo	(SMB)
Pantosteus plebeius	Rio Grande sucker	(RGS)
Order Siluriformes		
Family Ictaluridae	bullhead catfishes	
Ictalurus melas	black bullhead	(BBH)
Ictalurus natalis	yellow bullhead	(YBH)
Ictalurus punctatus	channel catfish	(CCT)
Pylodictis olivaris	flathead catfish	(FLC)

Table 5. continued.

SCIENTIFIC NAME	COMMON NAME AND ABBREVIATION	
Order Cyprinodontiformes		
Family Poeciliidae	livebearers	
Gambusia affinis	western mosquitofish	(MOS)
Order Perciformes		
Family Percichthyidae	temperate basses	
Morone chrysops	white bass	(WHB)
Family Centrarchidae	sunfishes	
Lepomis cyanellus	green sunfish	(GNS)
Lepomis macrochirus	bluegill	(BGL)
Lepomis megalotis	longear sunfish	(LES)
Micropterus salmoides	largemouth bass	(LMB)
Pomoxis annularis	white crappie	(WCR)
Pomoxis nigromaculatus	black crappie	(BCR)

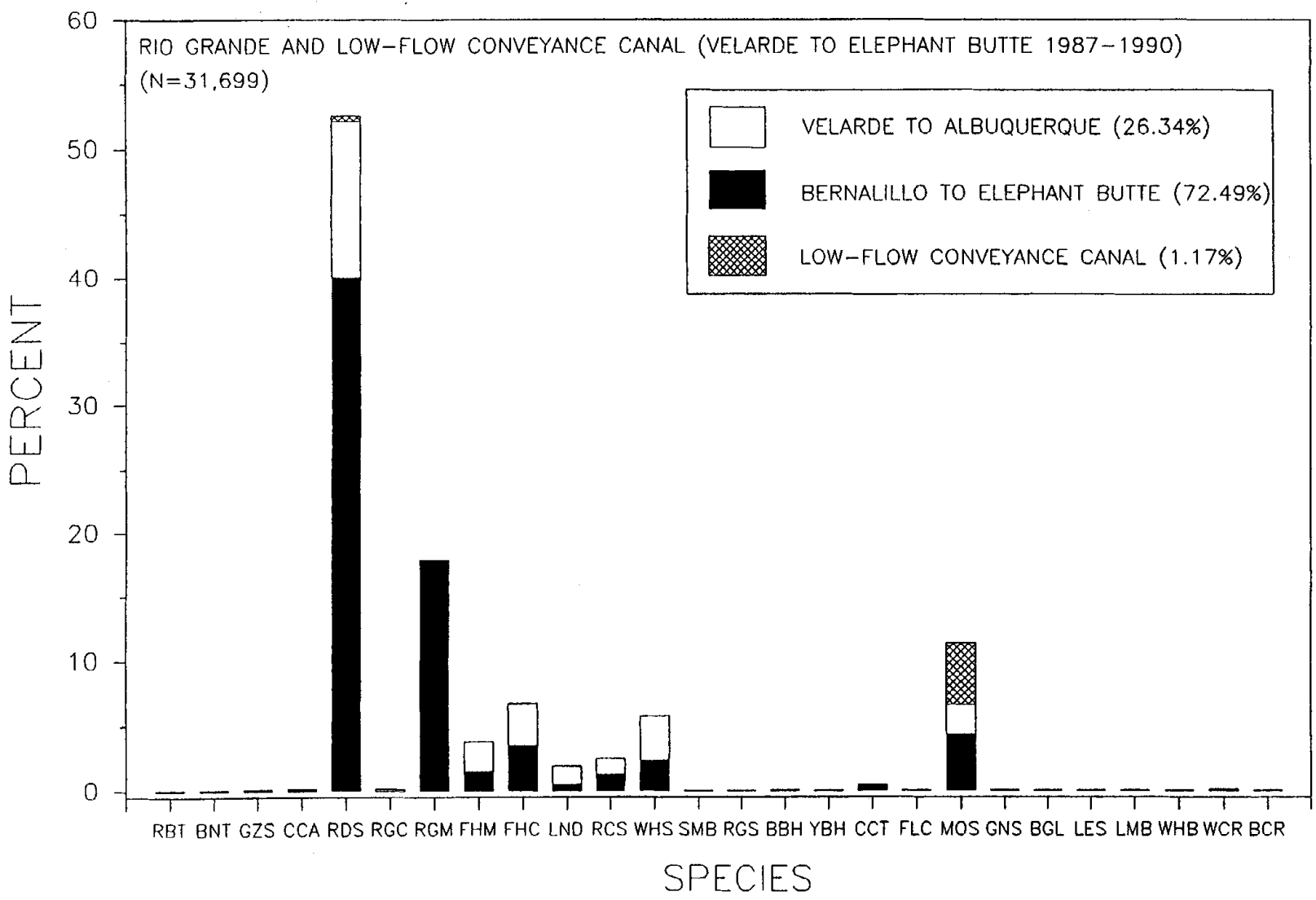

Figure 4. Percentage of fish collected in each of the three study reaches during inventory sampling, 1987-1990.

Table 6. Summary of 1987-1990 Rio Grande and Low-Flow Conveyance Canal ichthyofaunal composition between Velarde and Elephant Butte Reservoir (N=88 collections).

SPECIES	RESIDENT STATUS	TOTAL NUMBER OF SPECIMENS	RANK ABUNDANCE	FREQUENCY OF OCCURRENCE	% TOTAL
SALMON AND TROUT					
rainbow trout	I	1	23	1	0.003
brown trout	I	3	18	3	0.01
HERRINGS					
gizzard shad	I	30	13	8	0.10
CARPS AND MINNOWS					
common carp	I	51	10	20	0.16
red shiner	N	16,670	1	75	52.59
Rio Grande chub	N	43	11	5	0.14
Rio Grande silvery minnow	N	5,669	2	46	17.88
fathead minnow	N	1,077	6	62	3.40
flathead chub	N	2,098	4	64	6.62
longnose dace	N	608	8	44	1.92
SUCKERS					
river carpsucker	N	795	7	43	2.51
white sucker	I	1,811	5	52	5.71
smallmouth buffalo	N	2	20	1	0.006
Rio Grande sucker	N	8	17	3	0.03
BULLHEAD CATFISHES					
black bullhead	I	21	14	9	0.07
yellow bullhead	I	11	16	6	0.03
channel catfish	I	463	9	48	1.46
flathead catfish	I	1	23	1	0.003
LIVEBEARERS					
western mosquitofish	I	2,280	3	61	7.19
SUNFISHES					
green sunfish	I	2	20	2	0.006
bluegill	I	3	18	3	0.01
longear sunfish	I	1	23	1	0.003
largemouth bass	I	14	15	9	0.04
white bass	I	1	23	1	0.003
white crappie	I	34	12	18	0.11
black crappie	I	2	20	1	0.006
TOTAL		31,699			

(STATUS: N = NATIVE, I = INTRODUCED)

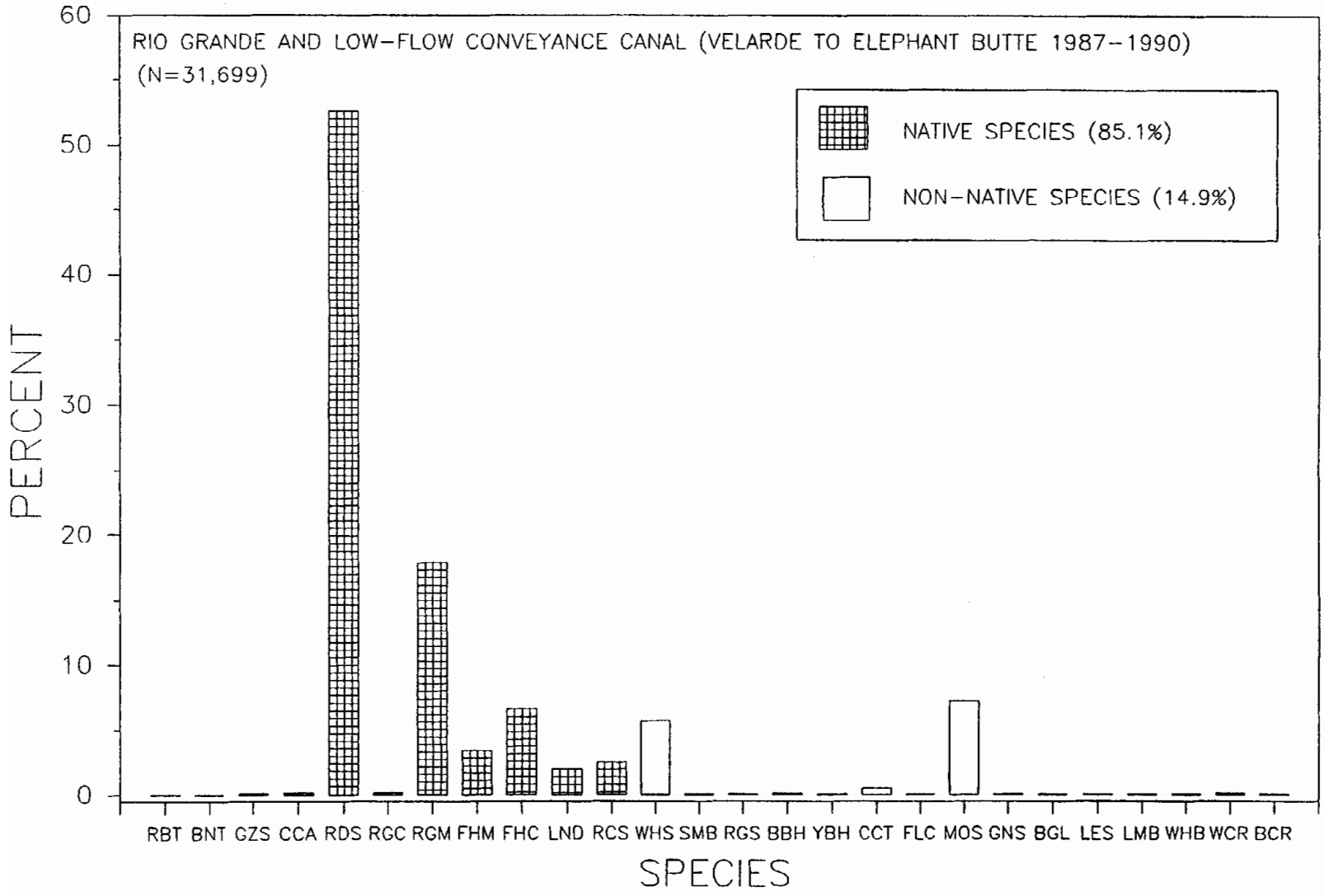

Figure 5. Ichthyofaunal composition of the Rio Grande and Low-Flow Conveyance Canal, based on inventory sampling, 1987-1990.

The 27 samples taken in 1990 at the 16 upper Rio Grande sites yielded 22 species represented by 8,348 specimens (Table 7, Figure 6). Native taxa (N=8) numerically dominated the samples, comprising 77.2% (N=6,446). Red shiner, the most abundant species (N=3,838), was 46% of the sample and 59.5% of the native catch in the upper reach. Five species (4 introduced and 1 native) were collected only in this reach of the study area.

The 14 non-native fish species collected in the upper Rio Grande in 1990 were 22.8% (N=1,902) of the total catch from that reach. Two, western mosquitofish and white sucker, comprised a combined 93% of the non-native fish total catch. The third-most abundant introduced fish species, channel catfish (Ictalurus punctatus) (N=102), was only 1% of the total catch and 5% of the non-native catch. The other 11 non-native taxa ranged in abundance from 1 to 13 individuals.

A total of 50 samples at 27 sites was taken from 1987-1988 in the Rio Grande between Bernalillo and the upper-end of Elephant Butte Reservoir (Table 8, Figure 7). These collections produced 18 species and 22,978 specimens. The seven native taxa were 89% (N=20,374) of the total catch with two species, red shiner and Rio Grande silvery minnow, comprising 90% (N=18,355) of that total. The least abundant native, smallmouth buffalo (N=2), comprised only 0.01% of the native catch, whereas the next least abundant native fish, longnose dace (Rhinichthys cataractae) (N=150), represented approximately 1% of the native catch. The other three native taxa from this reach ranged in abundance between 365 and 1,098 specimens.

Eleven non-native fish species, represented by 2,604 specimens, were collected during 1987-1988 in the Rio Grande between Bernalillo and Elephant Butte Reservoir. Western mosquitofish (N=1,358) and white sucker (N=753) were 52% and 29%, respectively, of the non-native fish total catch from this reach. Channel catfish (N=356) was the only other species to comprise a significant portion (14%) of the non-native catch.

The 11 collections made in the Low-Flow Conveyance Canal in 1988 produced 373 specimens and 11 species (Table 9, Figure 8). As in the Rio Grande, red shiner was the numerically dominant (N=143) native fish, while western mosquitofish was the most abundant (N=210) introduced fish. These two species comprised a combined 95% of the total catch. The other three native and six non-native species were represented by five or fewer specimens.

Inventory

The upper-most reach of the upper Rio Grande study area (sites 1-16) contained several species characteristic of cold, clear, fast flowing waters (Table 10). Rainbow trout (Oncorhynchus mykiss), brown trout (Salmo trutta), Rio Grande chub (Gila pandora), and Rio Grande sucker (Pantosteus plebeius) were collected only at upstream sites (sites 1-7). Although the number of salmonids collected was small (N=4), this was most likely a reflection of bias in sampling methods as opposed to a true indication of their relative abundance. Rio Grande chub, a Rio Grande basin endemic cyprinid taken in five samples in the upper portion of the study area, was not collected downstream of inventory site 4 (Otowi Bridge). It was most abundant (N=36) at the Velarde Diversion Dam collection locality (site 1) and has been collected in the mainstem Rio Grande upstream into Colorado.

Table 7. Summary of 1990-1991 Rio Grande ichthyofaunal composition between Velarde and Albuquerque (N=27 collections).

SPECIES	RESIDENT STATUS	TOTAL NUMBER OF SPECIMENS	RANK ABUNDANCE	FREQUENCY OF OCCURRENCE	% TOTAL
SALMON AND TROUT					
rainbow trout	I	1	20	1	0.01
brown trout	I	3	13	3	0.04
HERRINGS					
gizzard shad	I	13	10	3	0.16
CARPS AND MINNOWS					
common carp	I	4	12	3	0.05
red shiner	N	3,838	1	19	45.98
Rio Grande chub	N	43	9	5	0.52
Rio Grande silvery minnow	N	3	13	2	0.04
fathead minnow	N	707	5	22	8.47
flathead chub	N	999	3	24	11.97
longnose dace	N	458	6	22	5.49
SUCKERS					
river carpsucker	N	390	7	10	4.67
white sucker	I	1,054	2	24	12.63
Rio Grande sucker	N	8	11	3	0.10
BULLHEAD CATFISHES					
black bullhead	I	2	16	2	0.02
yellow bullhead	I	2	16	2	0.02
channel catfish	I	102	8	10	1.22
LIVEBEARERS					
western mosquitofish	I	712	4	21	8.53
SUNFISHES					
green sunfish	I	1	20	1	0.01
largemouth bass	I	3	13	2	0.04
white bass	I	1	20	1	0.01
white crappie	I	2	16	2	0.02
black crappie	I	2	16	1	0.02
TOTAL	8,348				

(STATUS: N = NATIVE, I = INTRODUCED)

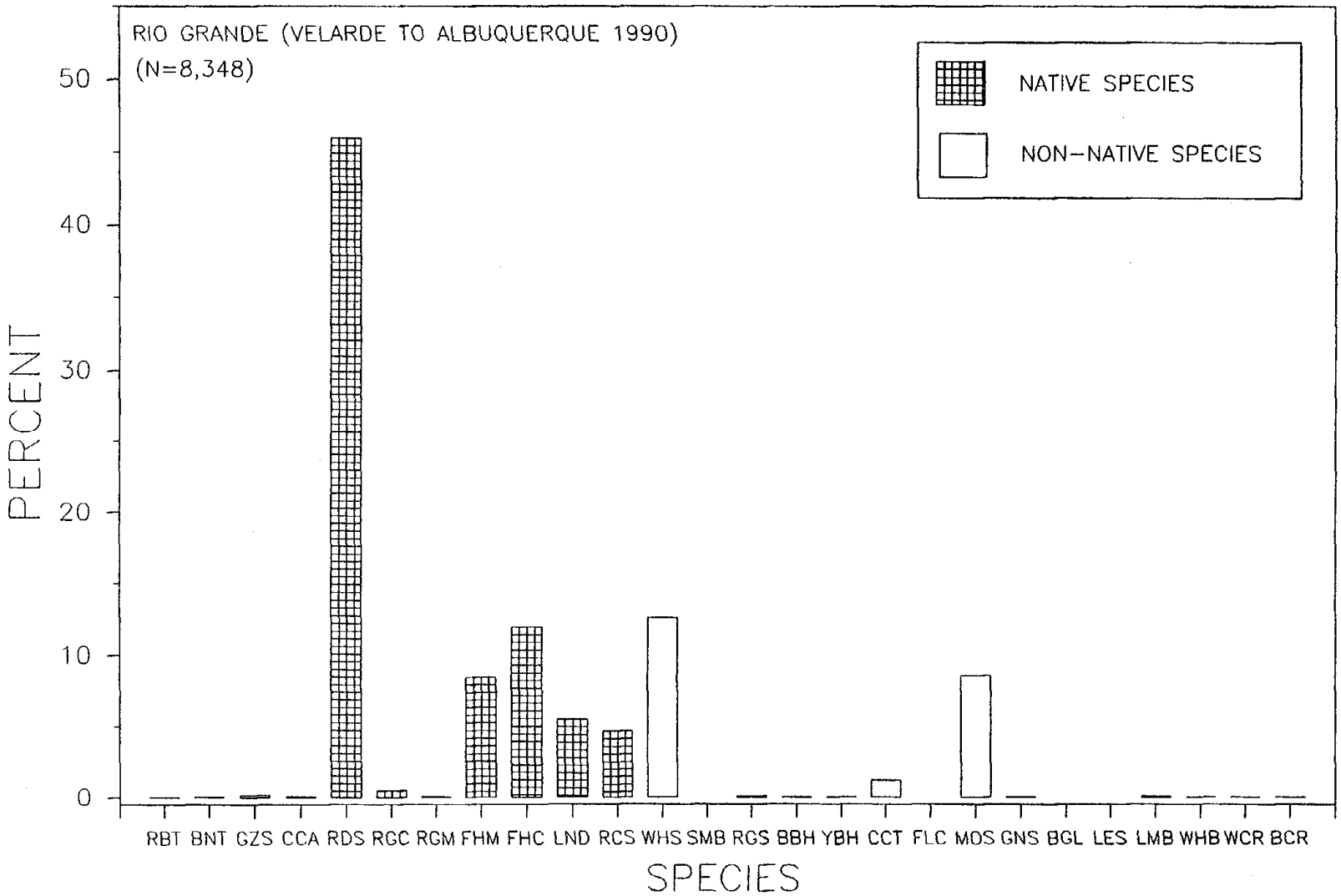

Figure 6. Ichthyofaunal composition of the Rio Grande, based on 1990 inventory sampling, between Velarde and Albuquerque.

Table 8. Summary of 1987-1988 Rio Grande ichthyofaunal composition between Bernalillo and Elephant Butte Reservoir (N=50 collections).

SPECIES	RESIDENT STATUS	TOTAL NUMBER OF SPECIMENS	RANK ABUNDANCE	FREQUENCY OF OCCURRENCE	% TOTAL
HERRINGS					
gizzard shad	I	16	13	4	0.07
CARPS AND MINNOWS					
common carp	I	47	10	17	0.20
red shiner	N	12,689	1	49	55.22
Rio Grande silvery minnow	N	5,666	2	44	24.66
fathead minnow	N	365	7	36	1.59
flathead chub	N	1,098	4	39	4.78
longnose dace	N	150	9	22	0.65
SUCKERS					
river carpsucker	N	404	6	32	1.76
white sucker	I	753	5	25	3.28
smallmouth buffalo	N	2	17	1	0.009
BULLHEAD CATFISHES					
black bullhead	I	18	12	6	0.08
yellow bullhead	I	9	15	4	0.04
channel catfish	I	356	8	37	1.55
LIVEBEARERS					
western mosquitofish	I	1,358	3	33	5.91
SUNFISHES					
green sunfish	I	1	18	1	0.004
bluegill	I	3	16	3	0.01
largemouth bass	I	11	14	7	0.05
white crappie	I	32	11	16	0.14
TOTAL		22,978			

(STATUS: N = NATIVE, I = INTRODUCED)

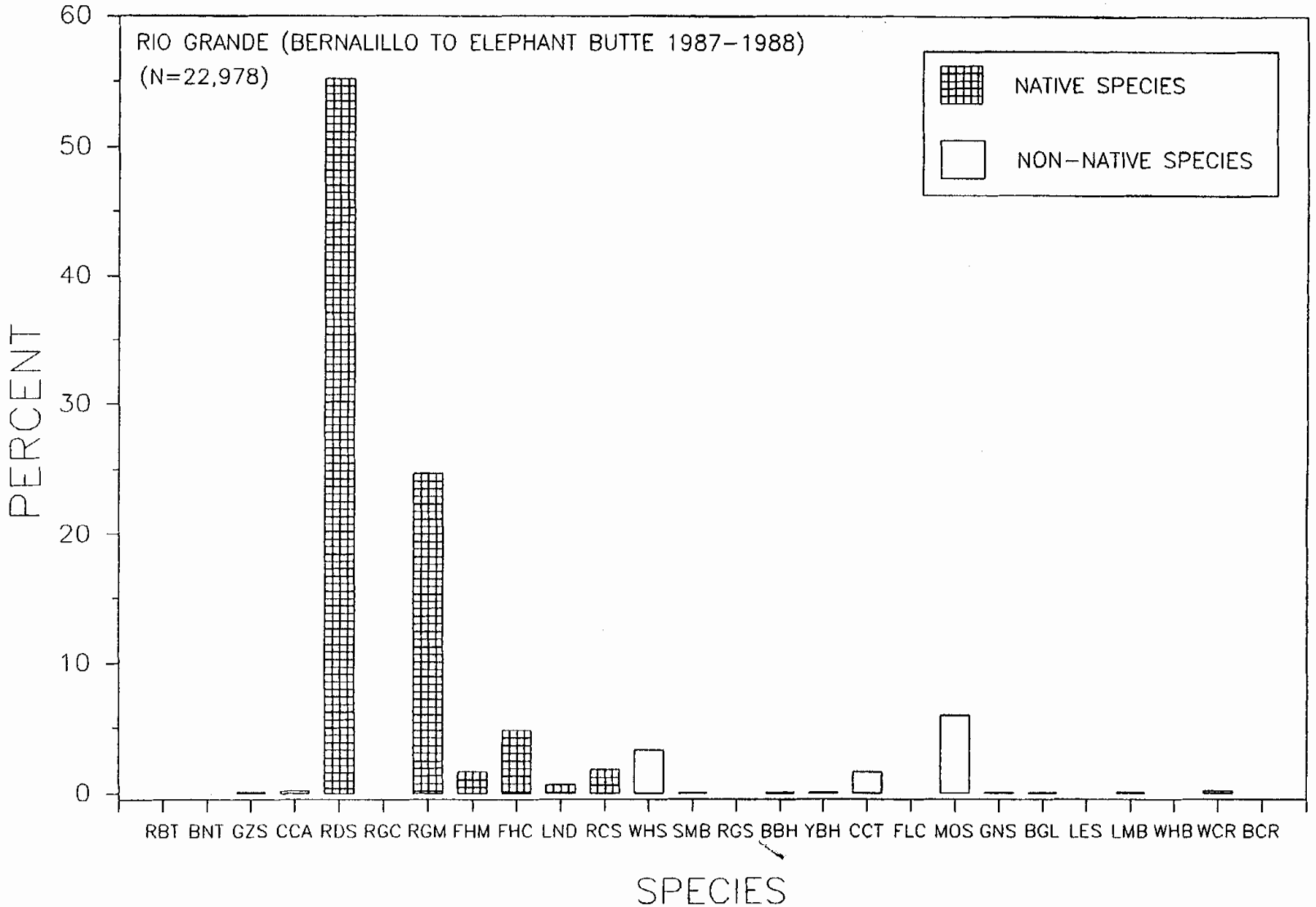

Figure 7. Ichthyofaunal composition of the Rio Grande, based on 1987-1988 inventory sampling, between Bernalillo and Elephant Butte.

Table 9. Summary of 1987-1989 Low-Flow Conveyance Canal ichthyofaunal composition N=11 collections).

SPECIES	RESIDENT STATUS	TOTAL NUMBER OF SPECIMENS	RANK ABUNDANCE	FREQUENCY OF OCCURRENCE	% TOTAL
HERRINGS					
gizzard shad	I	1	6	1	0.27
CARPS AND MINNOWS					
red shiner	N	143	2	7	38.34
fathead minnow	N	5	3	4	1.34
flathead chub	N	1	6	1	0.27
SUCKERS					
river carpsucker	N	1	6	1	0.27
white sucker	I	4	5	3	1.07
BULLHEAD CATFISHES					
black bullhead	I	1	6	1	0.27
channel catfish	I	5	3	1	1.34
flathead catfish	I	1	6	1	0.27
LIVEBEARERS					
western mosquitofish	I	210	1	7	56.30
SUNFISHES					
longear sunfish	I	1	6	1	0.27
TOTAL		373			

(STATUS: N = NATIVE, I = INTRODUCED)

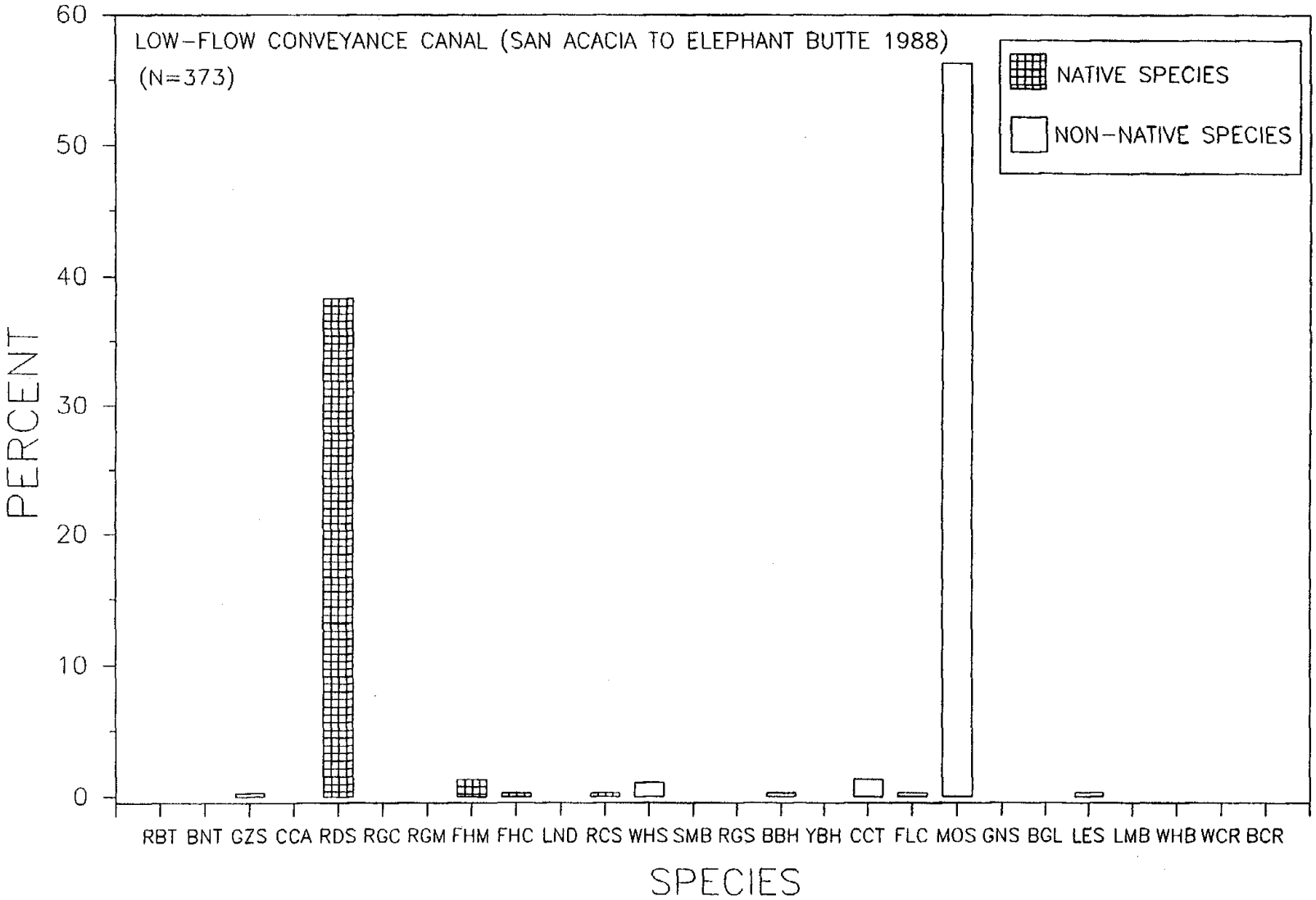

Figure 8. Ichthyofaunal composition of the Low-Flow Conveyance Canal, based on 1988 inventory sampling, between San Acacia and Elephant Butte.

Table 10. Ichthyofaunal composition for 1987-1992 samples (43 collection localities) taken in the Rio Grande between Velarde and Elephant Butte Reservoir. Site numbers correspond to Figure 1.

	SITE									
SPECIES	1	2	3	4	5	6	7	8	9	10
SALMON AND TROUT										
rainbow trout	1	-	-	-	-	-	-	-	-	-
brown trout	1	1	-	-	-	-	-	1	-	-
HERRINGS										
gizzard shad	-	-	1	-	-	-	-	10	-	-
CARPS AND MINNOWS										
common carp	-	2	-	-	-	-	-	-	1	-
red shiner	1	9	2	80	-	-	1	1	1	2
Rio Grande chub	36	1	3	3	-	-	-	-	-	-
Rio Grande silvery minnow	-	-	-	-	-	-	-	-	-	-
fathead minnow	45	27	19	76	1	74	14	58	42	1
flathead chub	13	32	90	133	42	-	-	12	12	-
longnose dace	36	57	61	14	20	-	-	101	23	8
SUCKERS										
river carpsucker	-	-	-	-	-	-	-	24	-	-
white sucker	83	56	22	32	1	62	25	212	73	2
smallmouth buffalo	-	-	-	-	-	-	-	-	-	-
Rio Grande sucker	-	-	4	-	-	-	4	-	-	-
BULLHEAD CATFISHES										
black bullhead	-	1	-	-	-	-	-	-	-	-
yellow bullhead	-	-	-	-	-	-	-	-	-	-
channel catfish	-	-	-	-	-	-	1	2	-	-
LIVEBEARERS										
western mosquitofish	-	3	2	14	1	231	151	59	4	1
SUNFISHES										
green sunfish	-	-	1	-	-	-	-	-	-	-
bluegill	-	-	-	-	-	-	-	-	-	-
largemouth bass	-	2	-	-	-	1	-	-	-	-
white bass	-	-	-	-	-	-	-	1	-	-
white crappie	-	-	1	-	-	-	-	1	-	-
black crappie	-	-	-	-	-	-	-	2	-	-
TOTAL	216	191	206	352	65	368	196	484	156	14

Table 10. continued.

SPECIES	SITE 11	12	13	14	15	16	17	18	19	20
SALMON AND TROUT										
rainbow trout	-	-	-	-	-	-	-	-	-	-
brown trout	-	-	-	-	-	-	-	-	-	-
HERRINGS										
gizzard shad	-	-	-	-	-	2	-	-	-	-
CARPS AND MINNOWS										
common carp	-	3	-	-	-	1	-	1	-	-
red shiner	49	589	1,372	529	617	659	119	656	250	24
Rio Grande chub	-	-	-	-	-	-	-	-	-	-
Rio Grande silvery minnow	-	41	-	3	-	1	-	828	723	-
fathead minnow	20	97	129	90	26	18	-	49	9	-
flathead chub	9	181	78	361	61	41	112	249	4	1
longnose dace	40	97	32	37	3	23	12	6	-	1
SUCKERS										
river carpsucker	1	29	59	58	162	98	37	-	8	1
white sucker	59	586	42	205	64	18	4	17	9	1
smallmouth buffalo	-	-	-	-	-	-	-	-	-	-
Rio Grande sucker	-	-	-	-	-	-	-	-	-	-
BULLHEAD CATFISHES										
black bullhead	-	-	-	1	-	1	-	6	-	-
yellow bullhead	-	-	-	-	2	-	-	-	-	-
channel catfish	2	6	-	40	36	25	4	1	3	1
LIVEBEARERS										
western mosquitofish	1	81	14	4	82	146	14	23	25	52
SUNFISHES										
green sunfish	-	-	-	-	-	-	-	1	-	-
bluegill	-	-	-	-	-	-	-	-	-	-
largemouth bass	-	-	-	-	-	-	-	-	-	-
white bass	-	-	-	-	-	-	-	-	-	-
white crappie	-	10	-	-	-	-	-	7	-	-
black crappie	-	-	-	-	-	-	-	-	-	-
TOTAL	181	1,720	1,726	1,328	1,053	1,033	302	1,844	1,031	81

Table 10. continued.

SPECIES	SITE 21	22	23	24	25	26	27	28	29	30
SALMON AND TROUT										
rainbow trout	-	-	-	-	-	-	-	-	-	-
brown trout	-	-	-	-	-	-	-	-	-	-
HERRINGS										
gizzard shad	-	-	-	-	-	-	-	-	-	9
CARPS AND MINNOWS										
common carp	-	2	2	-	-	3	2	3	3	5
red shiner	511	645	325	141	356	843	297	2,147	1,174	2,274
Rio Grande chub	-	-	-	-	-	-	-	-	-	-
Rio Grande silvery minnow	267	27	61	139	65	38	12	100	57	2,319
fathead minnow	16	14	8	31	5	63	31	8	41	35
flathead chub	6	22	5	2	8	5	1	70	7	470
longnose dace	3	1	-	3	-	1	-	14	-	7
SUCKERS										
river carpsucker	11	-	5	3	2	9	36	26	94	55
white sucker	12	4	11	16	-	58	4	32	2	-
smallmouth buffalo	-	-	-	-	-	-	-	-	-	2
Rio Grande sucker	-	-	-	-	-	-	-	-	-	-
BULLHEAD CATFISHES										
black bullhead	-	-	-	-	-	-	-	-	-	3
yellow bullhead	-	1	-	-	-	-	1	2	5	-
channel catfish	42	7	5	2	5	8	10	61	33	28
LIVEBEARERS										
western mosquitofish	62	38	1	165	-	86	25	16	64	20
SUNFISHES										
green sunfish	-	-	-	-	-	-	-	-	-	-
bluegill	1	-	-	-	-	1	-	-	-	-
largemouth bass	2	3	3	1	-	1	1	-	-	-
white bass	-	-	-	-	-	-	-	-	-	-
white crappie	2	4	-	-	1	2	1	1	-	1
black crappie	-	-	-	-	-	-	-	-	-	-
TOTAL	935	768	426	503	442	1,118	421	2,480	1,480	5,228

Table 10. continued.

SPECIES	SITE 31	32	33	34	35	36	37	38	39	40
SALMON AND TROUT										
rainbow trout	-	-	-	-	-	-	-	-	-	-
brown trout	-	-	-	-	-	-	-	-	-	-
HERRINGS										
gizzard shad	-	-	-	-	1	-	1	-	5	-
CARPS AND MINNOWS										
common carp	-	-	11	-	1	-	-	-	1	-
red shiner	212	267	221	9	202	-	302	922	191	127
Rio Grande chub	-	-	-	-	-	-	-	-	-	-
Rio Grande silvery minnow	108	243	32	9	22	-	187	58	34	68
fathead minnow	-	1	-	3	1	-	9	3	3	1
flathead chub	14	8	11	2	13	-	4	7	6	3
longnose dace	-	-	1	-	-	-	-	-	-	1
SUCKERS										
river carpsucker	6	3	6	6	20	-	16	1	12	3
white sucker	-	-	85	-	-	-	6	-	3	-
smallmouth buffalo	-	-	-	-	-	-	-	-	-	-
Rio Grande sucker	-	-	-	-	-	-	-	-	-	-
BULLHEAD CATFISHES										
black bullhead	-	-	-	-	-	-	-	-	2	-
yellow bullhead	-	-	-	-	-	-	-	-	-	-
channel catfish	9	10	-	11	5	-	20	36	2	14
LIVEBEARERS										
western mosquitofish	15	3	10	8	235	-	17	25	35	-
SUNFISHES										
green sunfish	-	-	-	-	-	-	-	-	-	-
bluegill	-	-	-	-	-	-	-	-	-	-
largemouth bass	-	-	-	-	-	-	-	-	-	-
white bass	-	-	-	-	-	-	-	-	-	-
white crappie	-	-	-	-	1	-	-	-	1	-
black crappie	-	-	-	-	-	-	-	-	-	-
TOTAL	364	535	377	48	501	0	562	1,052	295	217

Table 10. continued.

SPECIES	SITE 41	42	43
SALMON AND TROUT			
rainbow trout	-	-	-
brown trout	-	-	-
HERRINGS			
gizzard shad	-	-	-
CARPS AND MINNOWS			
common carp	-	2	8
red shiner	117	203	80
Rio Grande chub	-	-	-
Rio Grande silvery minnow	93	20	114
fathead minnow	-	2	2
flathead chub	2	-	-
longnose dace	-	-	6
SUCKERS			
river carpsucker	-	-	3
white sucker	-	-	1
smallmouth buffalo	-	-	-
Rio Grande sucker	-	-	-
BULLHEAD CATFISHES			
black bullhead	-	6	-
yellow bullhead	-	-	-
channel catfish	7	18	4
LIVEBEARERS			
western mosquitofish	31	136	170
SUNFISHES			
green sunfish	-	-	-
bluegill	-	-	1
largemouth bass	-	-	-
white bass	-	-	-
white crappie	1	-	-
black crappie	-	-	-
TOTAL	251	387	389

Rio Grande sucker, taken at two localities (sites 3 and 7) in the upper study area, was represented by four specimens from each locality. The non-native white sucker, conversely, was more abundant throughout this study reach. At sites of sympatry with Rio Grande sucker, white sucker was at least 5-times more abundant. White sucker is known to hybridize with Rio Grande sucker and the latter does not appear to reach potential levels of abundance in the presence of the former. White sucker was most abundant in the upper study area, comprising 12.6% of the total catch compared to 3.3% of the catch in the Rio Grande from Bernalillo downstream to Elephant Butte.

Flathead chub (Platygobio gracilis) and longnose dace were also numerically important components of the upper study area ichthyofauna together comprising 17.4% (N=1,457) of the total catch. Both species persisted in collections in the lower reach occurring in at least 44% of the samples. However, in the lower Rio Grande study area, flathead chub and longnose dace were only 4.8% and 0.7% of the total catch, respectively. No more than 14 longnose dace was collected at any of the downstream sampling localities.

Approximately 73% (N=22,978) of the fish collected during the inventory were taken in the Rio Grande between Bernalillo and Elephant Butte Reservoir. The most important difference in the Rio Grande ichthyofaunal community between the upper and lower reaches was the addition of the Rio Grande silvery minnow as a major faunal component (24.7%) in the lower reach. This species occurred regularly in collections downstream of Bernalillo in the mainstem of the Rio Grande. Generally, however, <20 adults per sample were taken at sites between Bernalillo and Isleta. Downstream from Isleta to Elephant Butte Reservoir, collections of >50 Rio Grande silvery minnow were common. The largest collections were made below Isleta and San Acacia Diversion dams in late summer when most discharge from the Rio Grande was diverted to canals. Subsequent non-systematic 1990-1991 collections in this reach (not included in the appended database) suggest a much reduced range and significantly lower population densities of Rio Grande silvery minnow. In the lower portion of the Velarde to Albuquerque study area (site 14), three Rio Grande silvery minnow were collected in 1990. A total of 41 Rio Grande silvery minnow was collected just upstream of this locality (site 12) in 1987-1988.

The next two most abundant species in this reach were western mosquitofish (N=1,358) and flathead chub (N=1,098). Western mosquitofish comprised 5.9% of the total catch downstream of Bernalillo compared with 8.5% upstream of Albuquerque. Flathead chub density, conversely, decreased from 12% of the upstream catch to 4.8% in the lower Rio Grande study section. In addition, 43% (N=470) of flathead chub taken in the lower reach were collected directly below San Acacia Diversion Dam. When periods of drought occur during the irrigation season, reaches directly below diversion dams are frequently the only watered sections of the river and as such tend to concentrate fish.

The 11 collections (Table 11) in the Low-Flow Conveyance Canal produced the fewest specimens (N=373) and least species-rich ichthyofaunal community (11 species). Red shiner (N=143) and western mosquitofish (N=210) accounted for 95% of the catch from this system. Two of the remaining nine species were represented by five specimens, one by four individuals, and the other six by single fish. Two species, flathead catfish (Pylodictis olivaris) and longear sunfish (Lepomis megalotis), were taken only in the Low-Flow Conveyance Canal.

Table 11. Ichthyofaunal composition for 1987-1989 samples (11 collection localities) taken in the Low-Flow Conveyance Canal. Site numbers correspond to Figure 1.

	SITE									
SPECIES	1	2	3	4	5	6	7	8	9	10
HERRINGS										
gizzard shad	-	-	-	-	-	1	-	-	-	-
CARPS AND MINNOWS										
red shiner	-	-	1	25	100	-	9	1	1	-
fathead minnow	1	2	1	1	-	-	-	-	-	-
flathead chub	-	-	-	-	-	-	-	-	-	-
SUCKERS										
river carpsucker	-	-	-	-	-	1	-	-	-	-
white sucker	-	1	-	-	2	1	-	-	-	-
BULLHEAD CATFISHES										
black bullhead	-	-	-	-	-	-	-	-	-	-
channel catfish	-	-	-	-	-	-	-	-	-	-
flathead catfish	-	-	-	-	-	-	-	-	-	-
LIVEBEARERS										
western mosquitofish	128	57	10	9	1	2	-	-	-	-
SUNFISHES										
longear sunfish	-	-	-	-	-	1	-	-	-	-
TOTAL	129	60	12	35	103	6	9	1	1	0

Table 11. continued.

SPECIES	SITE 11
HERRINGS	
gizzard shad	-
CARPS AND MINNOWS	
red shiner	6
fathead minnow	-
flathead chub	1
SUCKERS	
river carpsucker	-
white sucker	-
BULLHEAD CATFISHES	
black bullhead	1
channel catfish	5
flathead catfish	1
LIVEBEARERS	
western mosquitofish	3
SUNFISHES	
longear sunfish	-
TOTAL	17

ICHTHYOFAUNAL COMPOSITION OF MACROHABITAT SITES

A total of 5,941 specimens representing 18 species was taken in the 331 seine hauls made during 29 visits to the nine macrohabitat sites (Table 12). Fish were taken in 57% (N=187) of the seine samples. The number of specimens per species ranged from one (for three species) to 3,365. Although there were twice as many introduced (N=12) as native species, the native taxa numerically dominated the sample, comprising 78% of the total catch (Figure 9).

There was considerable similarity between the results of the inventory and macrohabitat community composition (Figure 10). Of the cumulative 26 species caught during this study, 18 (69%) were taken in both phases of work. With the exception of Rio Grande silvery minnow, those species unique to inventory sampling were represented by eight or fewer specimens and accounted for <0.1% of the total catch.

Red shiner was the most abundant (N=3,365; 57%) and frequently encountered (132 of 187 samples; 71%) species in macrohabitat sampling. Likewise, it was the most abundant (N=1,667; 53%) and frequently encountered species during the inventory work. Eight of the nine most abundant species in inventory collections were also the most numerous species in macrohabitat samples. Rio Grande silvery minnow, the second-most common fish in the inventory study, was the only abundant inventory species absent from macrohabitat samples.

Western mosquitofish was the second-most abundant species in the macrohabitat samples, comprising 16% of the total catch. This non-native accounted for 72% of the introduced species catch in macrohabitat samples though it was unevenly distributed at the six sites where it occurred. A combined total of 10 western mosquitofish was collected at three sites accounting for approximately 1% of its total catch.

Flathead chub, while the second-most common native species (N=621; 10.5%), was considerably less abundant than red shiner. There were over 5-times as many red shiner collected as flathead chub. The remaining four native species, ranging in abundance from eight Rio Grande chub to 284 longnose dace, cumulatively comprised 11% of the total catch. There were no species, either native or introduced, that were unique to the macrohabitat sampling phase of the study.

Two other numerically important non-native fish species were white sucker (N=161) and channel catfish (N=154). These were the sixth and seventh-most abundant species in macrohabitat samples, and the second and third-most common non-native taxa in both inventory and macrohabitat samples. None of the other non-native fish species collected during macrohabitat sampling (N=9) was represented by more than nine specimens.

Statistical examination (Wilcoxon Rank Sums Test) of the data-set was necessary to determine if there were difference in the fish community collected during macrohabitat and inventory sampling (Figure 11). A lack of difference ($p > 0.05$) would indicate that macrohabitat collections provided a representative sample of the fish community and would allow for extrapolation between macrohabitat and inventory samples. The test yielded p-values >0.05 for all sites indicating that there was no difference between the fish communities collected during macrohabitat and inventory sampling. The p- values, which ranged from 0.1320 (macrohabitat site 9; Bosque del Apache) to 0.9614 (macrohabitat site 4; Central Avenue bridge), can not be used as an indication of relative similarity between the two sampling designs.

Table 12. Summary of 1989-1992 Rio Grande ichthyofaunal composition (based on macrohabitat sampling; N=29) between Velarde and Elephant Butte Reservoir.

SPECIES	RESIDENT STATUS	TOTAL NUMBER OF SPECIMENS	RANK ABUNDANCE	FREQUENCY OF OCCURRENCE	% TOTAL
SALMON AND TROUT					
rainbow trout	I	4	13	2	0.067
brown trout	I	1	16	1	0.017
HERRINGS					
gizzard shad	I	5	12	1	0.084
CARPS AND MINNOWS					
common carp	I	8	10	7	0.135
red shiner	N	3,365	1	132	57.300
Rio Grande chub	N	8	10	5	0.135
fathead minnow	N	245	5	56	4.12
flathead chub	N	621	3	80	10.50
longnose dace	N	284	4	38	4.78
SUCKERS					
river carpsucker	N	144	8	19	2.42
white sucker	I	161	6	18	2.71
BULLHEAD CATFISHES					
black bullhead	I	1	16	1	0.017
yellow bullhead	I	1	16	1	0.017
channel catfish	I	154	7	35	2.59
LIVEBEARERS					
western mosquitofish	I	926	2	30	15.59
SUNFISHES					
bluegill	I	2	14	2	0.034
largemouth bass	I	9	9	2	0.151
white crappie	I	2	14	2	0.034
TOTAL		5,941			

(STATUS: N = NATIVE, I = INTRODUCED)

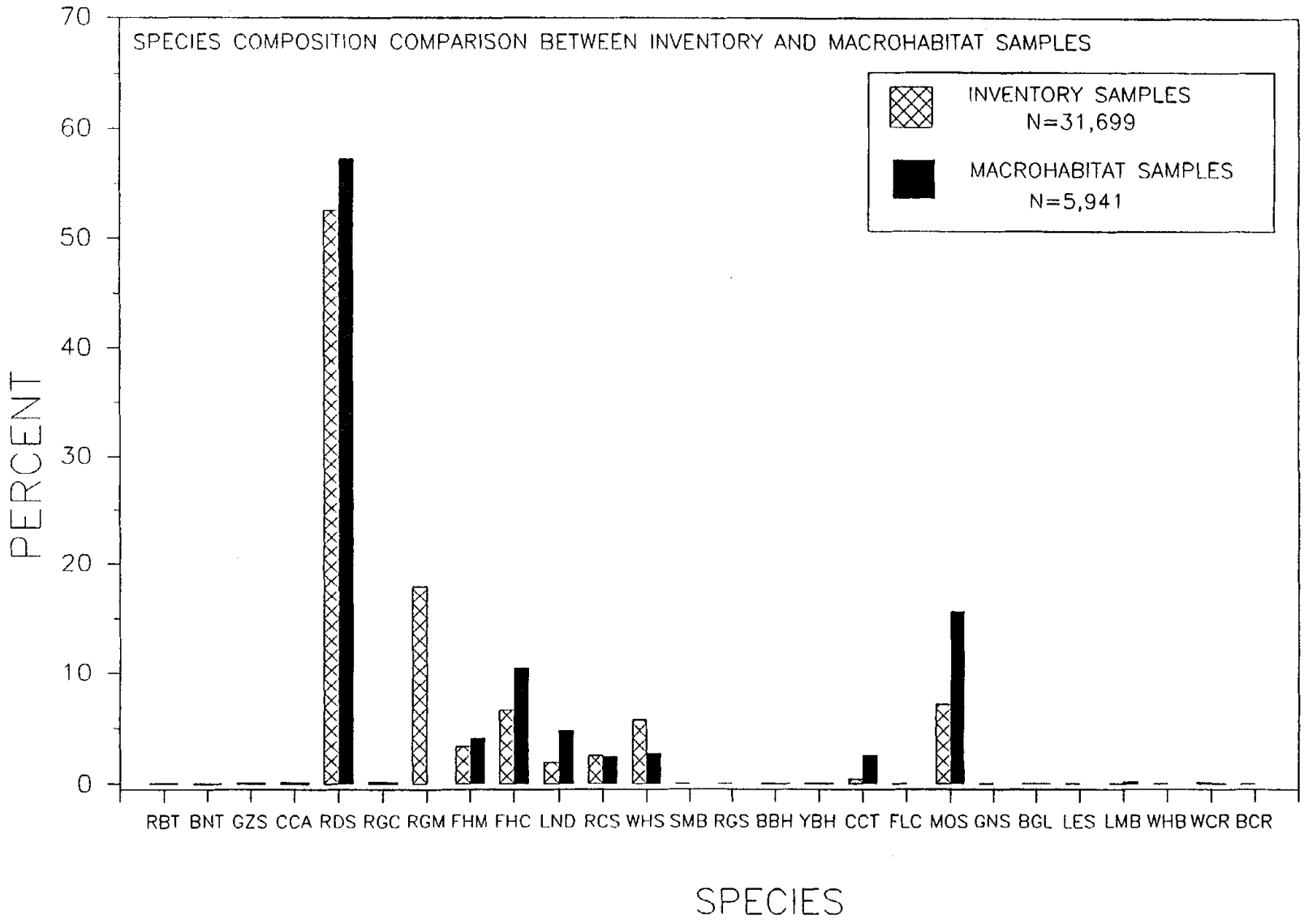

Figure 9. Comparison of ichthyofaunal composition of the Rio Grande, based on inventory and macrohabitat sampling.

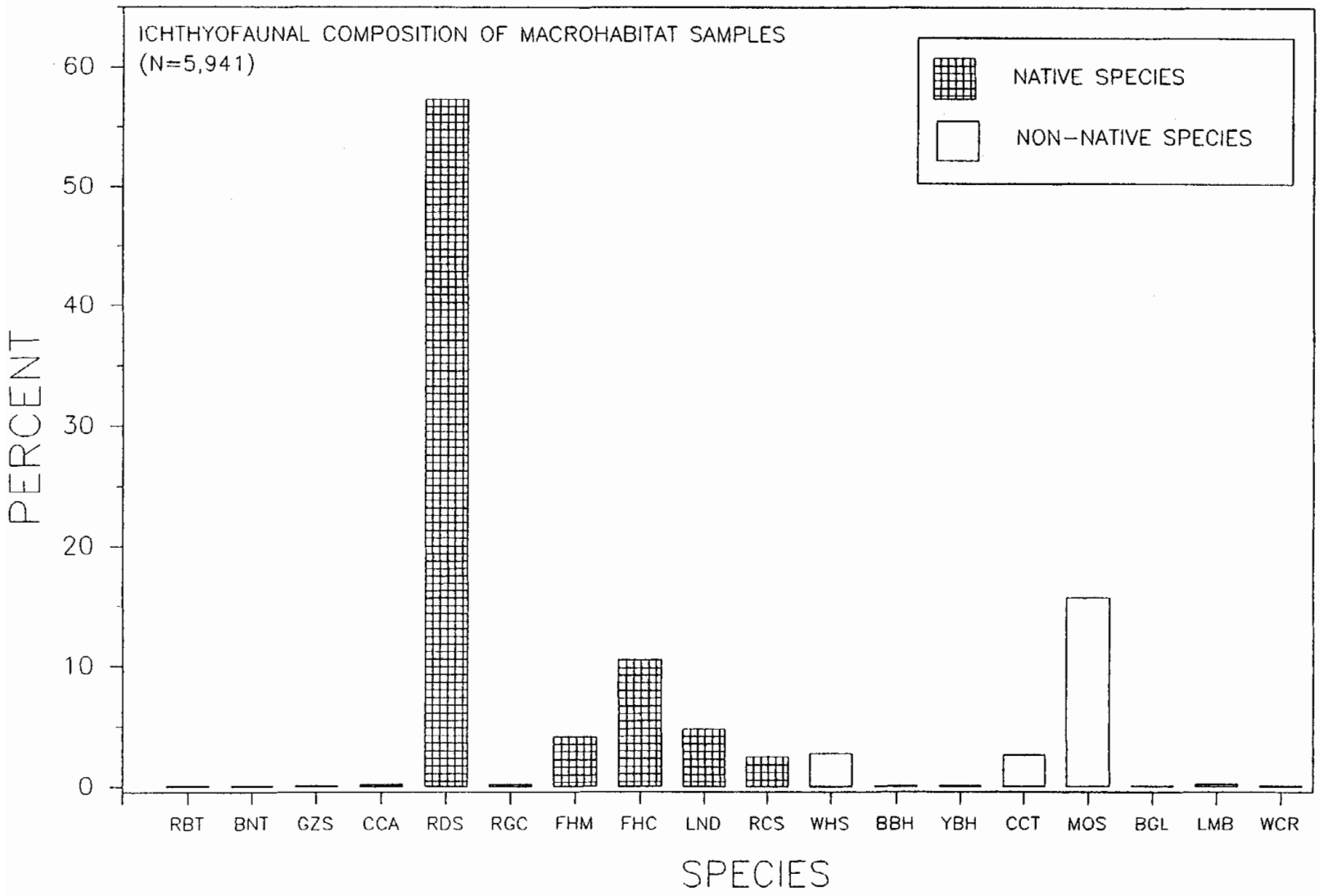

Figure 10. Ichthyofaunal composition of the Rio Grande, based on macrohabitat sampling, between Velarde and Bosque del Apache.

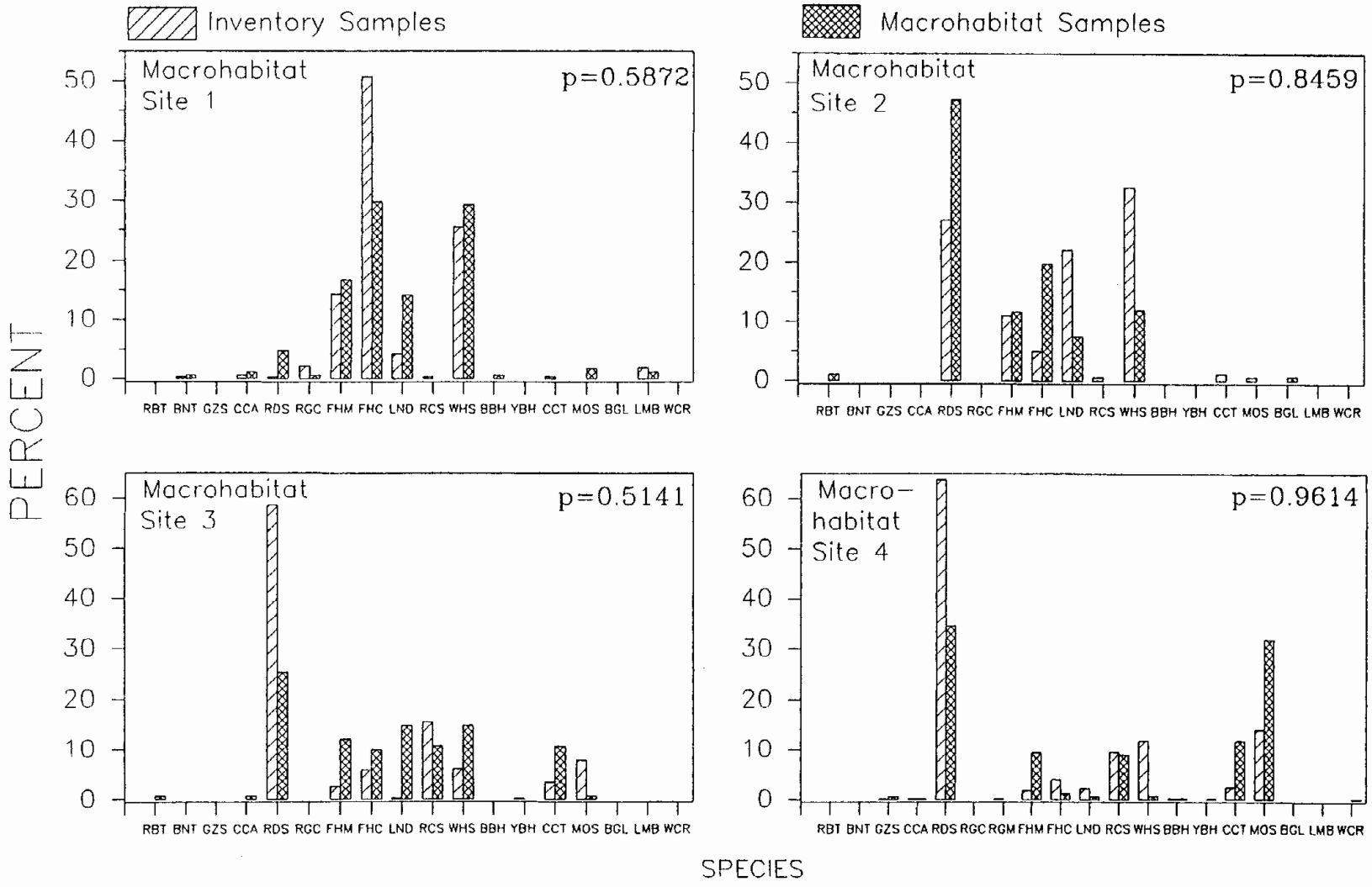

Figure 11. Comparison of inventory and macrohabitat percentage fish species richness at macrohabitat sites.

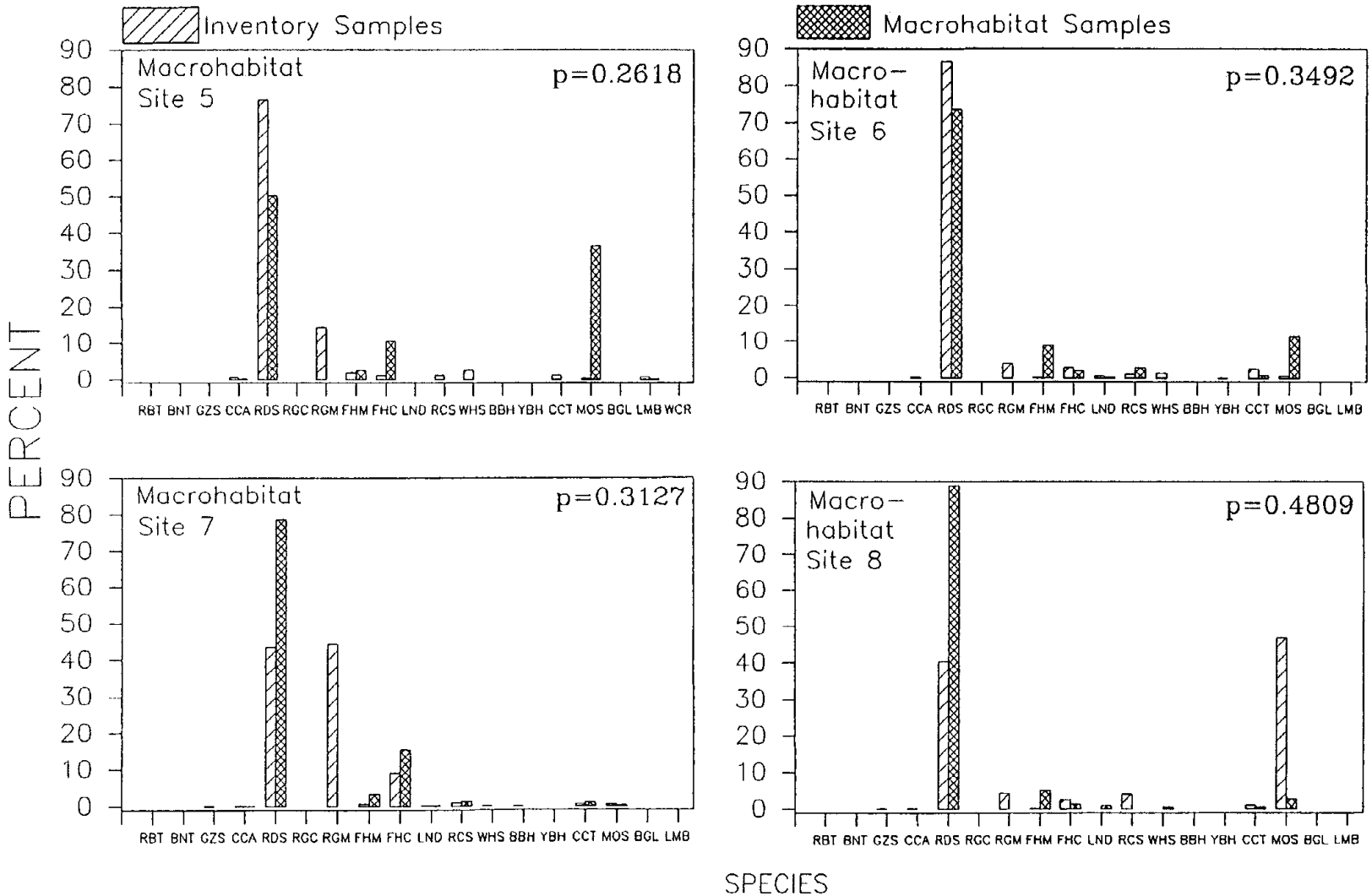

Figure 11. continued.

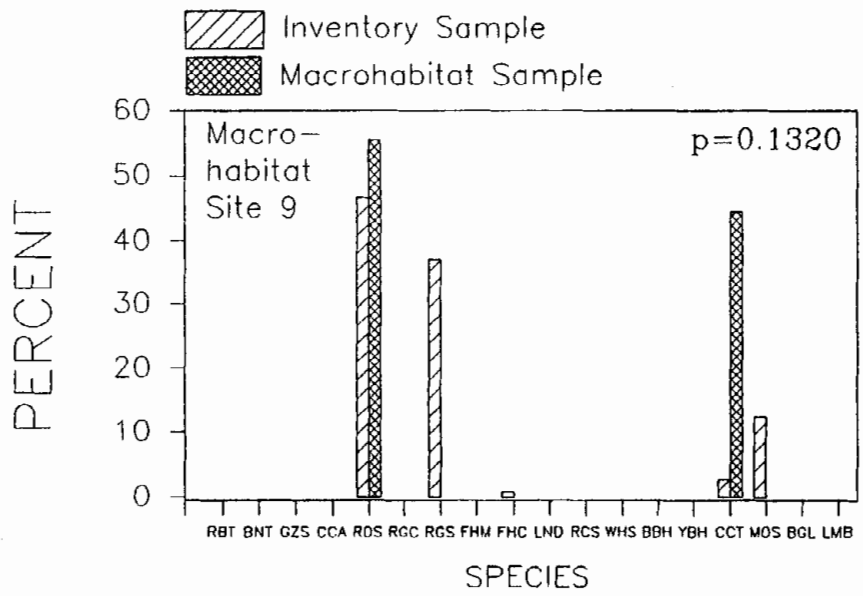

Figure 11. continued.

Species Composition Per Site

MACROHABITAT SITE 1

The most upstream macrohabitat site was the second most species-rich sampling locality, yielding 11 species represented by 385 specimens (Table 13, Figure 12). All cyprinid and catostomid species (N=8) collected during the macrohabitat phase of this survey were present at this sampling location. Longnose dace numerically dominated the ichthyofaunal community, accounting for 51% of the catch, while the second-most abundant fish, white sucker, was represented by 98 specimens or 25% of the sample (Figure 13). Each of these species (longnose dace and white sucker) reached their greatest abundance and highest percentage of catch/site at macrohabitat site 1. Six native fish species dominated the community accounting for 72% (N=276) of the catch, whereas white sucker (N=98) represented 90% of the non-native assemblage.

With the exception of flathead chub, which comprised 14% of the catch (N=55), each of the remaining species (N=8) accounted for less than 5% of the total sample. Species unique to this locality were brown trout and Rio Grande chub (N=8), both of which were associated with cool-cold, clear, fast flowing habitats. Four of the 11 species, brown trout, red shiner, river carpsucker (Carpiodes carpio), and channel catfish, were represented by single specimens. This was the only macrohabitat site where red shiner was not the most abundant cyprinid. Largemouth bass (Micropterus salmoides), which was taken at only two of the macrohabitat sites, reached its greatest abundance at macrohabitat site 1 (N=7).

MACROHABITAT SITE 2

A total of 292 fish representing seven species was collected at the Angostura Diversion Dam macrohabitat locality. Native fish taxa comprised 86% (N=252) of the catch. Red shiner was the most abundant species (N=138) accounting for more than 54% of the native species. Longnose dace was the second most common species followed by flathead chub and fathead minnow (Pimephales promelas). White sucker (N=35), the most abundant introduced fish, was 88% on the non-native catch. The other two introduced fish, rainbow trout and bluegill (Lepomis macrochirus), were represented by three and two individuals, respectively. This was one of two sites where rainbow trout (macrohabitat sites 2 & 3) was collected and the only sampling station where bluegill occurred. It was also one of two sites which did not yield ictalurids.

MACROHABITAT SITE 3

The Alameda Avenue bridge (State Highway 528) site produced 142 specimens representing five native and five non-native species. All of the catostomids and cyprinids except Rio Grande chub, collected during habitat-association sampling were present at this site. Single specimens of rainbow trout, common carp (Cyprinus carpio), and western mosquitofish were taken. This was the most downstream locality for rainbow trout and the most upstream site for western mosquitofish.

Red shiner was the most abundant cyprinid (N=36) and longnose dace the least-common native minnow (N=14). The native cyprinids accounted for all except one of the cyprinid catch (N=88; 99%). The lone non-native minnow was a young-of-year common carp. Both sucker species, river carpsucker and white sucker, were present in about equal numbers. Channel catfish also comprised a notable (11%) portion of the sample and centrarchids were absent.

Table 13. Rio Grande ichthyofaunal composition (1987-1992) between Velarde and Elephant Butte Reservoir. Data based on macrohabitat samples (N=29 samples at 9 collection localities). Site numbers correspond to Figure 1.

	MACROHABITAT SITE NUMBER								
SPECIES	1	2	3	4	5	6	7	8	9
SALMON AND TROUT									
rainbow trout	-	3	1	-	-	-	-	-	-
brown trout	1	-	-	-	-	-	-	-	-
HERRINGS									
gizzard shad	-	-	-	5	-	-	-	-	-
CARPS AND MINNOWS									
common carp	2	-	1	2	2	-	1	-	-
red shiner	1	138	36	320	713	650	1,310	192	5
Rio Grande chub	8	-	-	-	-	-	-	-	-
fathead minnow	16	22	21	5	36	80	54	11	-
flathead chub	55	34	17	86	150	19	257	3	-
longnose dace	195	58	14	11	-	2	2	2	-
SUCKERS									
river carpsucker	1	-	15	82	-	25	21	-	-
white sucker	98	35	21	6	-	-	-	1	-
BULLHEAD CATFISHES									
black bullhead	-	-	-	1	-	-	-	-	-
yellow bullhead	-	-	-	1	-	-	-	-	-
channel catfish	1	-	15	109	-	7	17	1	4
LIVEBEARERS									
western mosquitofish	-	-	1	296	517	103	3	6	-
SUNFISHES AND OTHERS									
bluegill	-	2	-	-	-	-	-	-	-
largemouth bass	7	-	-	-	2	-	-	-	-
white crappie	-	-	-	2	-	-	-	-	-
TOTAL	385	292	142	926	1,420	886	1,665	216	9
# OF SPECIES	11	7	10	13	6	7	8	7	2
NATIVE SPECIES	6	4	5	5	3	5	5	4	1
NON-NATIVE SPECIES	5	3	5	8	3	2	3	3	1
# NATIVE FISHES	276	252	103	506	899	766	1,644	208	5
# NON-NATIVE FISHES	109	40	39	420	521	120	21	8	4
NUMBER OF TIMES SAMPLED	2	2	2	4	4	4	3	4	4

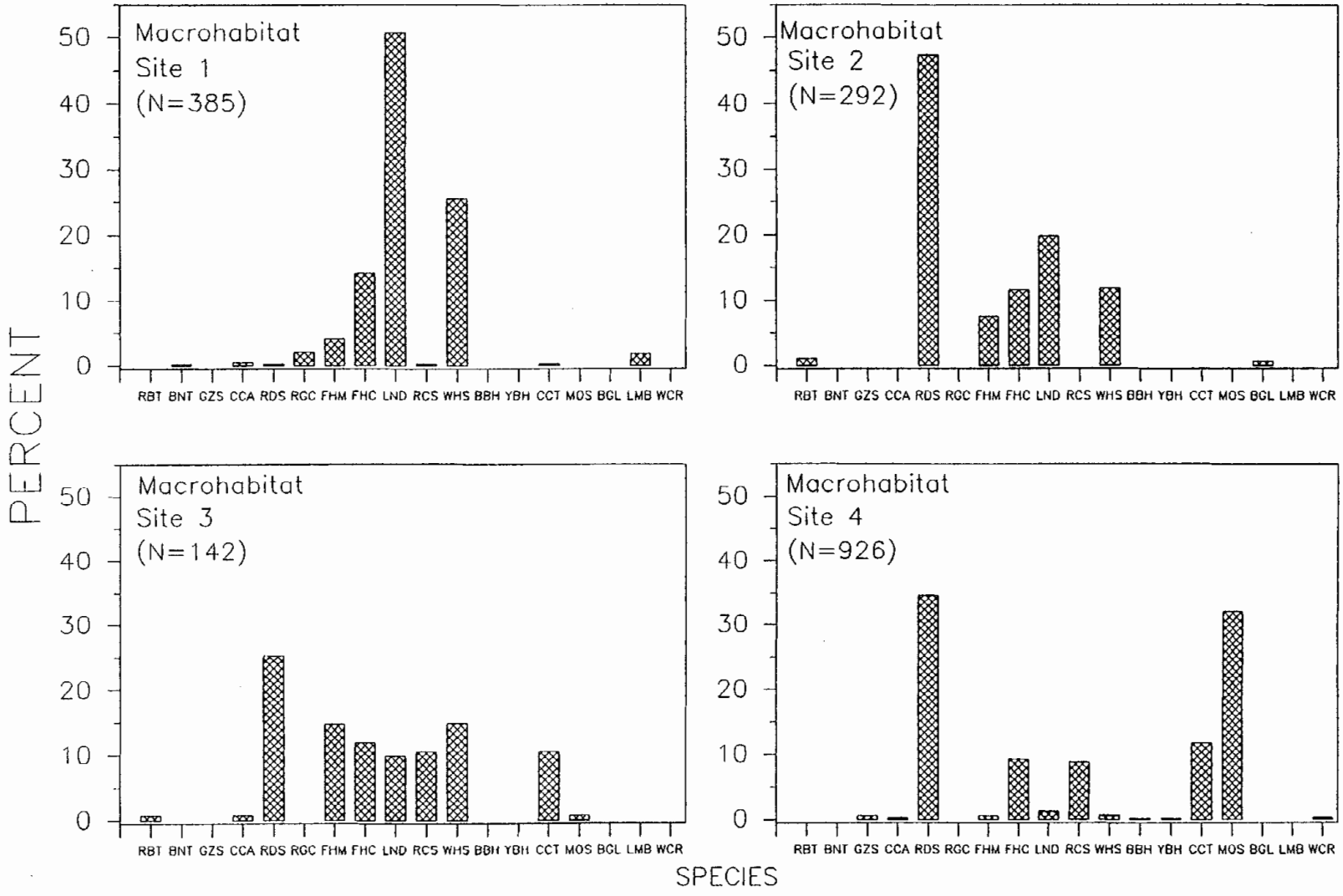

Figure 12. Ichthyofaunal composition (percent) at macrohabitat sites 1-4.

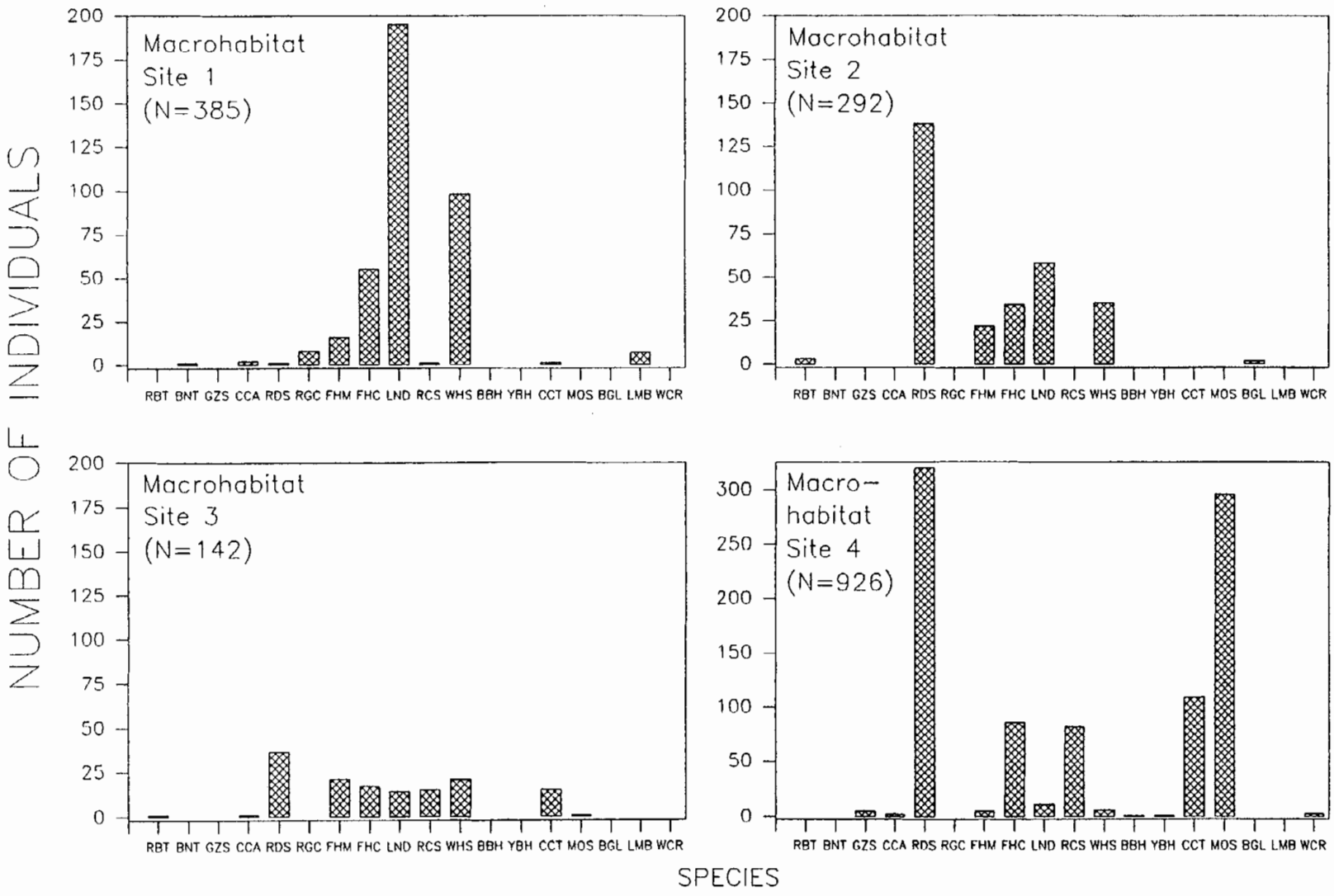

Figure 13. Ichthyofaunal composition (number of individuals) at macrohabitat sites 1-4.

The fish species at this site were relatively equal in abundance. Of the 10 species collected, seven were represented by more than one individual. The most abundant of those seven (red shiner) comprised 25% of the sample while the other six species ranged in percent composition from 11% to 15%. In comparison, the range of percent composition for the "core" species (those taxa represented by more than 5 individuals) at adjacent up and downstream sites, was 7-47% and 1-35%, respectively.

MACROHABITAT SITE 4

This was the most species-rich macrohabitat site, yielding 13 species and 926 specimens. The fish community appeared to be divided into three discrete levels of abundance. Two species, red shiner and western mosquitofish, dominated the community by number, accounting for 35% and 32% of the catch, respectively. The next three most abundant taxa ranged in percent composition from 9-12% for a combined total of 30%. The final group consisted of the eight least common fishes, accounting for 3.5% of the total catch at site 4. Four of those species, gizzard shad (Dorosoma cepedianum), black bullhead (Ictalurus melas), yellow bullhead (Ictalurus natalis), and white crappie (Pomoxis annularis), were collected only at this site. The only fish family collected during this survey that was not represented in macrohabitat site 4 collections was Salmonidae.

As at upstream sites, native taxa dominated the catch by number; 55% native vs. 45% non-native. However, of the 13 fish species collected, eight (62%) were introduced forms. This was the only sample location where the number of non-native species was greater than the number of native species.

The cyprinid community consisted of red shiner, flathead chub, longnose dace, fathead minnow, and common carp. Red shiner were 75% of the cyprinid population while river carpsucker were 96% of the catostomid community. The two most abundant non-native species were channel catfish (N=109) and western mosquitofish (N=296), accounting for 97% of all the introduced fish. This was the most upstream locality where western mosquitofish was a large percentage (32%) of the fish community.

MACROHABITAT SITE 5

The Turn macrohabitat site was one of the least diverse sampling localities, producing only six species (Figure 14). It did not yield any species unique to the site nor were there any representatives from the salmonid, clupeid, catostomid, or ictalurid families. At each of the other sites at least one catostomid or ictalurid specimen was taken. In addition, this was one of only two sites lacking longnose dace.

Three of the six species and 64% (N=899) of the total catch at this site were natives. As at most of the other macrohabitat sites, red shiner dominated both the cyprinid (79%) and total catch (50%). The second-most abundant species was western mosquitofish, which comprised 99% (N=517) of the non-native catch and 36% of the total catch. Flathead chub and fathead minnow, both native, were the next two most common species. The only other site where flathead chub was as abundant (N=150) during macrohabitat sampling was downstream of San Acacia (Figure 15). The other two fish species collected at this site, common carp (N=2) and largemouth bass (N=2), were a relatively small percentage of the total catch. This was the most downstream collection locality for centrarchids.

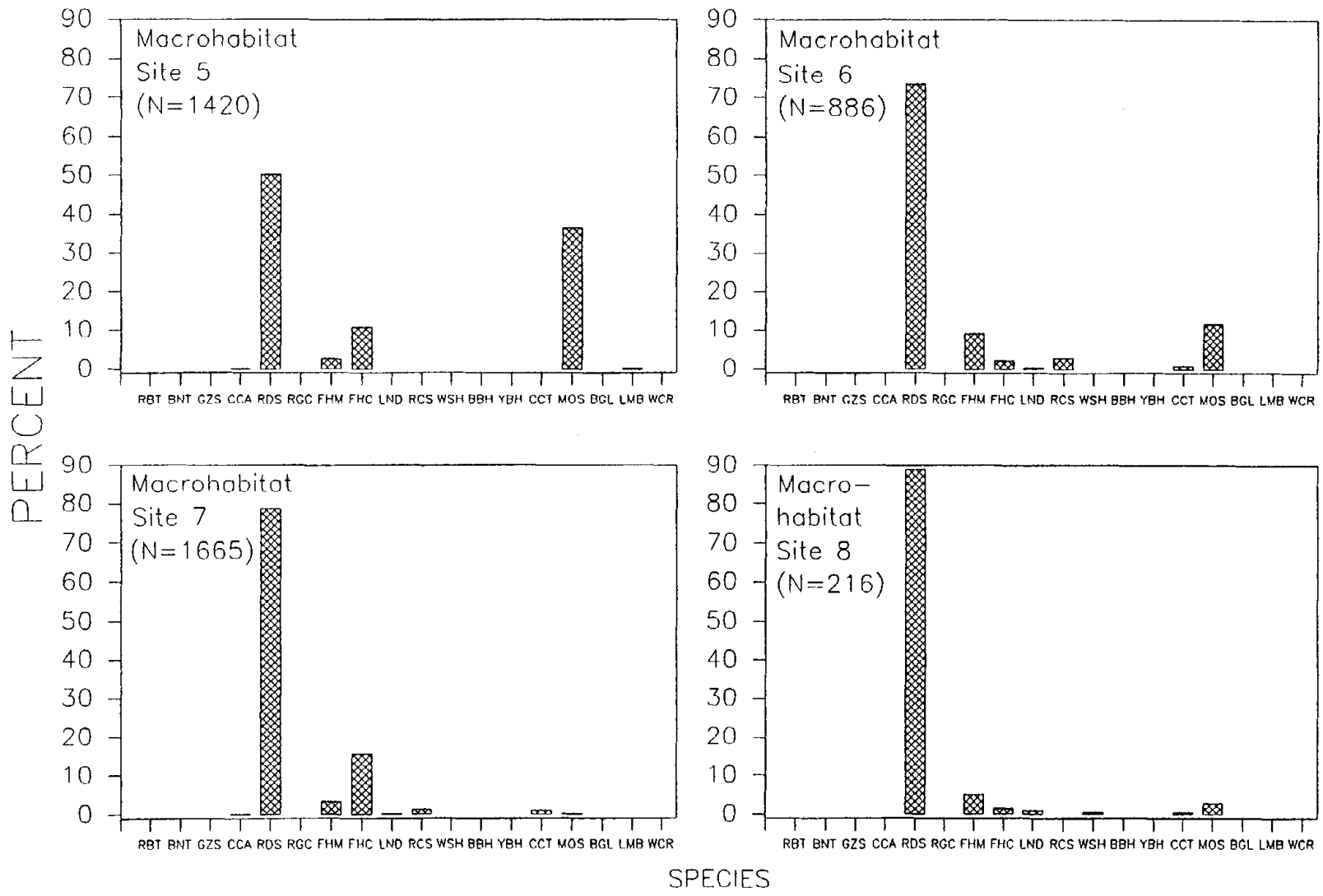

Figure 14. Ichthyofaunal composition (percent) at macrohabitat sites 5-8.

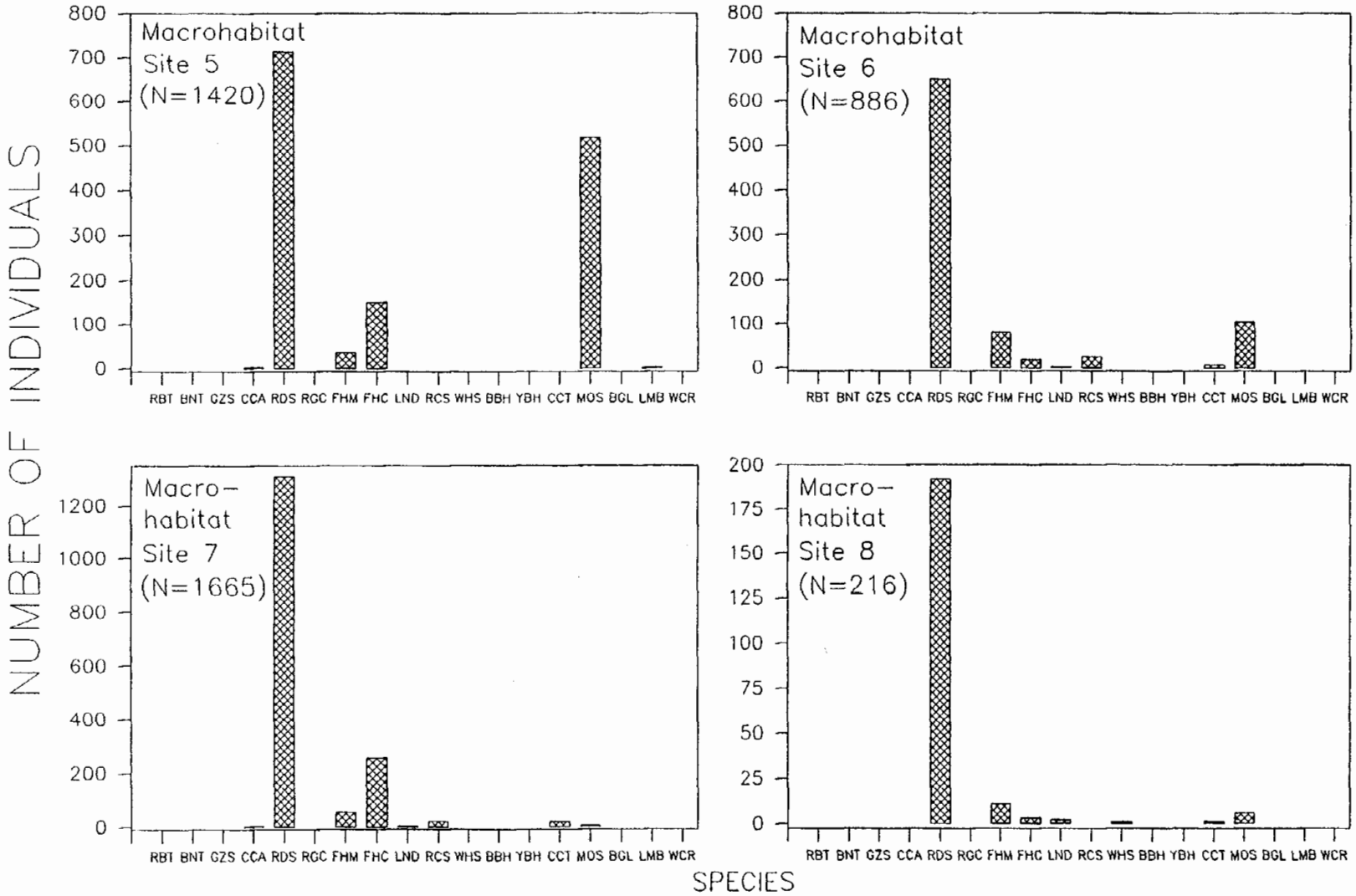

Figure 15. Ichthyofaunal composition (number of individuals) at macrohabitat sites 5-8.

MACROHABITAT SITE 6

The ichthyofaunal community at this site was dominated by red shiner, which represented 73% (N=650) of the catch and was more than 6 times more abundant than the next most common species, western mosquitofish (N=103; 12%). The other five species at this site were represented by 80 or fewer specimens.

Five of the seven species and 766 specimens (86%) were native. Cyprinidae was the most abundant family by species (N=4) and comprised 81% (N=751) of the catch. After red shiner, fathead minnow was the second-most abundant cyprinid (N=80) and accounted for 9% of the catch. River carpsucker (N=25) and channel catfish (N=7) were the only catostomid and ictalurid, respectively, present in our collections at this site. There was no species unique to this locality.

MACROHABITAT SITE 7

The three macrohabitat samples from San Acacia yielded eight species, five native and three non-native, and the largest number of specimens (N=1,665). Four species reached their greatest or second-greatest abundance at this site. It also produced the largest number (N=1,644) and percentage (99%) of native taxa. The three introduced fish species, common carp, western mosquitofish, and channel catfish were represented by 1-17 specimens. Western mosquitofish, which had been relatively abundant at macrohabitat localities 4-6, was represented by three specimens. Channel catfish, the most abundant non-native species (N=17), was more numerous only at macrohabitat site 4.

Cyprinid numerical dominance of the fish community was due to the large number of red shiner taken (N=1,310). This species comprised 79% of the total catch and 81% of the cyprinid sample. Flathead chub also reached its greatest abundance in these samples (N=257); however, because of the great number of red shiner collected, chub accounted for only 15% of the total catch. Fathead minnow (N=54) was the third-most common cyprinid and fish taxon. The only other native cyprinid, longnose dace, was represented by two specimens and accounted for 0.1% of the catch.

MACROHABITAT SITE 8

A total of 216 fish was collected during the four macrohabitat sampling forays at the Socorro site. This was the second fewest fish taken per collection. Four native and three non-native species were collected at this locality, of which 96% (N=208) were native forms. Single specimens of non-native white sucker and channel catfish were collected in addition to six western mosquitofish.

All native taxa collected (N=4) at this site were cyprinids. Red shiner was 92% of the native catch and 89% of the total catch. The next most common fish was fathead minnow (N=11), which accounted for 5% of the collection. Flathead chub and longnose dace, represented by three (1.4%) and two (0.9%) specimens, respectively, comprised the remainder of the native fish community.

MACROHABITAT SITE 9

The Bosque del Apache National Wildlife Refuge macrohabitat sampling locality was dry three of the four times we attempted to survey fish and habitat. A total of nine specimens, five red shiner and four channel catfish, were collected at this site during this study. This small number of fish was unimportant in examination of species distribution and abundance and community structure.

Accounts for species collected during macrohabitat sampling

Rainbow trout and Brown trout

Two species in the family Salmonidae were collected in this phase of the study. Rainbow trout was represented by four specimens and was present at two localities (sites 2 and 3). A single brown trout was collected at site 1, the most upstream locality. Brown trout was one of six species to be collected at only one locality. While these two species were not taken sympatrically, they were both probably present at sites 1 and 2. Site 3, Alameda Avenue Bridge, was not typical salmonid habitat and the individual rainbow trout collected there was probably an incidental downstream migrant.

Gizzard shad

A total of five juvenile gizzard shad was taken, in a single collection, at site 4 (Central Avenue Bridge). This was the only site where this species was taken in the macrohabitat phase of the study.

Common carp

A total of eight juvenile and sub-adult common carp was collected at five sites with the maximum number of individuals taken at any site being two. This species was certainly more abundant than this survey indicated. Their under-representation in these samples was likely an artifact of collecting techniques rather than an indication of low relative abundance.

Red shiner

This was the most abundant (N=3,365; 57%) and frequently encountered (132 of 331 seine hauls) fish during the macrohabitat phase of the study and the only species collected at all sites. At eight of the nine sites it was the most abundant fish (the only exception was site 1). Red shiner was generally less common at upstream localities. Red shiner comprised approximately 50% of the ichthyofaunal community at site 2 (Algodones Diversion Dam) but it was only 25% of the assemblage at site 3 (Figure 16). When the catches at these two sites were combined, red shiner accounted for < 10% of the total red shiner catch (Figure 17). Downstream from site 3, its percent of the community composition increased steadily to 79% (N=1,310) at site 7 and 89% (N=192) at site 8, respectively. In addition, the number of individuals at downstream localities also increased.

Rio Grande chub

Rio Grande chub was collected (N=8) at one locality (site 1) and was typically associated with cool, clear, fast flowing waters. While this species was known from the Rio Grande downstream of Cochiti Reservoir, it reaches its greatest relative abundance at more upstream localities. Its absence from downstream collections was not an artifact of collecting methodology.

Flathead chub

This species was present at eight of the nine sites (absent from site 9) and was the third-most abundant taxon (N=621), comprising 10.5% of the total macrohabitat catch. It was also the second-most frequently encountered species, occurring in 80 of the 331 collections that contained fish.

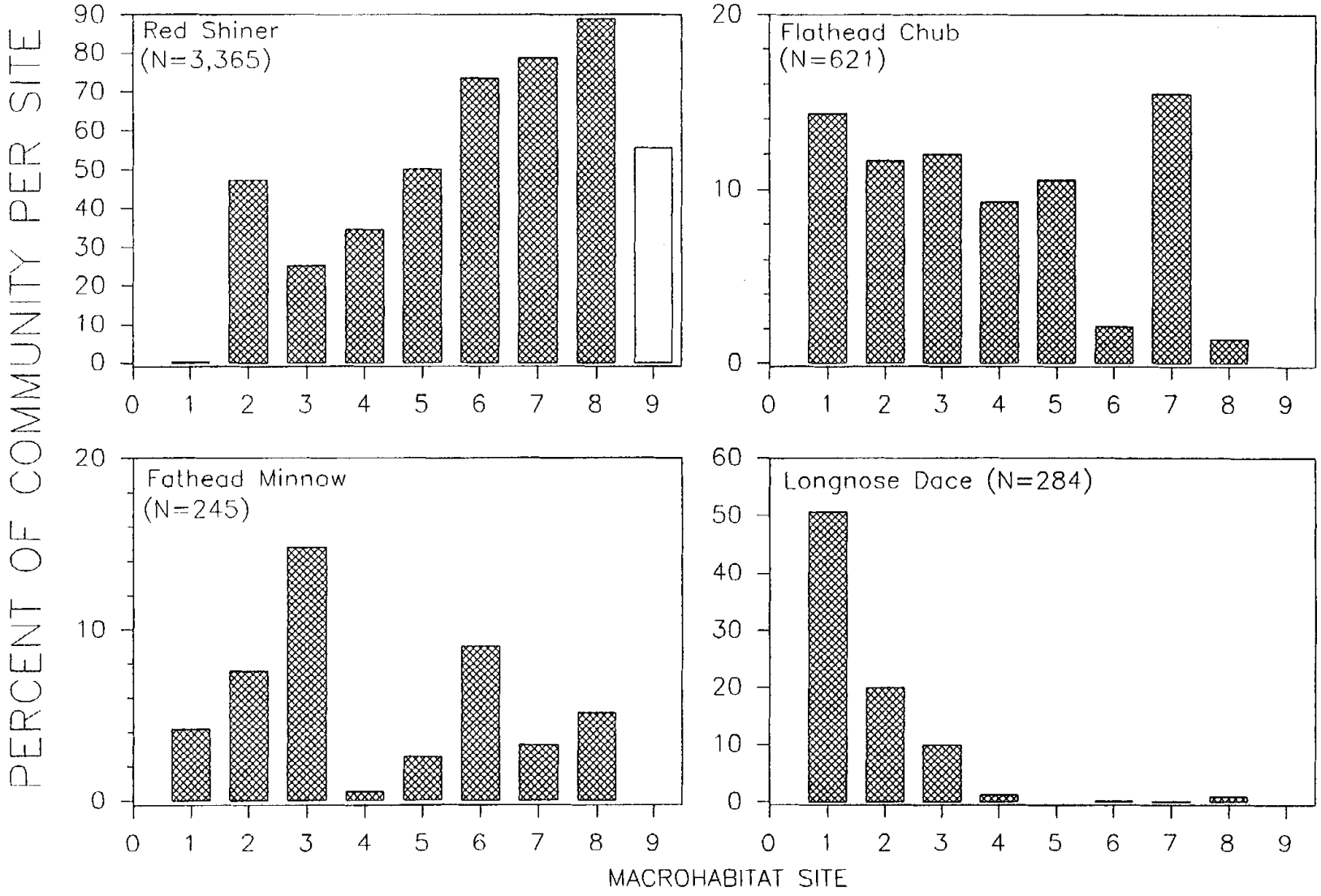

Figure 16. Percent per site of community comprised of red shiner, flathead chub, fathead minnow, and longnose dace. (The fill pattern for the site 9 histogram bar is empty to emphasize that only a total of 9 fish [5 red shiner] were collected at that site).

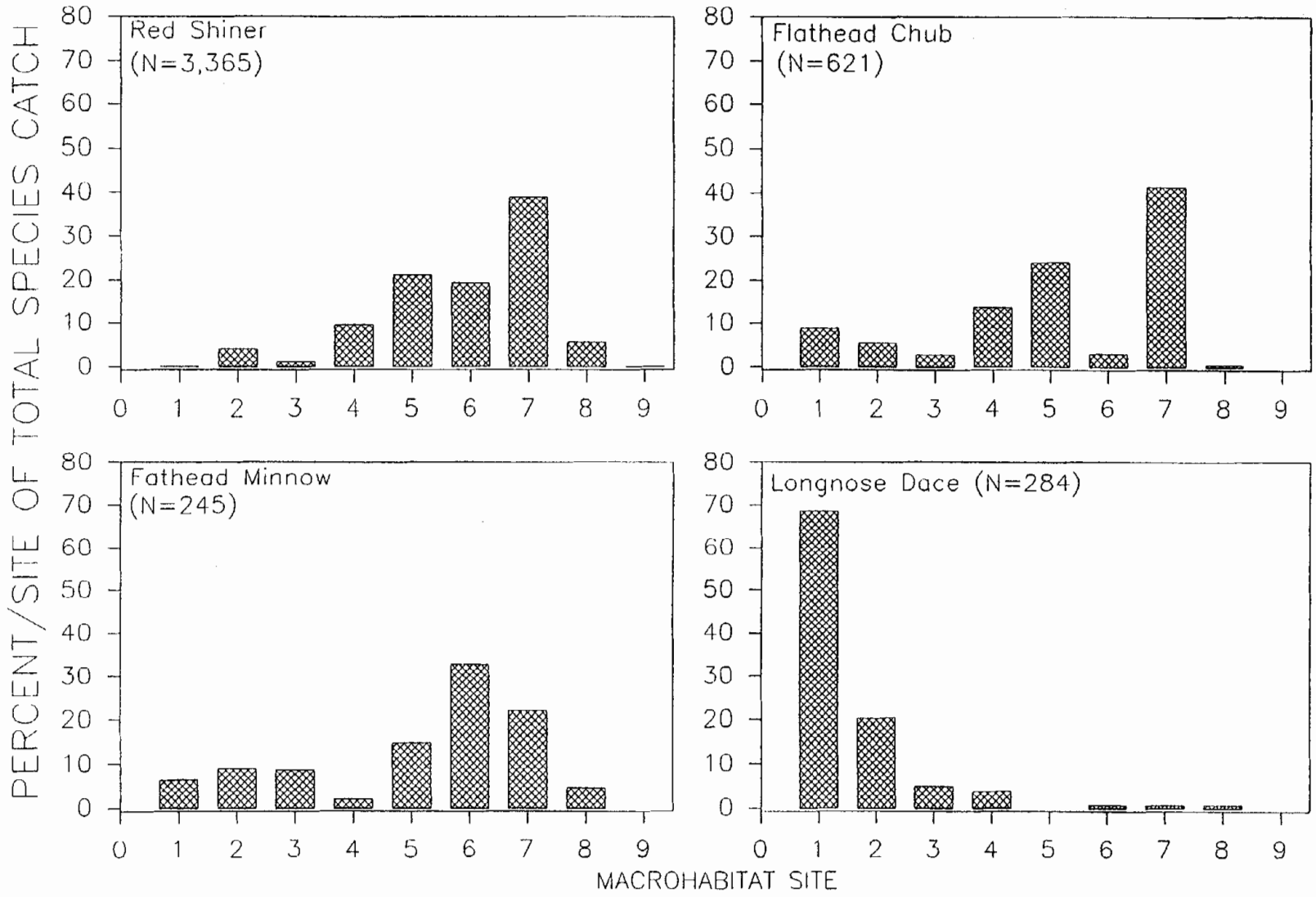

Figure 17. Percent of total red shiner, flathead chub, fathead minnow, and longnose dace catch at each site.

Flathead chub comprised between 9-16% of the ichthyofaunal community at most sites; exceptions were sites 6, 8, and 9. The 19 flathead chub collected at site 6 accounted for only 2% of the catch. At site 8, the downstream-most collection locality for this fish, three specimens were collected (1.3%).

There was a general decline in abundance of flathead chub downstream of site 5. The marked increase in abundance of this species at macrohabitat site 7 (San Acacia Diversion Dam) was not indicative of the normal longitudinal distribution of this taxon but was instead a result of the presence of atypical habitat for the lower portion of the study area.

Fathead minnow

Fathead minnow, which ranged in abundance from 0.5 to 14.8% of the fish community, was distributed throughout the macrohabitat study area but did not exhibit a discernable distribution pattern. It was the third-most frequently encountered species, occurring in 24% (N=80) of the collections, and was most abundant at site 6 (Arroyo los Alamo) and least common at site 4 (Central Avenue Bridge).

Longnose dace

This species constituted only 4.8% of the total catch but was nonetheless the fourth most abundant taxon. It exhibited a pattern of decreasing abundance at downstream macrohabitat sites. Longnose dace reached their greatest abundance at site 1 (N=195), comprising 51% of the total catch. At sites 2-4, this species ranged in abundance from 1.2 to 20%. While present at sites 6-8, there were never more than two specimens.

Longnose dace was the only species more abundant than red shiner at a macrohabitat site (site 1). Dace were typically found in clear, cool waters and were strongly associated with cobble or gravel substrate. The lack of this habitat in downstream reaches was the apparent reason for its decline in abundance.

River carpsucker

The only native catostomid collected during macrohabitat sampling was river carpsucker. A total of 144 specimens of this species was present in 19 collections, comprising 2.4% of the total catch. The river carpsucker was most abundant at sites 3 and 4 where it accounted for 11% and 9% of the fish community, respectively (Figure 18). While more abundant at site 4 than 3 (Figure 19), it was a smaller percentage of the community. It was absent at site 5 and at sites 6 (2.8%) and 7 (1.3%) was a less abundant component of the community. This distribution of this species seemed to be concentrated in the middle macrohabitat sites (3-7).

White sucker

White sucker was taken in approximately equal abundance (N=161) as river carpsucker (N=144) but comprised a greater percentage of the fish community at two of the three sites where they were sympatric (1 and 3). At site 4 (Central Avenue Bridge), river carpsucker accounted for 9% of the catch while white sucker was <1% of the total.

White sucker was most frequently taken at upstream localities. It was most abundant at site 1 where it was 25% of the fish community. A total of 96% of the white suckers taken in this phase of the study was collected at sites 1-3 and 99% were taken at sites 1-4; a single juvenile was collected at site 8.

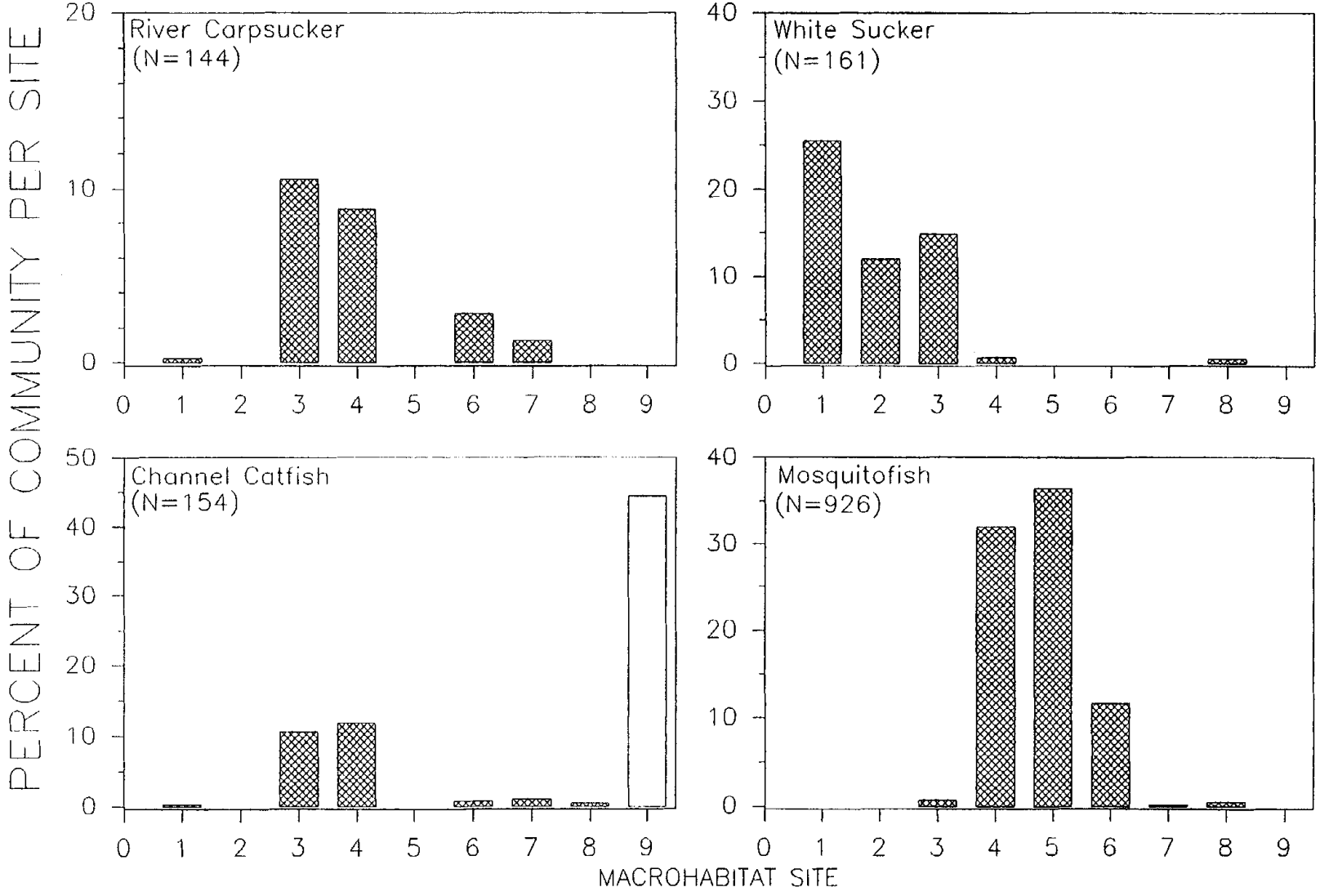

Figure 18. Percent per site of community comprised of river carpsucker, white sucker, channel catfish, and mosquitofish. (The fill pattern for the site 9 histogram bar is empty to emphasize that only a total of 9 fish [4 channel catfish] were collected at that site.

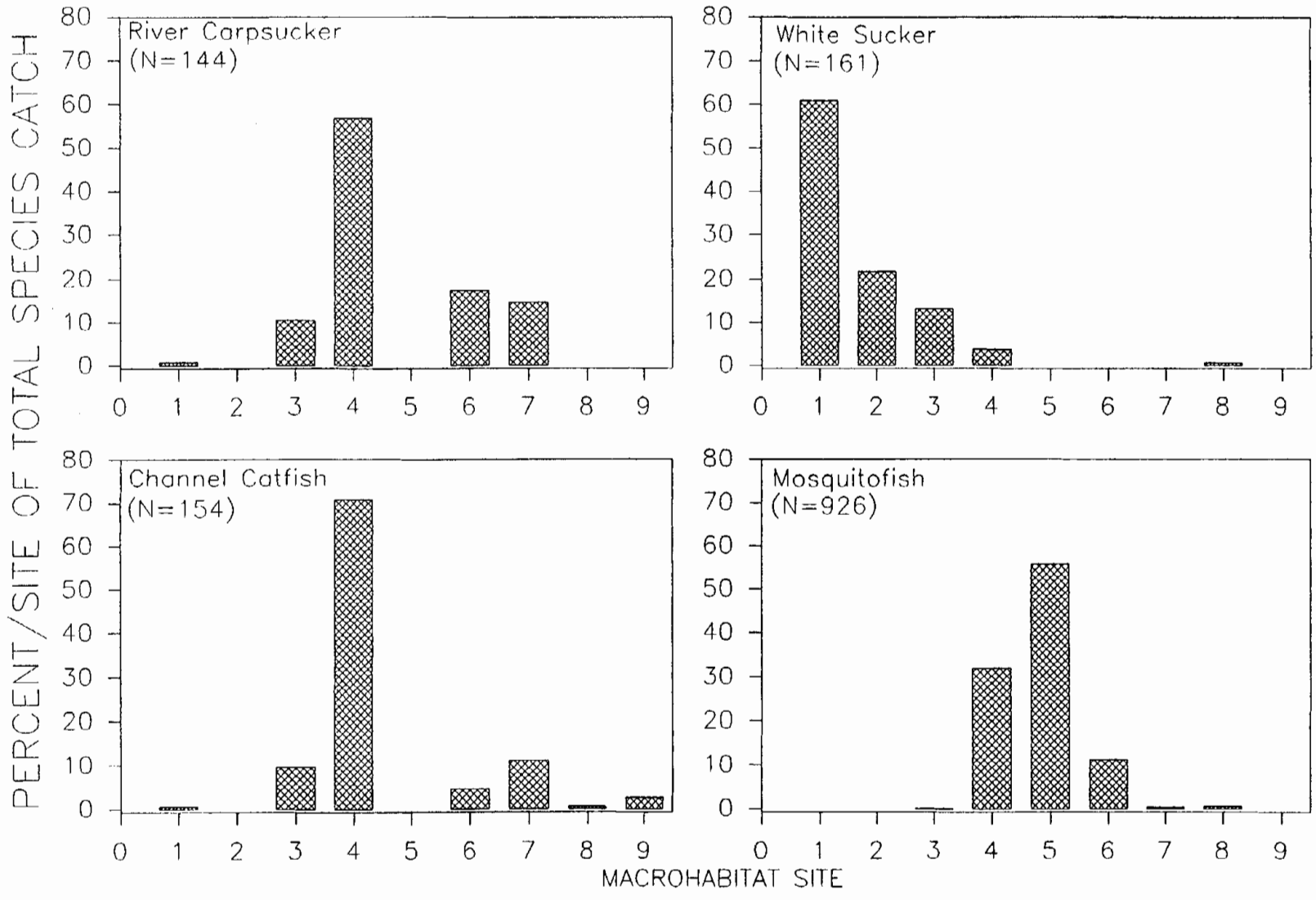

Figure 19. Percent of total river carpsucker, white sucker, channel catfish, and mosquitofish catch at each site.

Black bullhead and Yellow bullhead

These two species were both collected only at site 4 (Central Avenue Bridge) and were represented by one specimen each. Although present in most of the study area, neither species has ever been commonly collected.

Channel catfish

This species was the seventh-most abundant fish collected during the survey, comprising 2.6% (N=154) of the catch. The greatest number (N=109) and percentage (71%) of these fish was taken at site 4 (Central Avenue Bridge). Channel catfish comprised 12% of the catch at this site and 11% of the catch just upstream at site 3 (Alameda Avenue Bridge). Single channel catfish specimens were collected at sites 1 and 8 but they were absent from sites 2 and 5. This species comprised 44% (N=4) of the catch at site 9; however, only nine fish (total) were taken from this site. Channel catfish appeared to have a distribution and relative abundance pattern similar to river carpsucker; they were both rare at the upper and lower macrohabitat sites, absent from sites 2 and 5, and most common and of similar percentages at sites 3 and 4.

Western mosquitofish

Western mosquitofish was the only representative of the Order Cyprinodontiformes in the study area during macrohabitat sampling. It was the second-most abundant species (N=926), comprising 16% of the catch; however, it was absent from sites 1 and 2 and was only represented by one specimen at site 3. This species was most common at sites 4, 5, and 6 where it accounted for 99% (N=916) of the total western mosquitofish catch. It was the second-most abundant species at sites 4 and 5, comprising 32 and 36% of the catch, respectively. At downstream sites (7 and 8), western mosquitofish were $<1\%$ of the ichthyofaunal community.

Bluegill, Largemouth bass, and White crappie

Three genera of centrarchid, representing three species and 13 specimens, were collected during the macrohabitat fish study. Bluegill (N=2) was collected at site 2 and white crappie (N=2) was taken at site 4. Young-of-year largemouth bass (N=9) was collected at sites 1 and 5. Centrarchids were not taken sympatrically. These species are not native to the Rio Grande and stocking programs and reservoir escapees make determination of the ranges and relative abundances of these fish difficult.

MACROHABITAT AVAILABILITY

A total of 17 macrohabitat types was identified during the species-association and habitat-availability studies. One of these types, debris piles was sampled 36 times during species-association work but was not encountered during any of the 2900 habitat availability point measurements; therefore, it was not listed as an "available habitat". The absence of debris piles from the habitat availability data-set was not an accurate representation of its abundance but was instead primarily an artifact of size. The largest debris piles were only 2-3 m^2, and their small surface area, limited number, and the systematic nature of the sampling design made it unlikely that they would be encountered.

The 16 macrohabitat types recorded during the habitat availability study ranged in abundance from isolated pool and side channel eddy (two each) to main channel run (N=1,298). The seven most frequently encountered habitat types, which accounted for 97% of the macrohabitat availability samples were main and secondary channel run (54%), islands, (21%) main and secondary channel flats (16%), and main and secondary channel shoreline (6%)(Figure 20). The other nine macrohabitat types were each less than 1% of the sample and were not recorded at more than 22 locations.

Site 1: San Juan Pueblo

The most upstream macrohabitat site (San Juan Pueblo) was sampled on two occasions, but exhibited relatively little difference in general habitat availability between sample dates. It was characterized by high-velocity water confined to a single channel flowing over a gravel substrate. The river channel width ranged from 28-79 m with a mean width of 49 m. High flows during the winter-1992 sampling period resulted in deeper waters and higher velocities (Figure 21) than during summer 1991. At that time, over 75% of the velocity measurements were >100 cm/second.

Overall, main channel runs and main channel shoreline accounted for 88% of the macrohabitat types at this site (Figure 22). Low-velocity and island habitats were uncommon, comprising 4% of the sample. The remaining 8% of the macrohabitats at the San Juan Pueblo site were secondary channel runs or riffles.

High-velocity water dominated the macrohabitat data point samples taken at this site during the two sampling periods. A total of 67% of the points measured had water velocity >100 cm/second. Twenty-three percent of velocity data-points were between 121-130 cm/second. High-velocity at this site generally scoured the substrate clean of small particulate matter. A total of 86% of the substrate was comprised of either gravel (73.5%) or cobble (12.5%), while sand and silt combined comprised <10%. Water depth was generally <100 cm (71.5%); however, 22.5% of depth data-points were between 101-110 cm. Only 6% of the sampling points were deeper than 110 cm.

Site 2: Angostura Diversion Dam

The Angostura Diversion Dam macrohabitat site was surveyed on two occasions; summer-1991 and winter-1992 (Figure 23). Its mean channel width was 75 m with a range of 51-101 m. The high discharge during the winter-1992 sampling period resulted in greater velocities and deeper waters than were observed in the summer-1992 samples. Thirty-eight percent and 59% of the observations were in water velocity >90 cm/second during 1991 and 1992 sampling, respectively.

Main channel and secondary channel runs were the primary habitats, accounting for 74.5% of those present (Figure 24). While low-velocity macrohabitats were uncommon (N=3; 2 backwaters and 1 pool), islands increased from 4% of the sample at San Juan Pueblo to 15.5% at this site. The braiding of the channel was also apparent by the proportion of secondary channel macrohabitats (19.5%).

As at the San Juan Pueblo macrohabitat site, the largest number of velocity observations at this locality was in the 101-110 cm/second class (N=31). At this site, almost half (48.5%) of the measurements were in water moving 91 cm/second or faster and the highest velocity measured was a single observation of 141 cm/second.

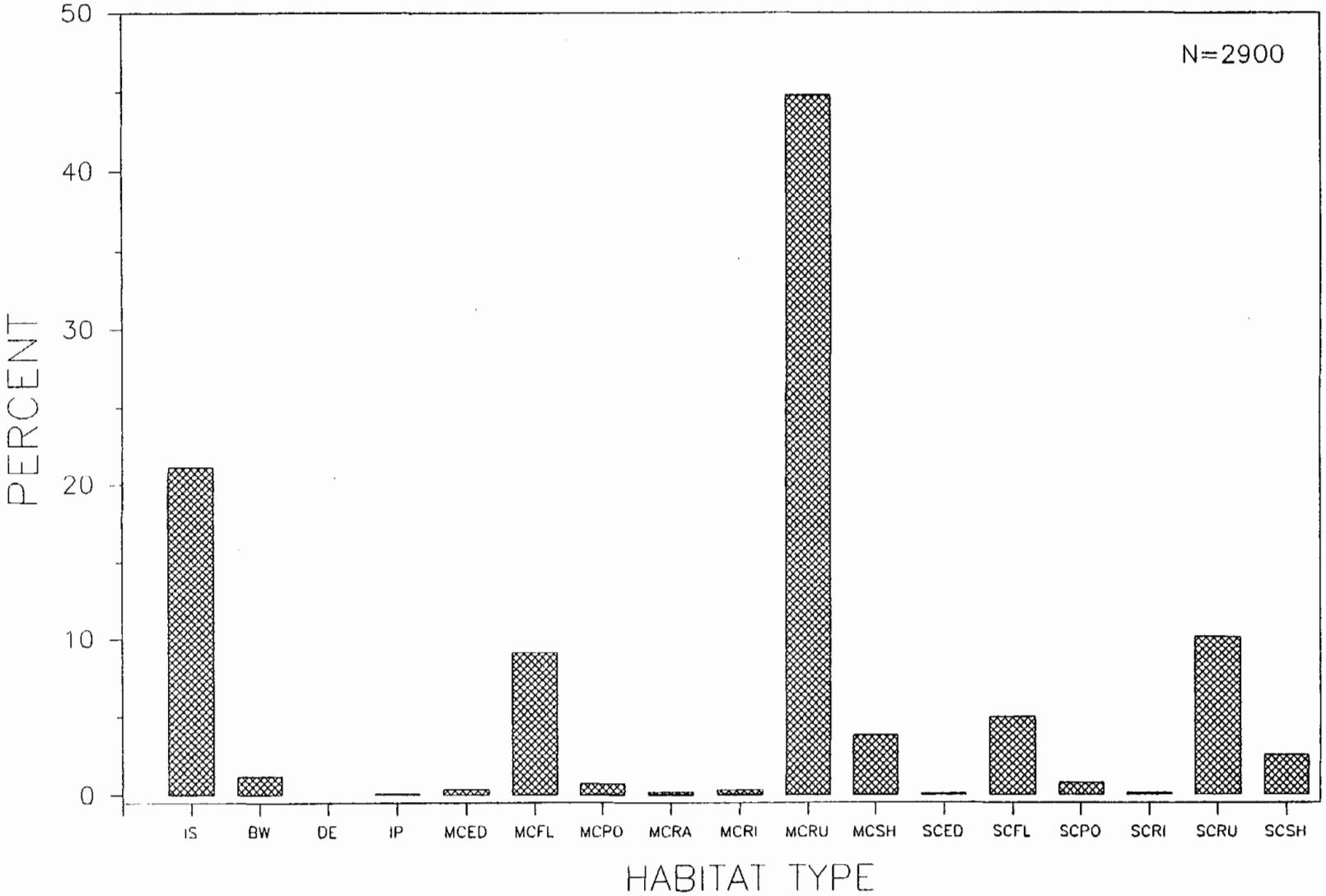

Figure 20. Percent of macrohabitat types in the Middle Rio Grande based on macrohabitat availability sampling.

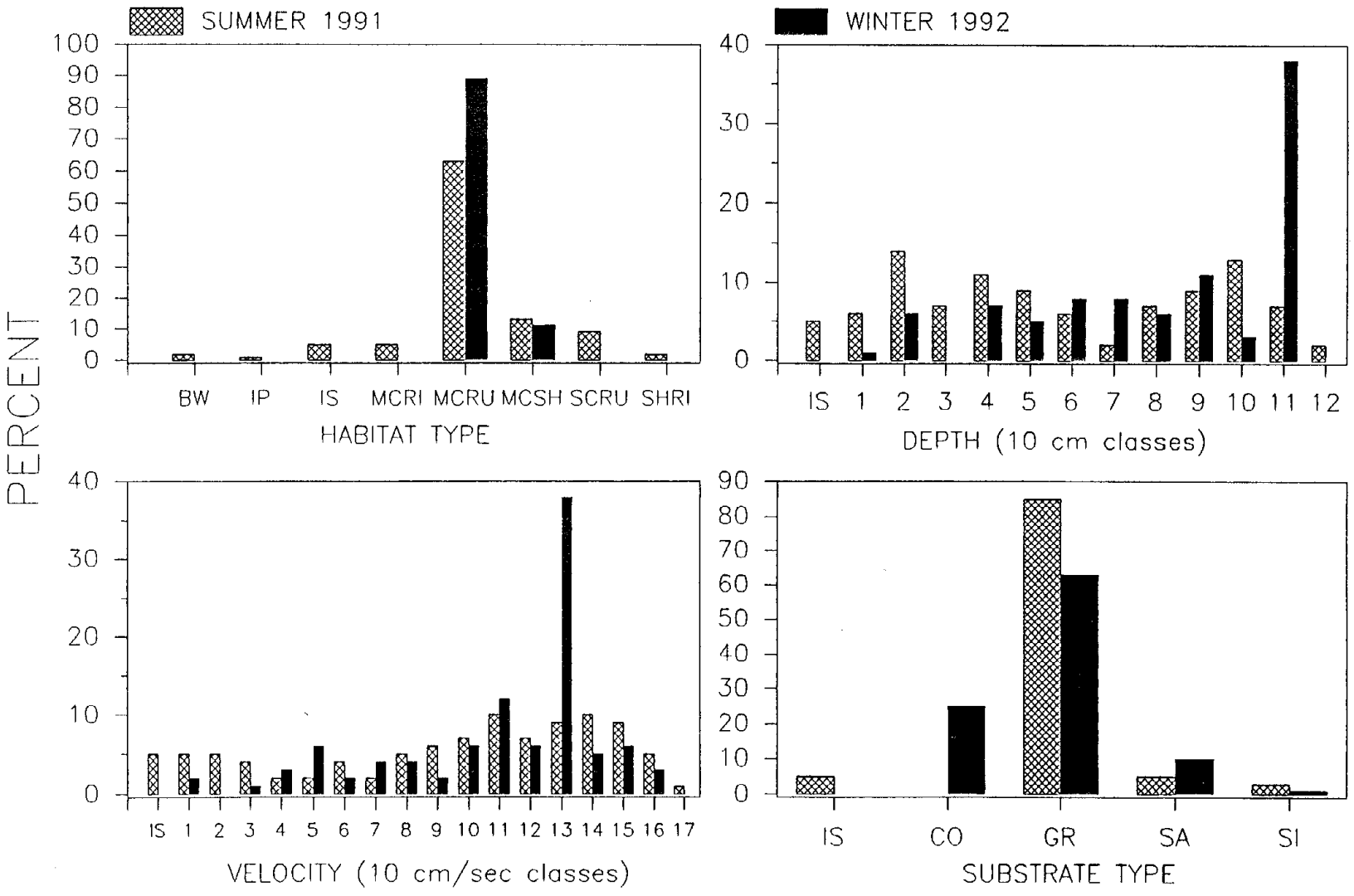

Figure 21. Macrohabitat variables per sampling period at macrohabitat site 1, San Juan Pueblo.

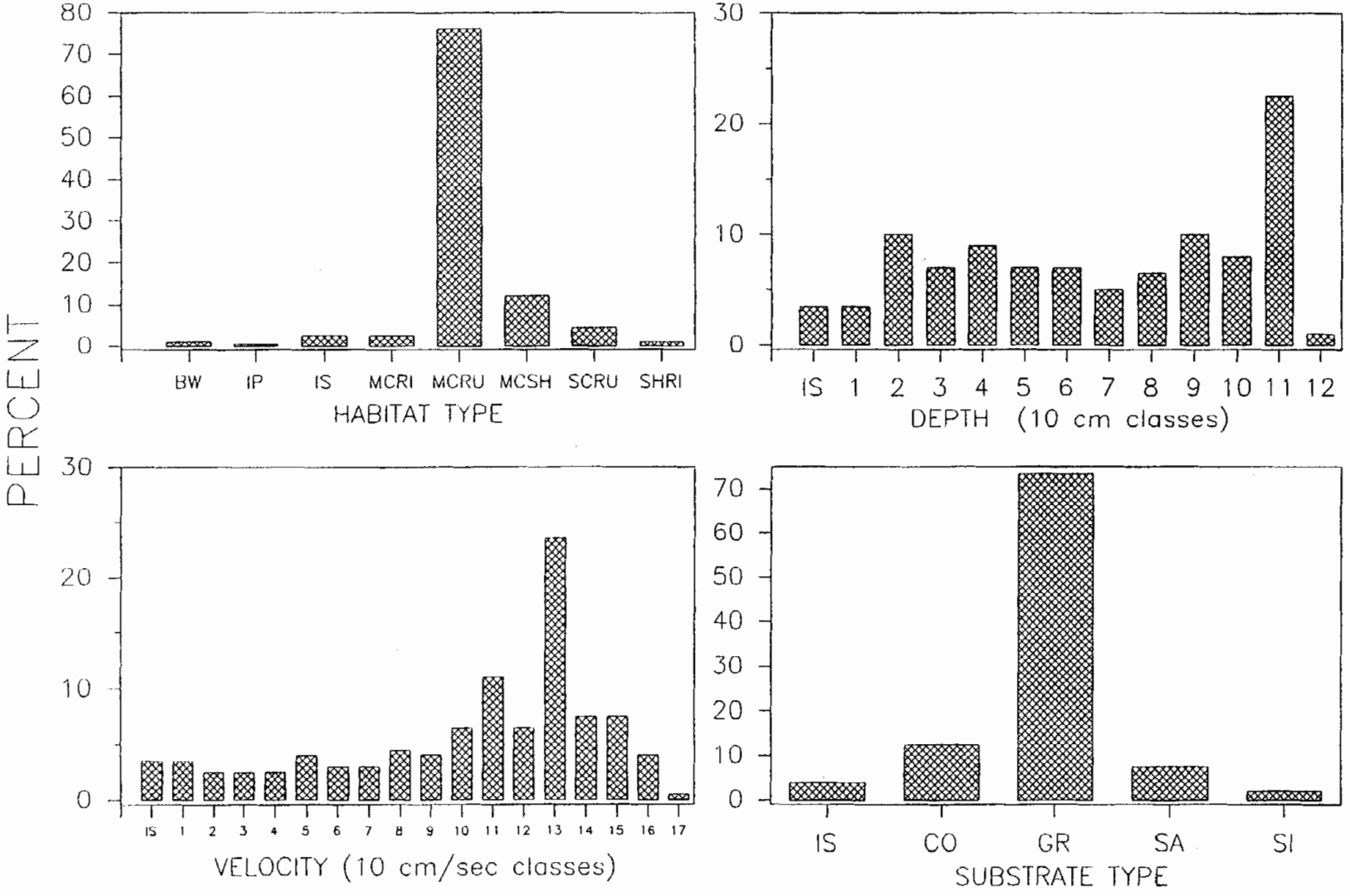

Figure 22. Macrohabitat variables summed for macrohabitat site 1, San Juan Pueblo.

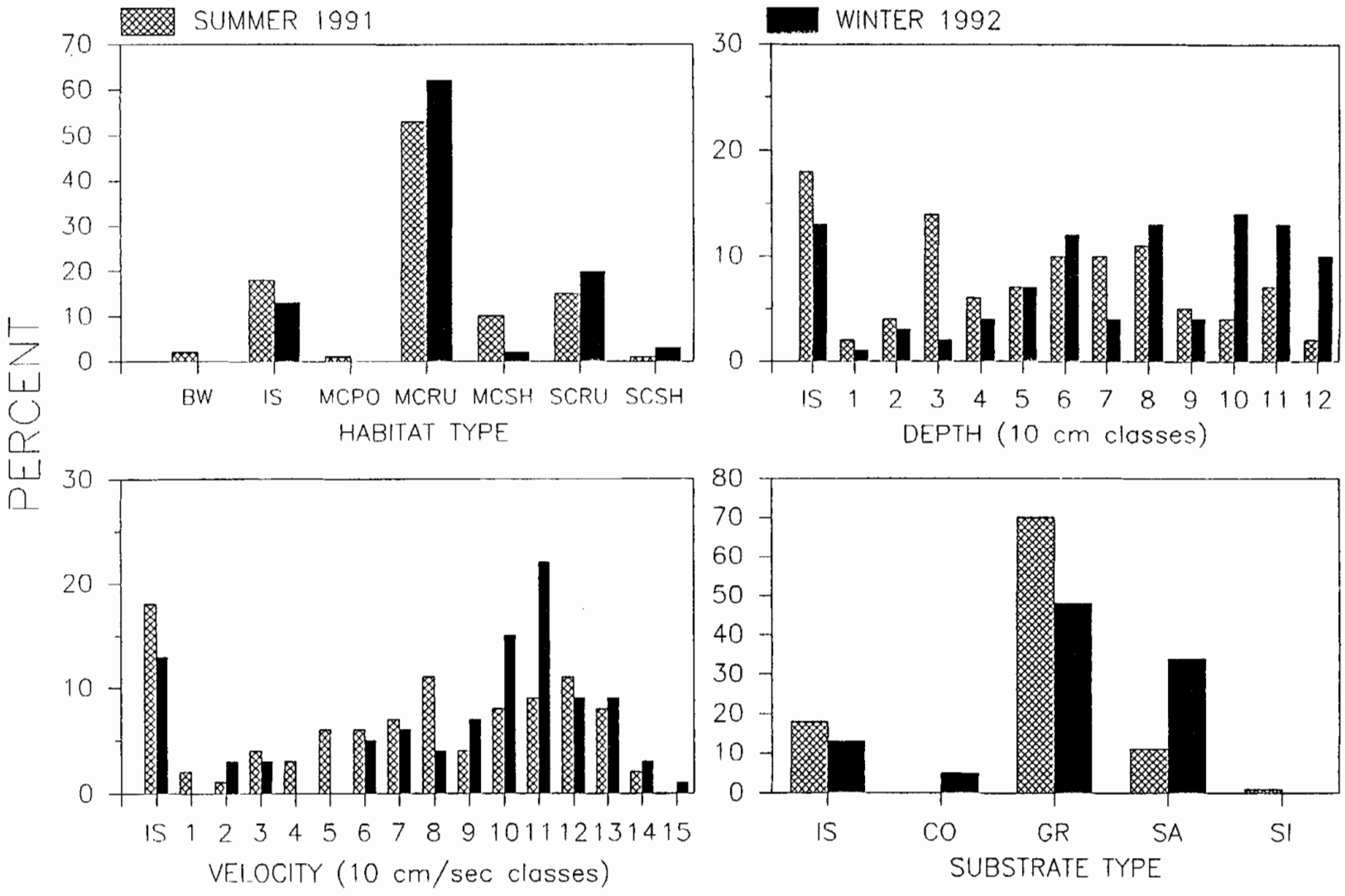

Figure 23. Macrohabitat variables per sampling period at macrohabitat site 2, Angostura.

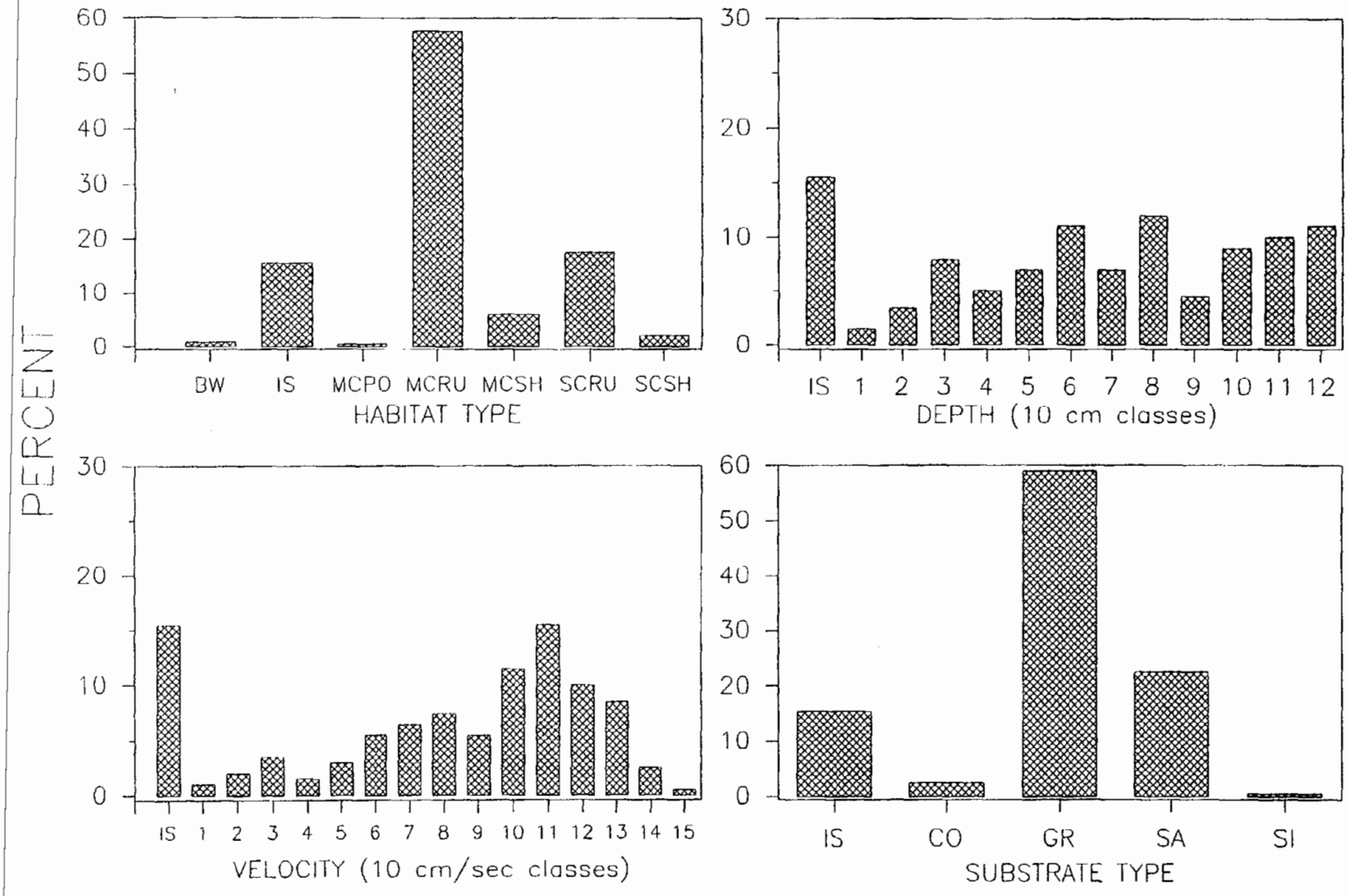

Figure 24. Macrohabitat variables summed for macrohabitat site 2, Angostura.

Gravel was the predominant substrate, accounting for 59% of the points sampled. Sand, the second-most abundant substrate, was present at 22.5% of the sampling points. Cobble and silt combined comprised 3% of the substrate while island habitats were the remaining 15.5%. When compared with San Juan Pueblo substrate, there was a 14.5% decrease in the number of observations in which gravel was the substrate and a corresponding 15% increase in the number of sites with sand substrate. Water depth was generally (64.5%) between 51-129 cm and relatively evenly distributed throughout the velocity classes within this range. There were an average of 9.3 observations in each of the five deepest categories (71-80, 81-90, 91-100, 101-110, 111-120 cm).

Site 3: Alameda Avenue Bridge

The Alameda Avenue Bridge, like sites 1 and 2, was only sampled on two occasions. With the exception of the increase in water velocity during the winter 1992 sampling, there was little difference in macrohabitat variables during the two sampling periods (Figure 25). It appeared to be the transitional site between upstream and downstream habitats. Upstream sites were characterized by narrow channels, limited braiding, high-velocity water, and gravel or cobble substrate. Downstream sites had wide channels, considerable braiding (i.e., more island habitat), lower velocities, and mainly sand or silt substrates. The mean wetted channel width at this site (187 m) was the largest of any of the macrohabitat sites.

Main-and secondary channel runs were the dominant macrohabitat types and comprised a total of 57.5% of the habitat measurements (Figure 26). Islands were the second most abundant macrohabitat (17%), followed by main channel flats (8.5%). Low-velocity habitats (pools and backwaters) accounted for 7% of the macrohabitats at this sites; an increase of 5.5% compared with macrohabitat site 2.

Water velocity also decreased compared to upstream localities. A total of 17.5% of the water velocity observations were >71 cm/second (71-129) while 47.5% were between 31-70 cm/second. Excluding islands, there were as many velocity points <30 cm/second as there were >71 cm/second. The greatest measured velocity was 113 cm/second during winter-1992. Just as water velocity decreased in mean and range between seasons, so did water depth. A total of 52% of the water depth measurements were <40 cm and only 16% were >71 cm in summer.

The most significant change in macrohabitat variables between this site and upstream localities was the change in substrate. Sand comprised 69% of substrate samples, while silt was 5% and gravel was 7.5%. This represented a three-fold increase in sand substrate and almost eight-fold decrease in gravel substrate.

Site 4: Central Avenue Bridge

The Central Avenue Bridge site was the most upstream macrohabitat locality that was sampled on four occasions; twice during winter and twice during summer. The relative abundance of macrohabitat variables for the two winter and two summer samples were similar. Velocity and depth (=discharge) was generally greatest during the winter and diminished in the summer (Figure 27). In addition, low-velocity habitats and islands were least common in the winter sampling period. Mean channel width was relatively constant throughout the study (81-93 m) and averaged 88 m.

There were 13 macrohabitats identified at the Central Avenue Bridge site with main (38.5%) and secondary (17.25%) channel runs constituting the majority of macrohabitats present (Figure 28). Islands were also an important component of the habitat, accounting for

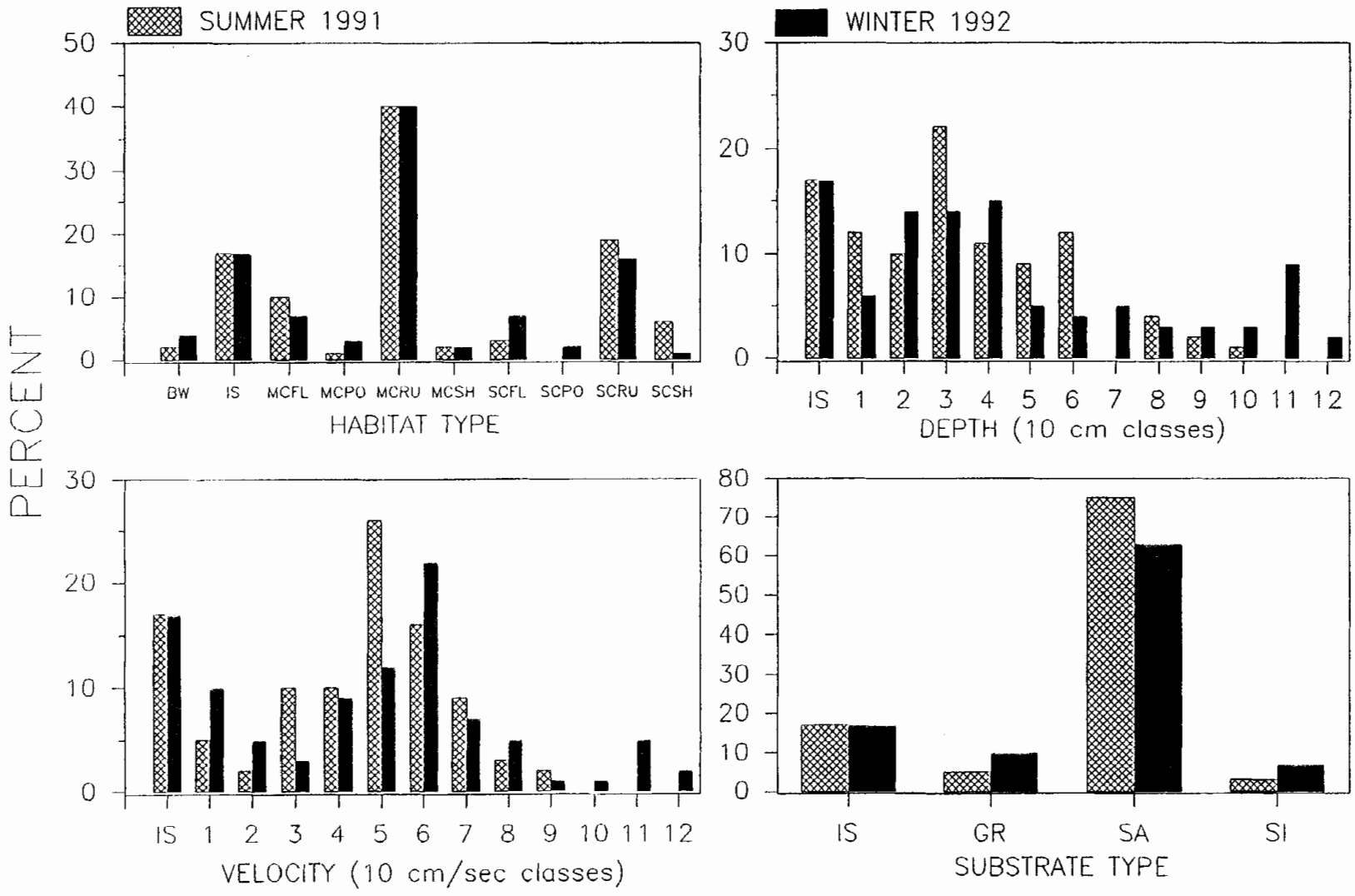

Figure 25. Macrohabitat variables per sampling period at macrohabitat site 3, Alameda Avenue Bridge.

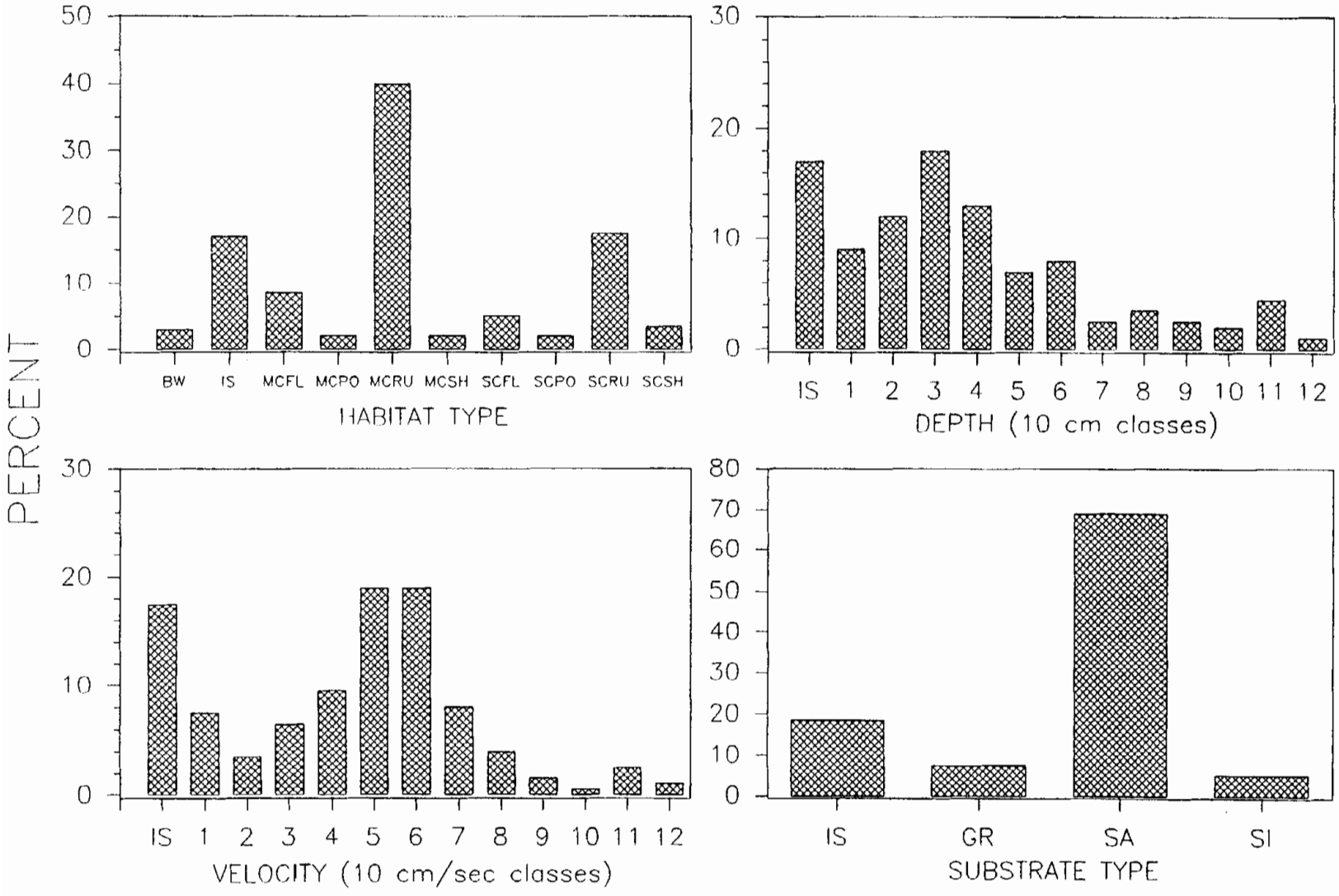

Figure 26. Macrohabitat variables summed for macrohabitat site 3, Alameda Avenue Bridge.

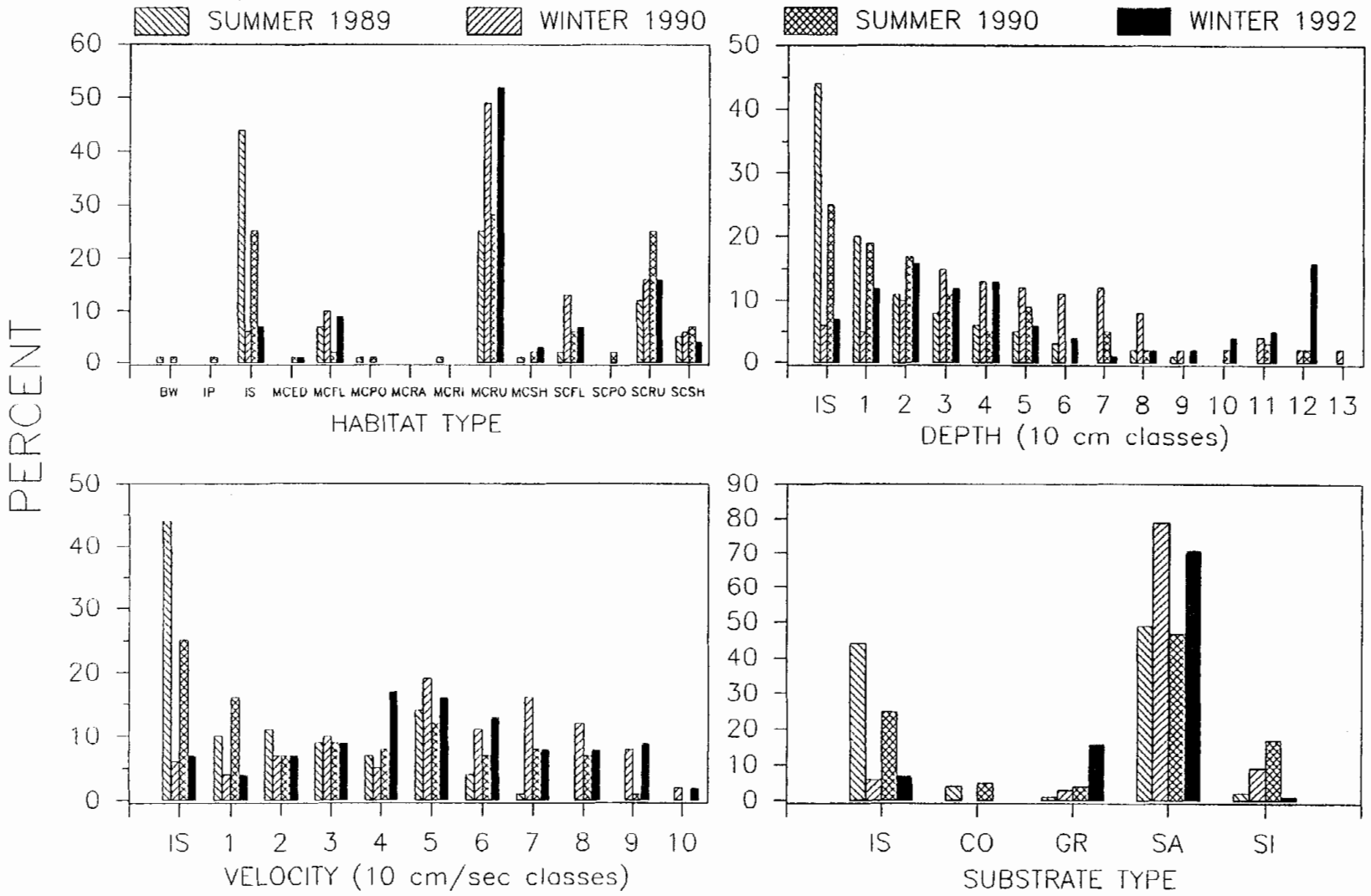

Figure 27. Macrohabitat variables per sampling period at macrohabitat site 4, Central Avenue Bridge.

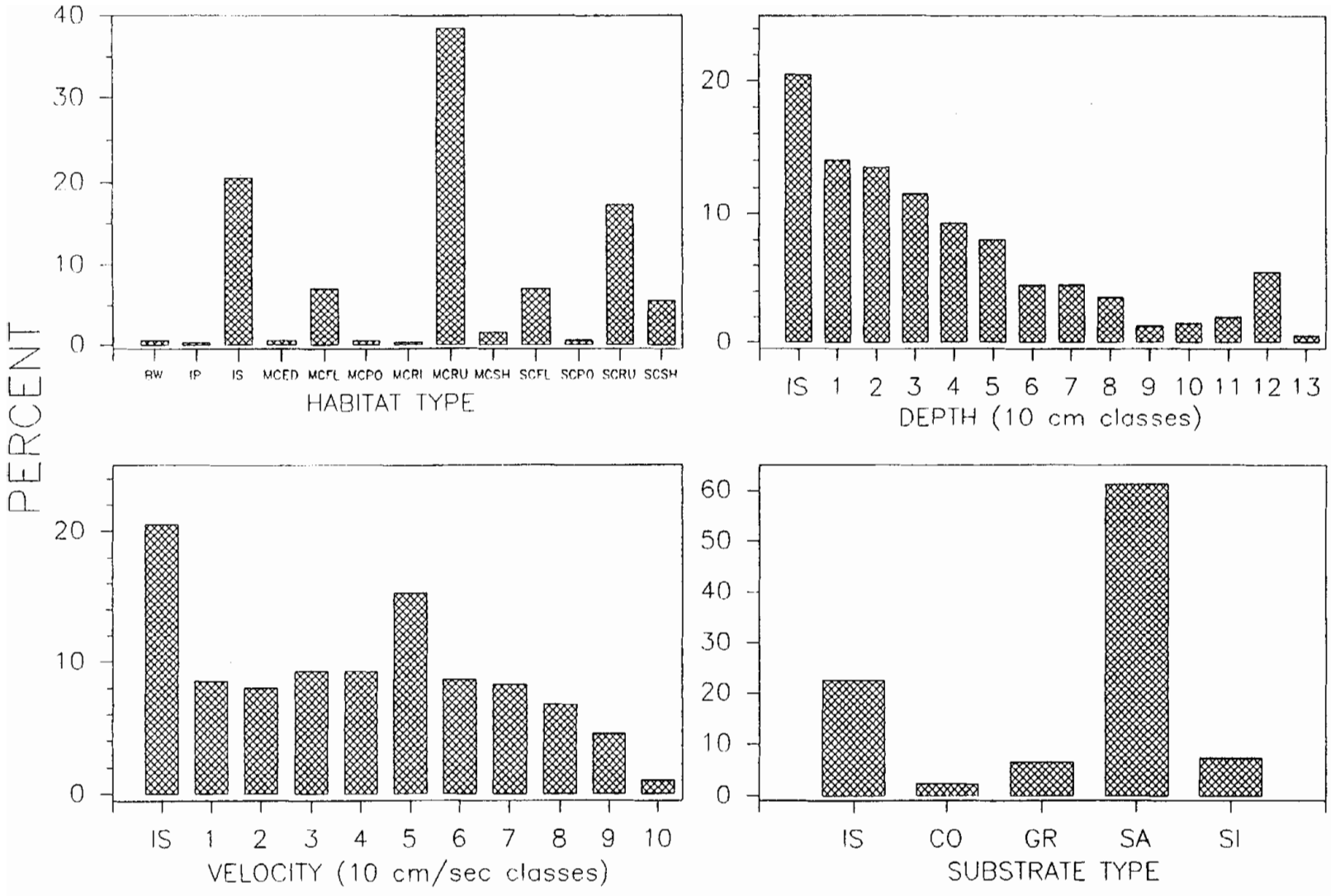

Figure 28. Macrohabitat variables summed for macrohabitat site 4, Central Avenue Bridge.

20.5% of the sample . The increase in islands translated into an increase in the amount of braiding of the river at this site. Both main and secondary channel flats were 7% of the habitat (=14%). Low-velocity habitats, most abundant during summer surveys, accounted overall for 2.25% of the total sample.

Velocity was relatively evenly distributed over the 11 classes. No velocity measurements were made at islands (20.5%). Of the remaining 318 velocity measurements, 78.5% were in velocity classes 0-90. The percent of observations in classes 1-4 and 6-9 ranged from 8.0-9.25 and 4.5-8.65, respectively. Only class 5 (41-50 cm/second) had more than 10% of the observations (15.25%).

Sand and silt were the two most frequently encountered substrata. They comprised 68.5% of the samples at the Central Avenue bridge site, while large substrata (cobble and gravel) were 8.75% of the substrate. Most of the large substrate material was associated with the deep and fast channel at the west bank of the site.

The water was relatively shallow at this sampling locality. Only 23.25% of the habitat points were in water >50 cm deep while 39% was between 1-30 cm deep. Main channel measurements yielded several data-points in depth classes 11-13.

Site 5: Turn

With the exception of the 1992-winter sample, there was relatively little variation between sampling dates for macrohabitat variables at site 5 (Turn). The high 1992 flows resulted in increased water depth and velocity, with 99% of the macrohabitat types as main channel runs and 100% of the substrate sand (Figure 29). Mean channel width at this site was the second largest in the study (124 m).

Main channel run was the most common of the 12 macrohabitats at this site (47%), followed by island (15.75%), main channel flat (13.75%), and secondary channel run (9.25%). Macrohabitat composition at this site was similar to Central Avenue Bridge. Flats and islands were 21% and 16% at Turn as compared to 14% and 20% at Central Avenue Bridge, respectively. Run habitat comprised about 56% of the habitat at both sites, and low-velocity waters accounted for a total of 2.5% of the macrohabitat at Turn as compared to 2.25% at Central Avenue bridge.

Almost 60% of the velocity measurements were between 31-70 cm/second while only 2.25% were >71 cm/second (Figure 30). Prior to the 1992 sample, only 1% of the velocity measurements were >81 cm/second. However, in 1992, 8% were >81 cm/second and 77% were >61 cm/second. In addition to the increased velocity, the river was considerably deeper in winter-1992 with 35% of the measurement points being >90 cm deep. Sand (74.5%) and silt (9%) were the only two substrate types recorded at this site. Islands comprised the remaining 16.5% of the substrate samples.

Site 6: Arroyo los Alamos

The Arroyo los Alamos macrohabitat site was fairly typical of the middle reach of the lower Rio Grande. The high flows in 1992 resulted in deeper and faster water than that recorded during the previous three sampling forays, but the flows did not significantly affect the macrohabitat or substrate composition of the site (Figure 31). The mean width of the channel ranged from 69-108 m, depending on flow. The average width of the river channel at this site was 84 m.

Main channel run was the dominant habitat type (43%) and islands comprised 19% of the study site (Figure 32). Secondary channel run and main channel flat each accounted for

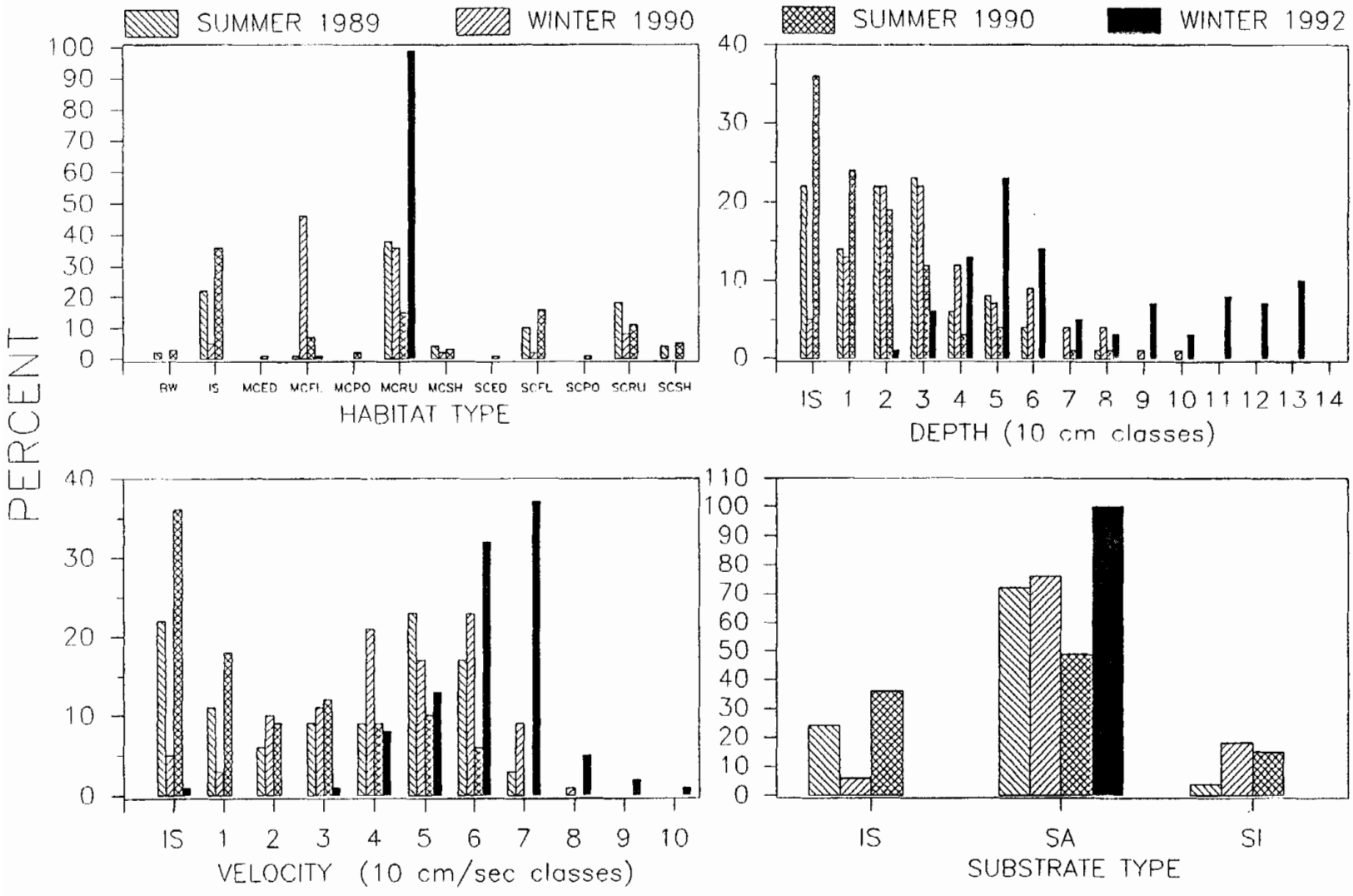

Figure 29. Macrohabitat variables per sampling period at macrohabitat site 5, Turn.

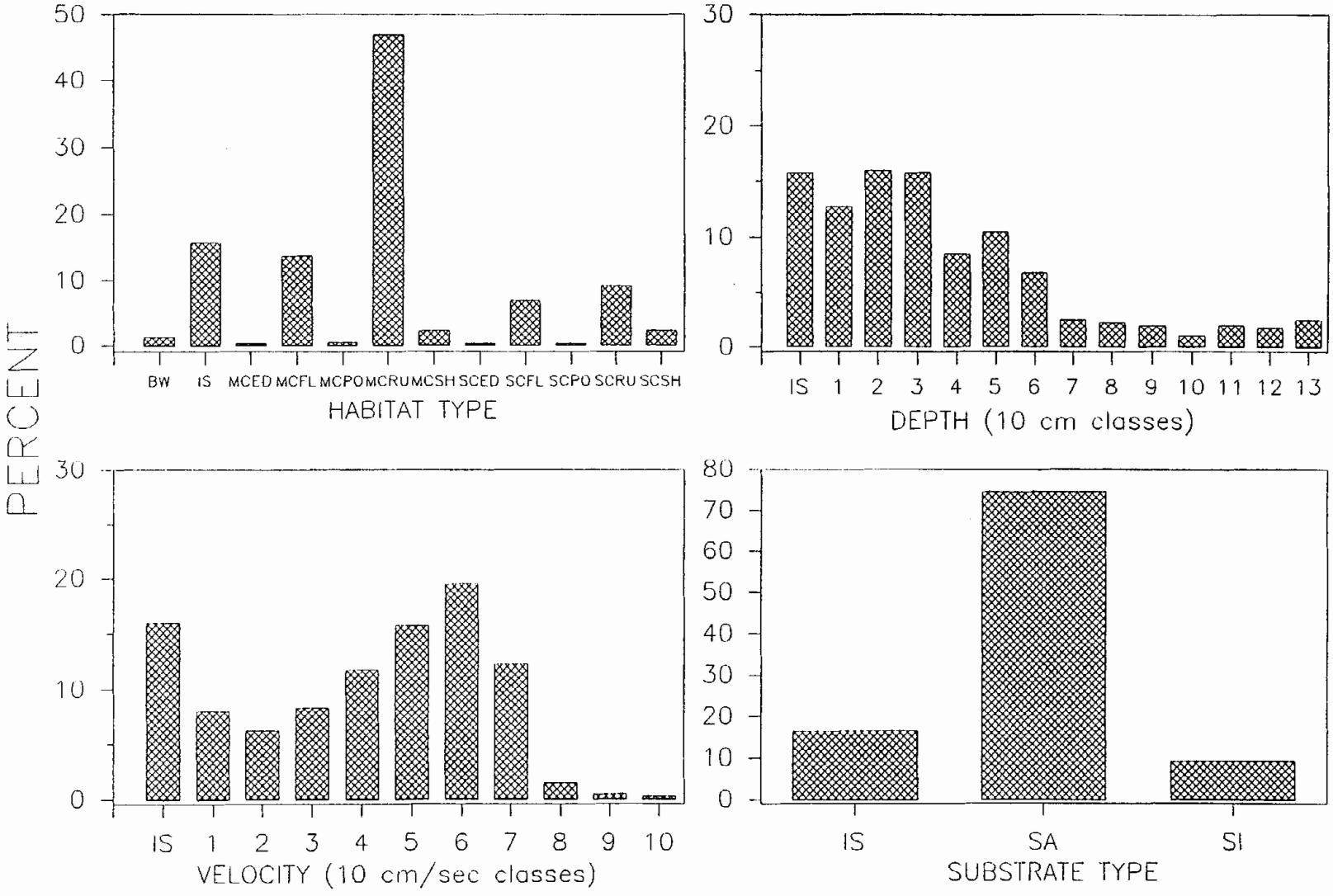

Figure 30. Macrohabitat variables summed for macrohabitat site 5, Turn.

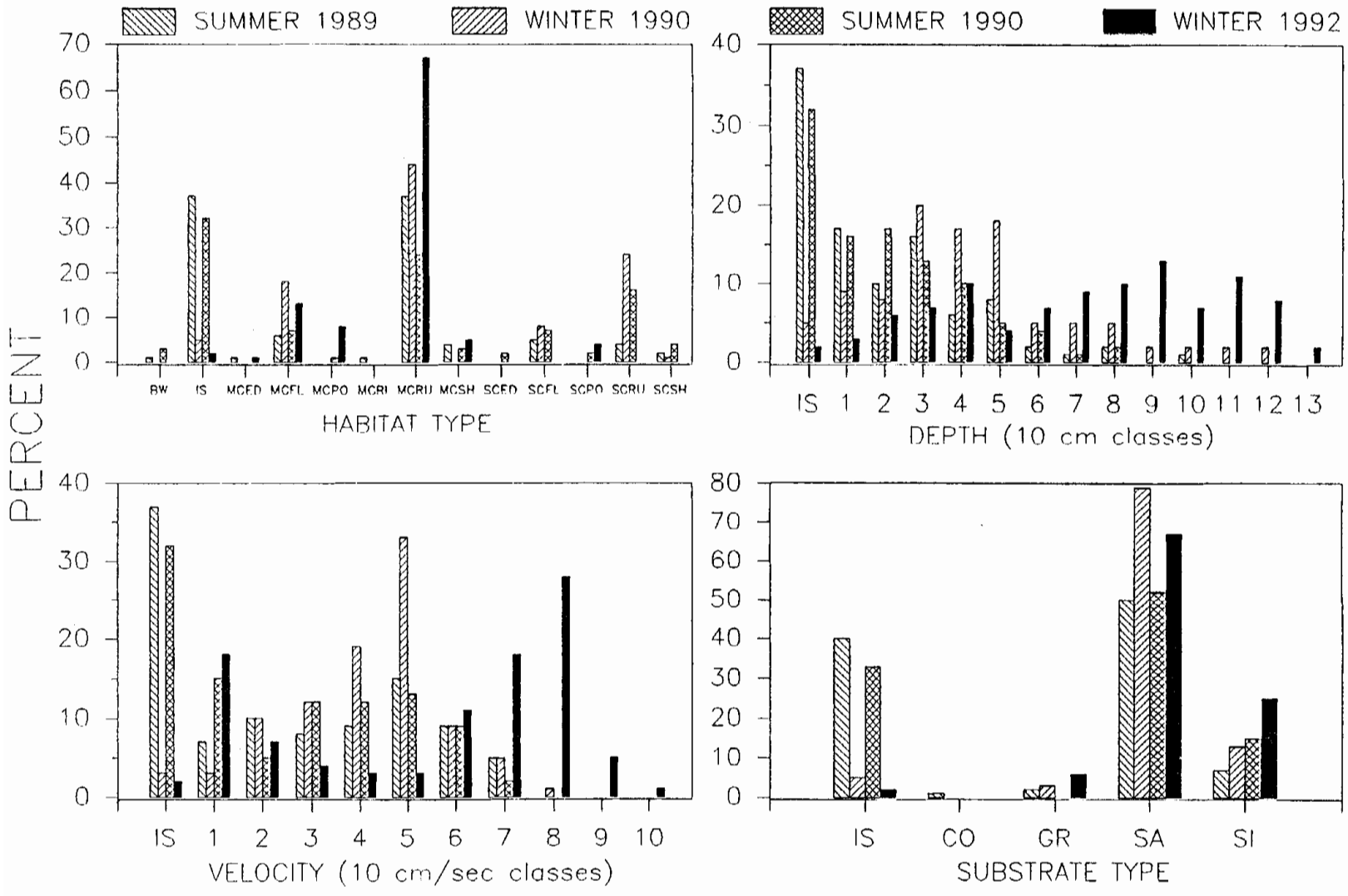

Figure 31. Macrohabitat variables per sampling period at macrohabitat site 6, Arroyo los Alamos.

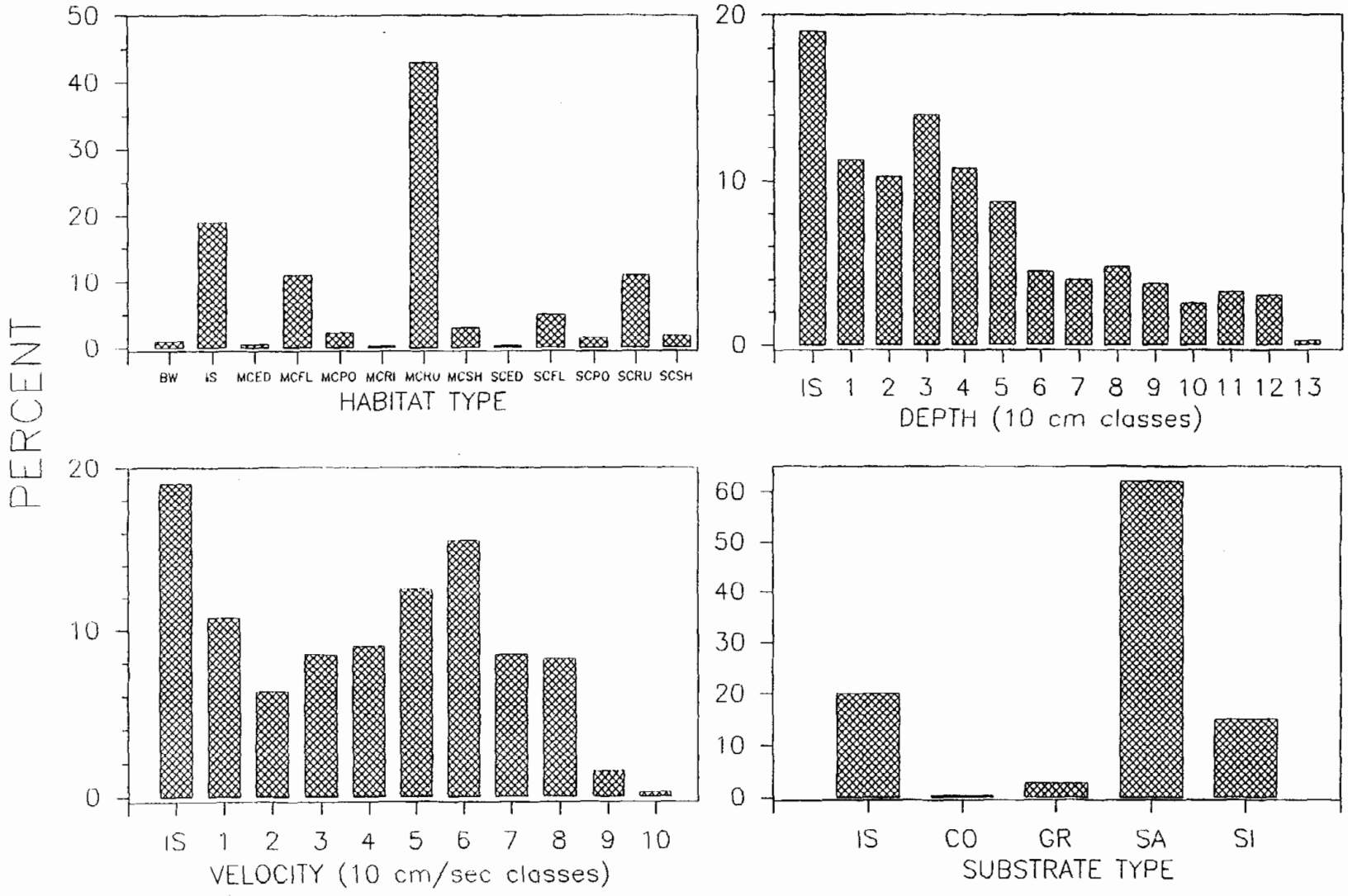

Figure 32. Macrohabitat variables summed for macrohabitat site 6, Arroyo los Alamos.

11% of the macrohabitat while secondary channel flat was 5%. Combined, these five habitat types were 89% of the macrohabitat at Arroyo los Alamos. The low-velocity habitats, backwater, pool, and eddy, were 5.5% of the recorded habitats.

Water velocity ranged between 0-87 cm/second. A total of 28% of the velocities was between 41-60 cm/second, 34.5% was $\leq$41 cm/second and 18.5% was >60 cm/second. Of the 64 water velocities >61 cm/second, 80% (N=51) were recorded during 1992.

One unusual characteristic of this site was the presence of an alluvial fan of gravel and cobble which washed into the river from Arroyo los Alamos. Sand (62%) and silt (15%) were the dominant substrata with gravel and cobble accounting for 3% of the substrata. In general, greater water depth occurred less often than at other macrohabitat sites. Excluding islands, which were 19% of the sample, 46.25% of the depth measurements were <40 cm deep and only 6.5% were > 100 cm deep.

Site 7: San Acacia Diversion Dam

The San Acacia Diversion Dam macrohabitat site was located directly below the base of the dam-face and was surveyed on three occasions. There was little difference in macrohabitat variables observed during the three sampling periods (Figure 33). Channel width at this site ranged from 25-188 m, yielding a mean width, over three visits, of 104 m.

There were 14 macrohabitats identified at this site, with runs accounting for 47.3% of the samples (32.3% main channel, 15% secondary channel) and island constitute 31.67% of the habitat (Figure 34). With the exception of Bosque del Apache, this was the largest percentage of island habitat encountered at a macrohabitat site. These islands did not create a braided river channel, but rather divided the river into two discrete channels. Secondary channel flat was the next most common habitat, but comprised only 4.0% of the total. Low-velocity habitats reached their greatest abundance at this site, representing 6.67% of the habitats. This was the only site where the habitat category "rapids" was observed.

Water velocity, generally <80 cm/second (96%), was most frequently between 0-30 cm/second (35%). There were two recordings of very high-velocity (152 and 180 cm/second) near the dam outflow in summer-1989. There were six substrate types recorded at this site. Sand and silt, still the most prevalent substrata, accounted for 52% (45.67% and 6.3%) of the habitat. Three rocky substrata (boulder, cobble, and gravel) comprised 14.3% of the habitat.

The water depth profile was similar to that seen up and downstream of this site. The deeper areas were less common than shallow. A total of 42% of the measurements were in water <30 cm deep. The addition of islands to this measurement yields 73.67% of the sites <30 cm deep. Only 1.3% of the depth readings were in water > 100 cm deep.

Site 8: Socorro

The next to last downstream macrohabitat site (Socorro) did not maintain perennial flows throughout the course of this study, but did have water during each sampling trip to it (Figure 35). The high winter-1992 flow did not significantly alter the macrohabitat or substrate composition of the site but did result in higher velocity and deeper water classes than were previously recorded. This site also exhibited the greatest variety in mean channel widths. During low flow periods, the channel averaged 39 and 73 m while high flow resulted in average widths of 162 and 165 m. The mean channel width at Socorro was 110 m.

Runs, flats, and shorelines were six of the eight (93%) macrohabitats identified at this site. Backwater was 2% of the habitat and island 5% (Figure 36). Only the San Juan Pueblo site (#1) had a smaller percentage (4%) of island macrohabitat than was present at Socorro.

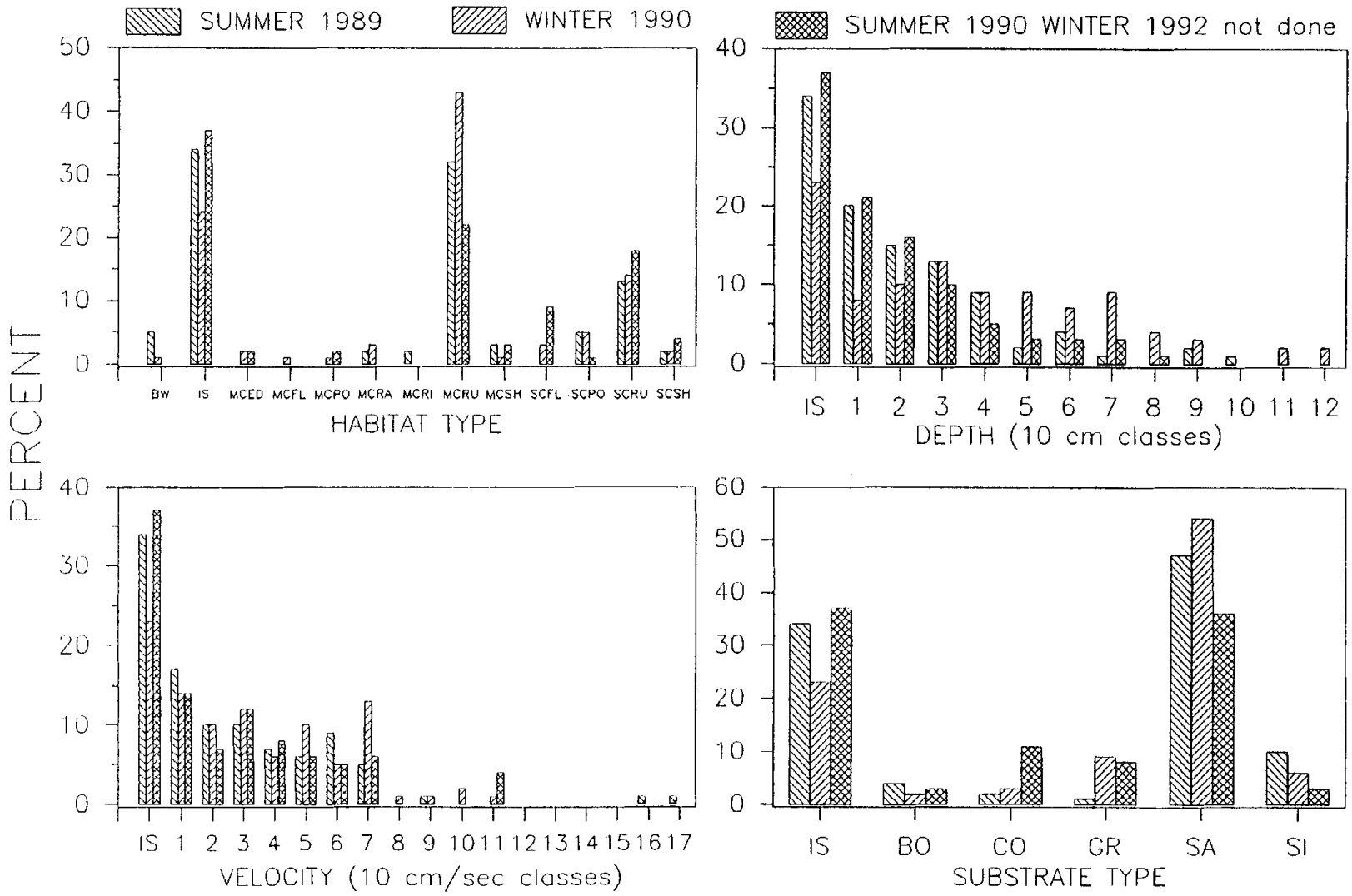

Figure 33. Macrohabitat variables per sampling period at macrohabitat site 7, San Acacia Diversion Dam.

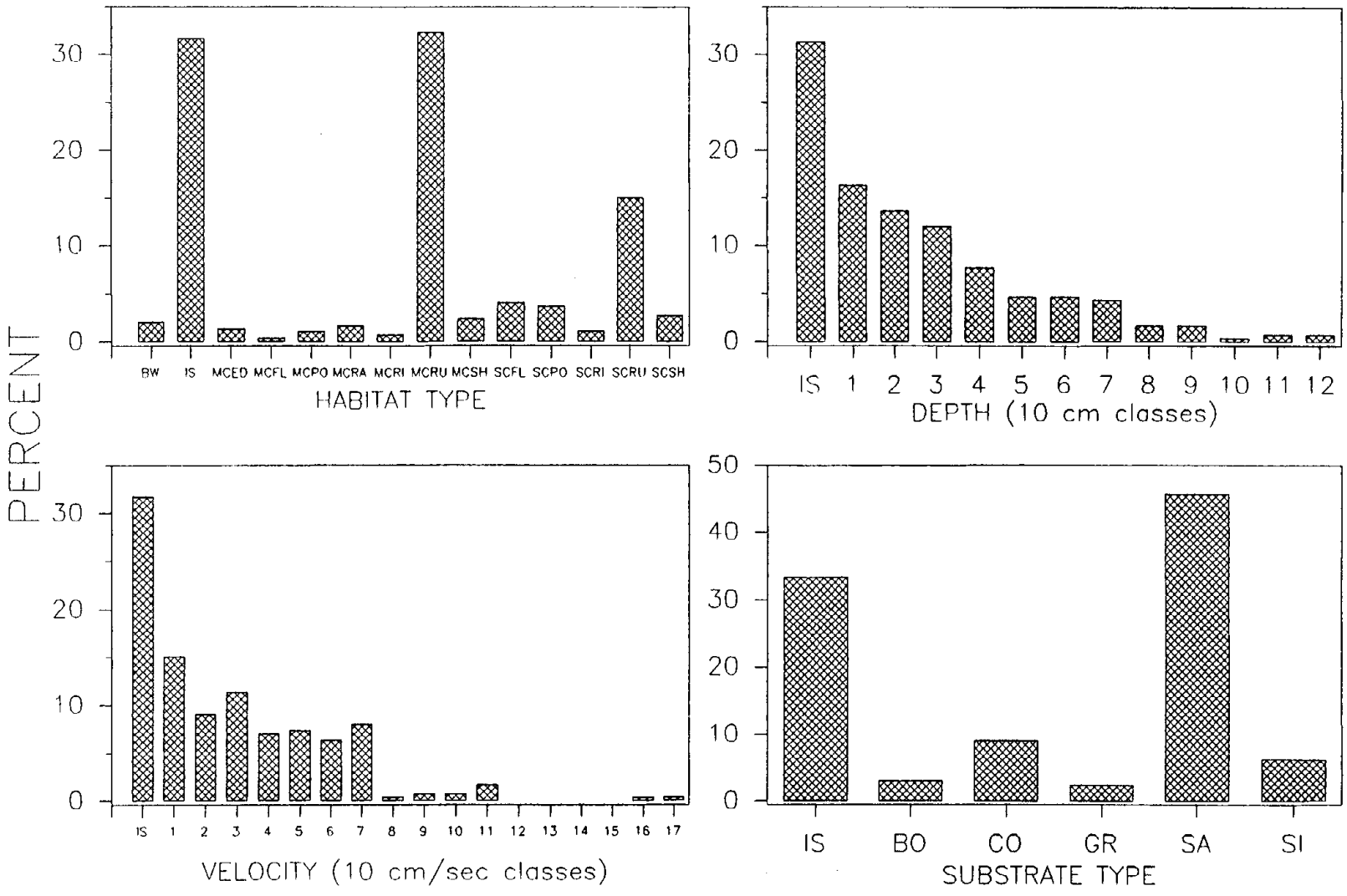

Figure 34. Macrohabitat variables summed for macrohabitat site 7, San Acacia Diversion Dam.

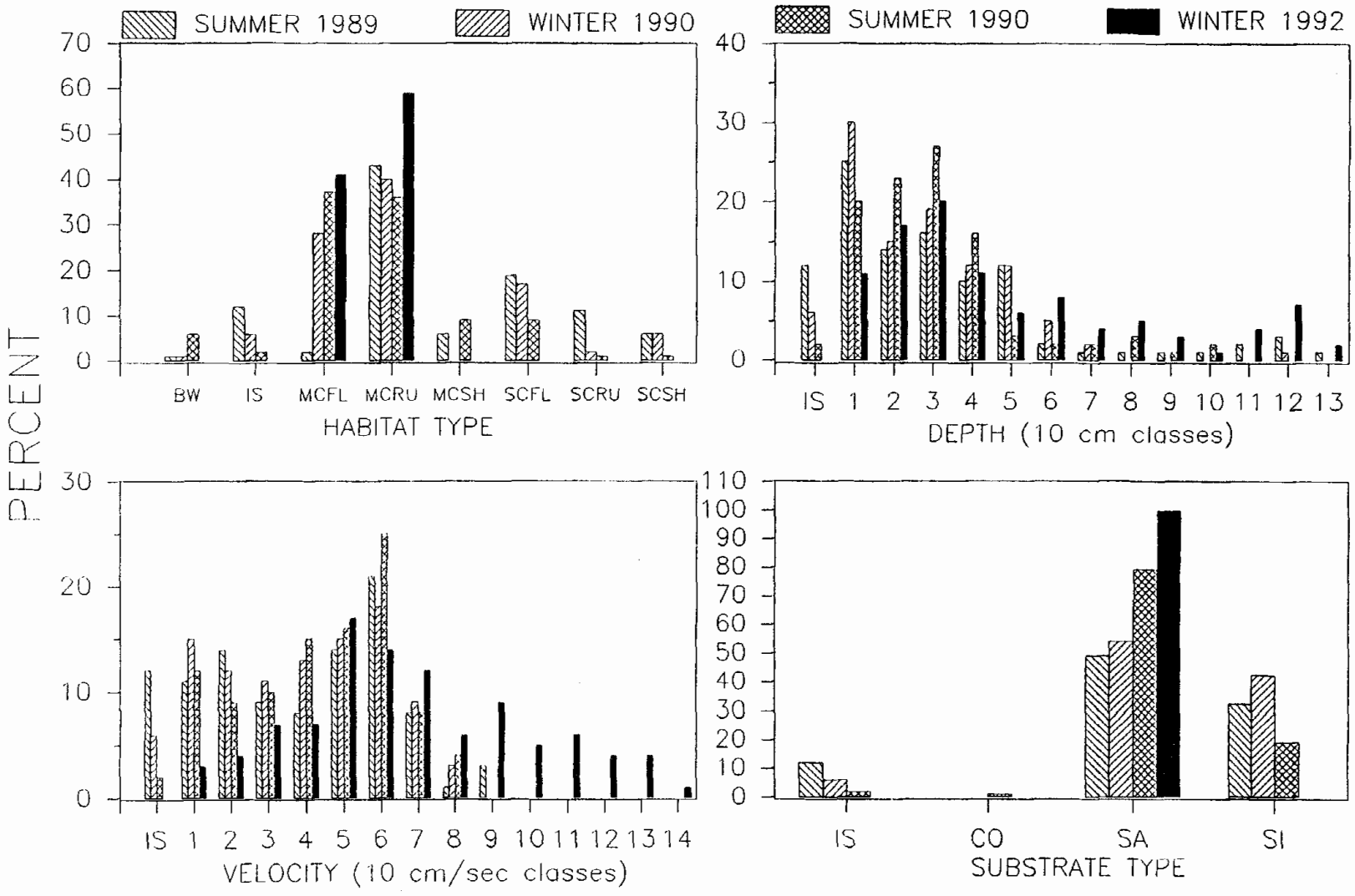

Figure 35. Macrohabitat variables per sampling period at macrohabitat site 8, Socorro.

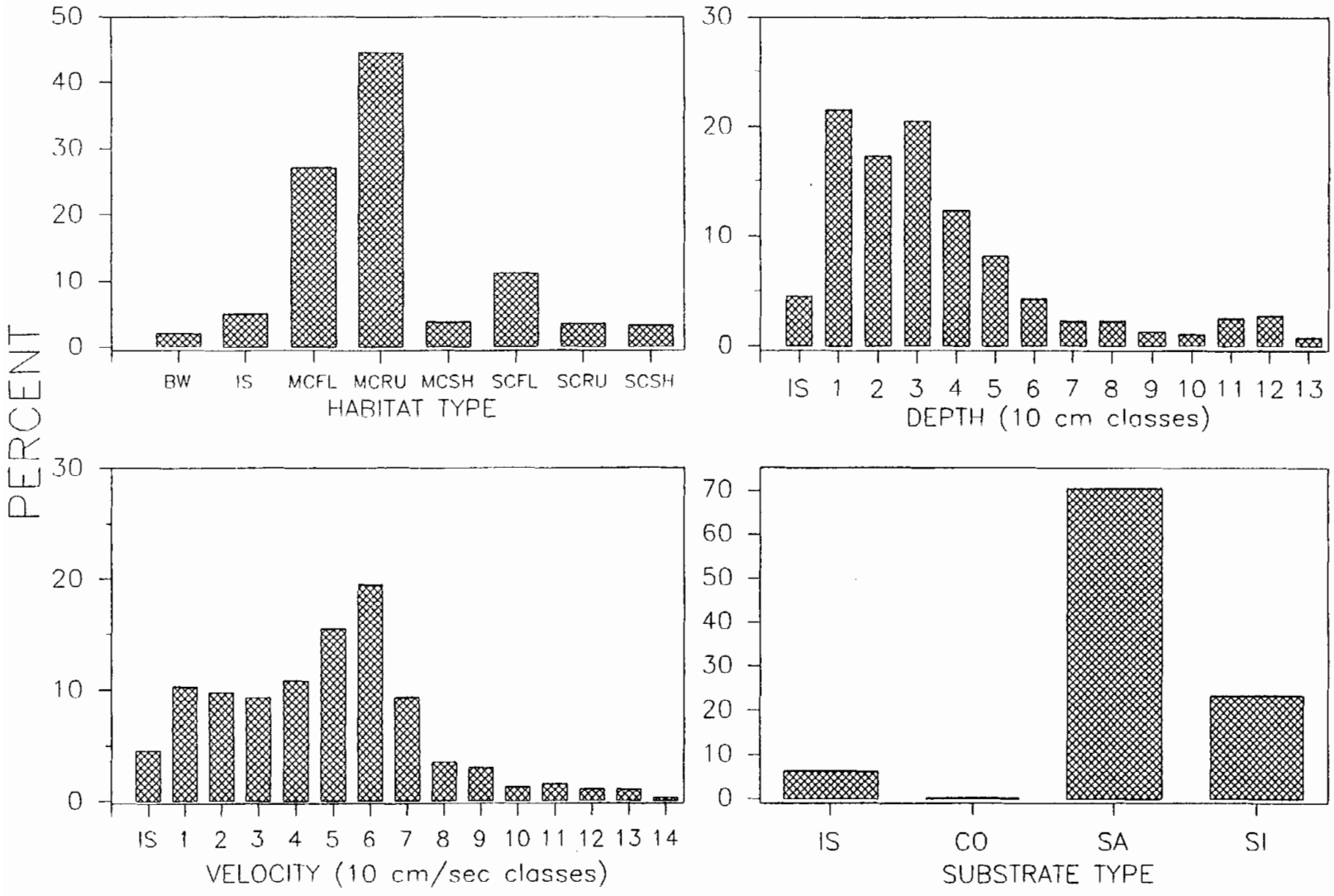

Figure 36. Macrohabitat variables summed for macrohabitat site 8, Socorro.

Water velocity ranged between 0-125 cm/second with all readings >91 cm/second (5%) occurring during the winter 1992 sample. Most of the velocity readings were either between 31-60 cm/second (45.75%) or 0-30 cm/second (29.25%). Sand and/or silt was the only substrata recorded during three of the four visits to the site. The exception was the summer-1990 sampling foray when cobble accounted for 1% of the substrate or 0.25% overall.

Depth profile at this site was relatively consistent throughout the study. There were few measurements taken in water >90 cm deep (7%) with the most frequently encountered depth-class being 0-10 cm. The first four depth classes (0-40 cm) comprised 71.5% of the readings while individual depth-classes >50 cm accounted for <5% of the total sample. The high winter-1992 flows resulted in a slight increase in the number of readings in waters between 101-130 cm deep.

Site 9: Bosque del Apache

The southern-most macrohabitat sampling locality, Bosque del Apache, was visited on four occasions but did not have flow during the winter-1990 and summer-1990 sampling trips. During the two periods without flow, all macrohabitat data points (depth, velocity, and substrate) (N=100) were recorded as "island." (Figure 37). Therefore, 50% of the recorded values were for dry periods and 50% for the two wet sampling occasions. Values from the two sampling efforts conducted while water was in the river were not parsed from the data-set and therefore cannot be >50%.

The channel at this site ranged from 20-43 m wide (mean=28 m) which was similar to macrohabitat site 1. During the two periods in which the river had flow at this site, main channel run was the dominant macrohabitat, comprising 39.75% of the habitat (Figure 38). The only other habitat type which comprised more than 5% of the total was main channel shoreline (5.25%). Low-velocity habitats were rare and were represented by a single main channel eddy.

There were two discrete velocity profiles at this locality which corresponded with the two occasions on which water was present. During the first (summer 1989), water velocity was <80 cm/second with 82% of the velocities occurring between 0-50 cm/second. During winter 1992, the largest percentage (38%) of velocities was between 161-170 cm/second with 68% of the velocity readings being >101 cm/second. These were the highest velocity measurements we obtained at any site during this study.

Like velocity, depth was very different during the two wet sampling periods at this site. In 1989, 92% of the water was <50 cm deep, while in 1992, 82% was >50 cm deep and 44% was >100 cm deep. These acute differences in habitat parameters are discernable from Figure 37 but are hidden when averaged over the course of the study and presented in Figure 38. Sand and silt were 54% and 44%, respectively, of the substrate in 1989 while sand was the only substrate recorded in 1992.

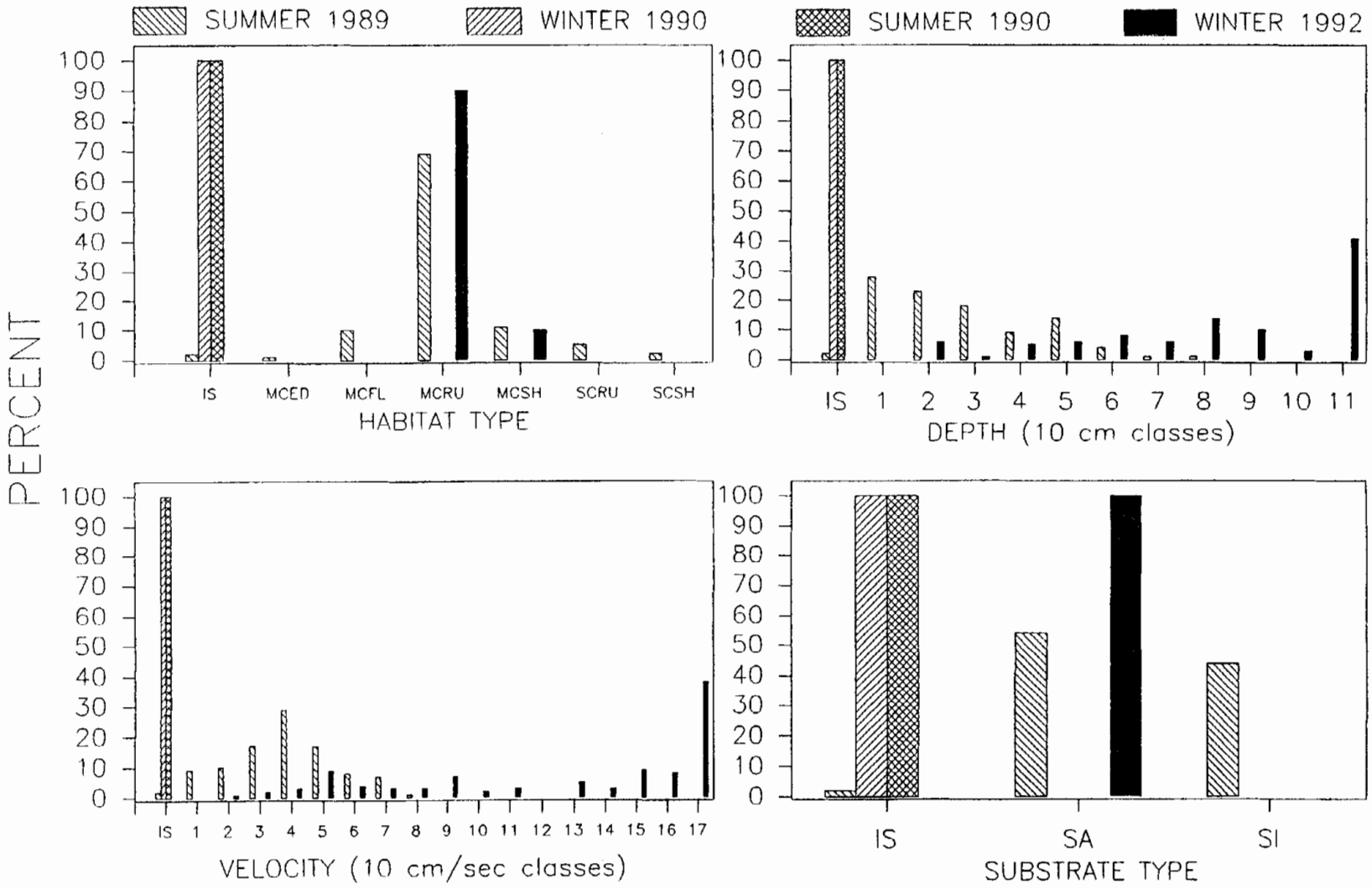

Figure 37. Macrohabitat variables per sampling period at macrohabitat site 9, Bosque de Apache.

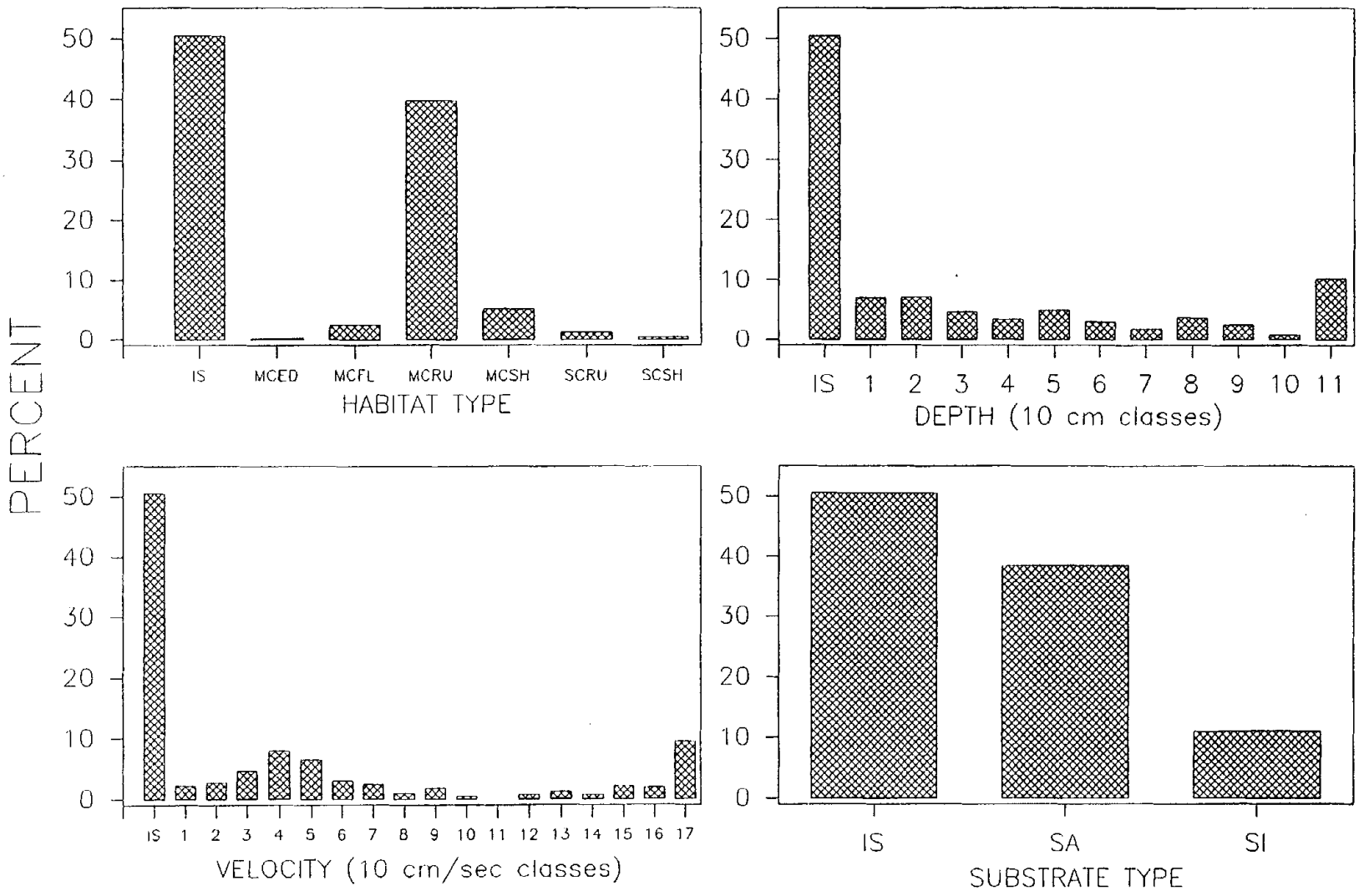

Figure 38. Macrohabitat variables summed for macrohabitat site 9, Bosque del Apache.

Longitudinal Distribution of Macrohabitat

The percentage of island habitat at the designated macrohabitat sites exhibited a general tendency to increase downstream (Figure 39). Site 1 had the least percentage of island habitat while San Acacia (site 7) and Bosque del Apache (site 9) each registered more than 30% island macrohabitat type. Socorro (site 8) did not fit the pattern as only 5% of the measurements taken at that locality were island macrohabitat type. This limited amount of braiding was due, in part, to the fact that during periods of reduced flow, water remained in the incised channel on the east bank of the river-bed. There was more braiding, than these data indicated, immediately up-and-downstream of this study site.

As expected, there was a relationship between the amount of island habitat and presence of main and secondary channel habitats (run and shoreline). Main channel runs were most common at the upper sites where island habitat was least abundant. At the middle sites (3-6), main channel runs were 39-47% of the macrohabitat and islands were 16-21% Secondary channel runs reached their greatest abundance at sites 2-4 when they were 17-18% of the macrohabitat type.

As secondary channel runs increased as a percentage of habitat, so did the occurrence of secondary channel shoreline habitat. Main channel shoreline habitat reached its greatest percentage of the sample at sites 1 and 2. Mean channel width at these two localities was the smallest of the sites sampled and, as the distance between macrohabitat measurements was a function of channel width (the greater the channel width the greater the distance the first and subsequent measurements are from shore), this increased the likelihood of multiple main channel shoreline data points.

Main and secondary channel flats exhibited a similar pattern of first appearance and increasing downstream abundance. Flat macrohabitat types, which were not present at the upper two sites, reached their greatest abundance at site 8 (Socorro). Flat was the second most abundant of the main channel habitat types. Its absence from upstream sites was a function of high gradient (and water velocity) and lack of sand substrate.

Riffle habitat, which was never more than 5% of the macrohabitat type at a site, was most common sites 1 and 7. Its presence at site 1 was due to the higher water velocity (than at downstream localities) and gravel-cobble substrate. Site 7 was directly below San Acacia Diversion Dam and the presence of riffle and rapid macrohabitats was due to the dam releases and the substrate (gravel-cobble-and boulder) placed below the dam to impede erosion.

Pool and eddy macrohabitat types occurred primarily at sites 2-7 while backwaters were encountered at all sites except Bosque del Apache (site 9). Backwater never comprised more than 3% of the macrohabitat at any site but may be more common than indicated. A backwater is an ephemeral habitat which can be drastically influenced by changes in flow. A secondary channel can be transformed into a backwater by a slight drop in flow. If the water level continues to decrease, the backwater transforms to an isolated pool and may eventually disappear. Conversely, an increase in flow will transform a backwater to a secondary channel. None of the other rare macrohabitat types (e.g. debris) were so intimately linked with flow.

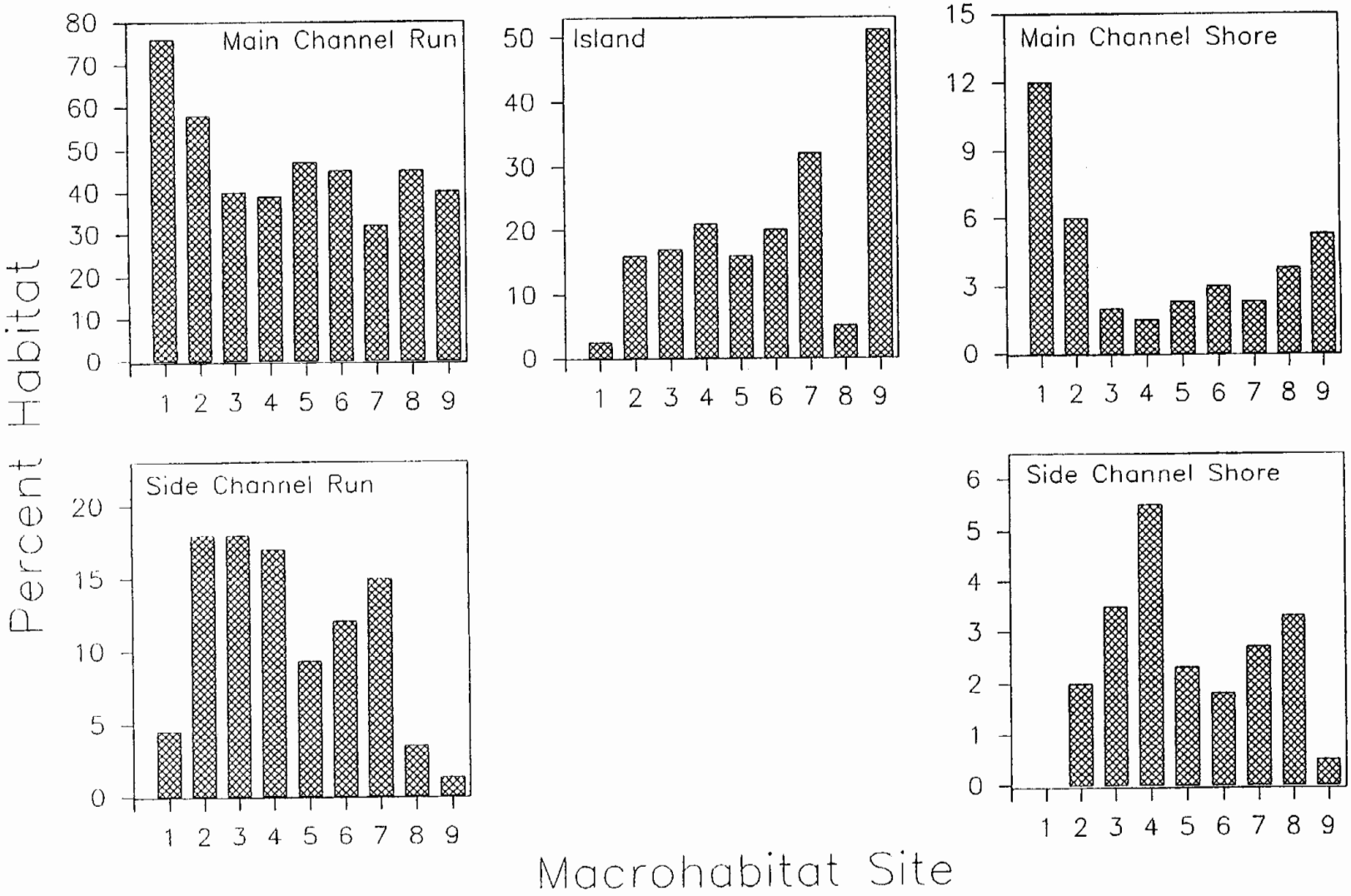

Figure 39. Longitudinal distribution of macrohabitat types in the Middle Rio Grande.

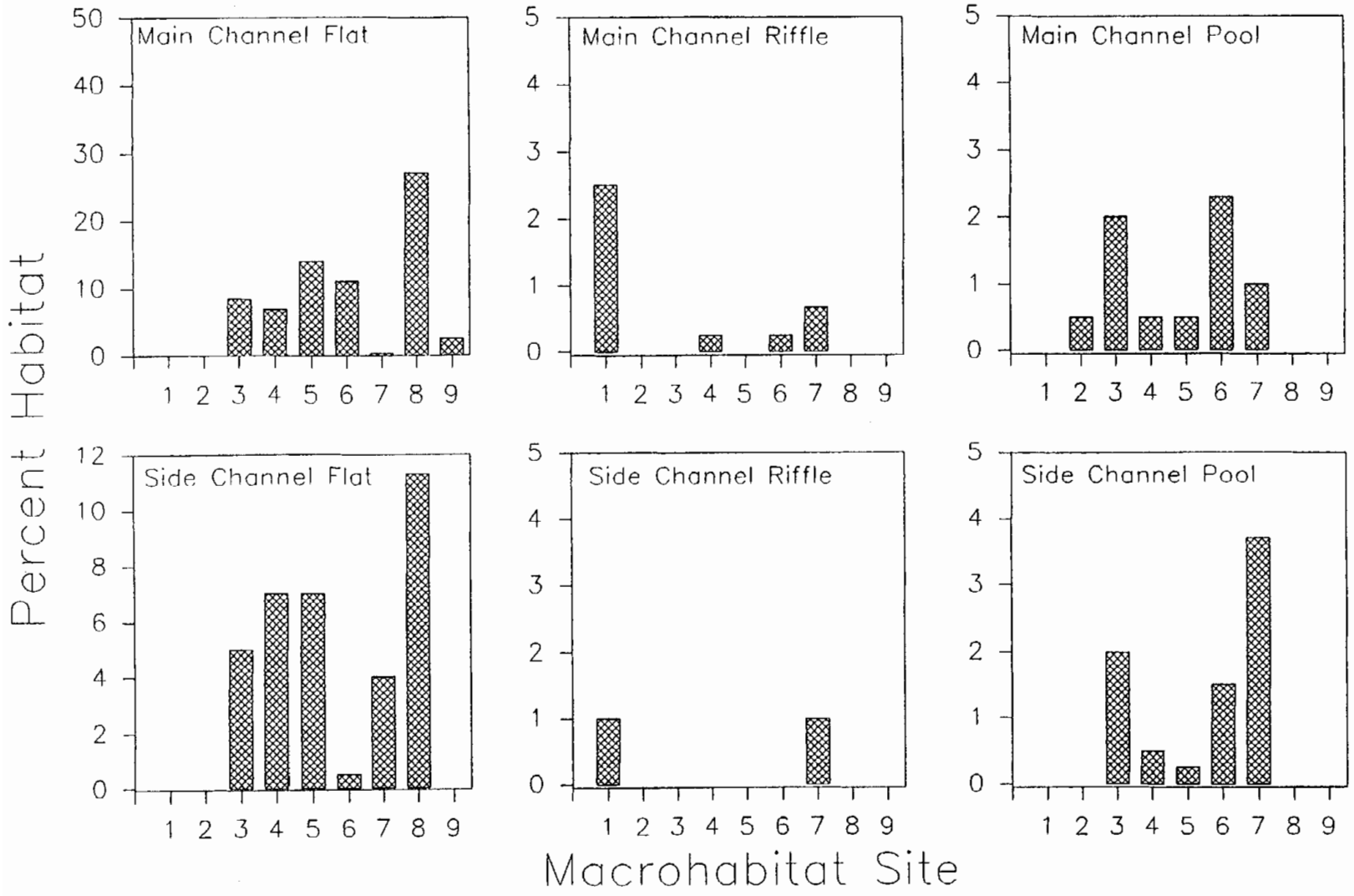

Figure 39. continued.

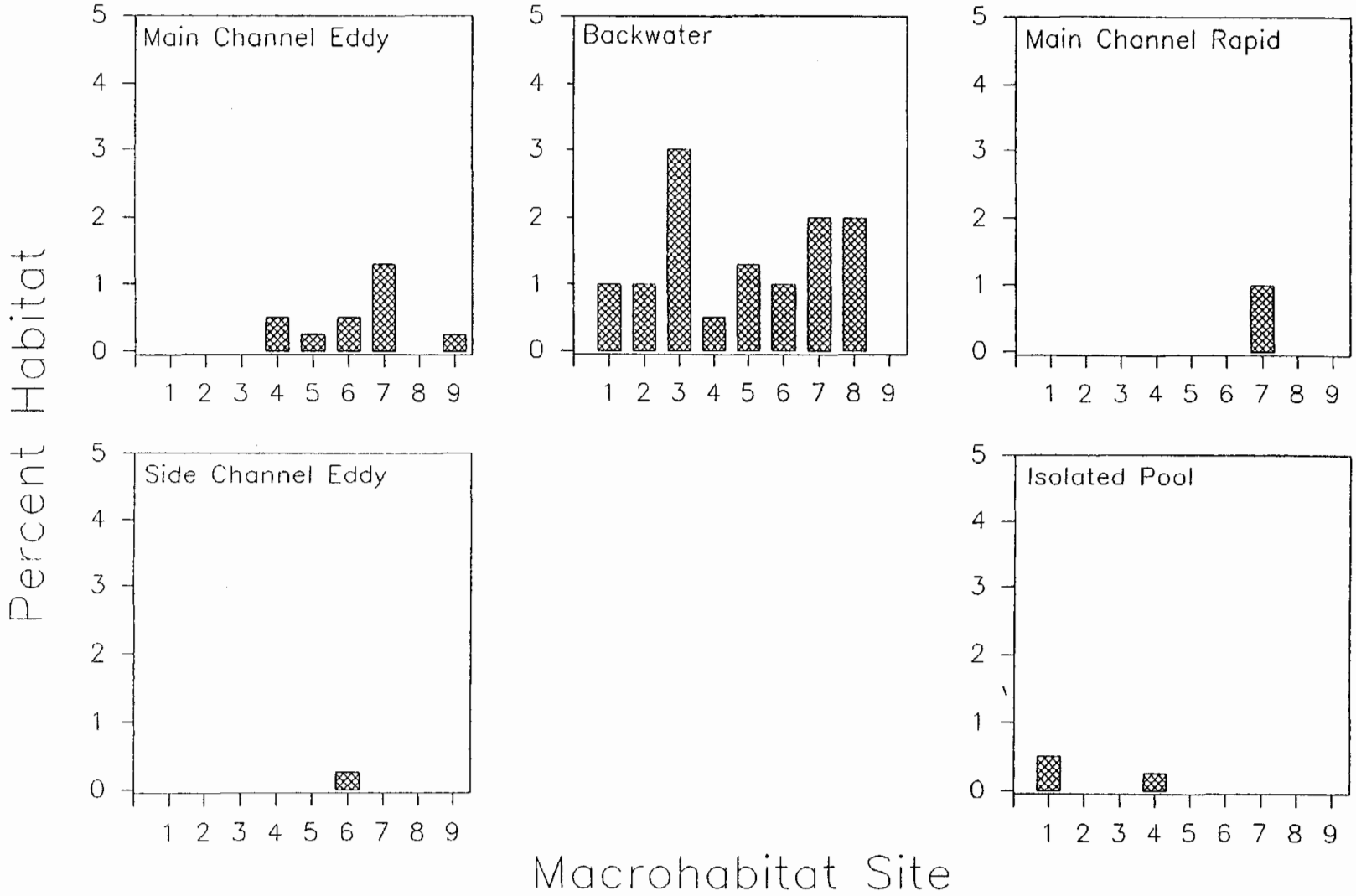

Figure 39. continued.

SPECIES HABITAT ASSOCIATIONS

The habitat associations of the eight species (red shiner, western mosquitofish, flathead chub, longnose dace, fathead minnow, white sucker, channel catfish, and river carpsucker) that were most common during macrohabitat sampling were examined. These eight species were represented by 5,900 specimens and comprised 99% of the total macrohabitat sampling catch. They ranged in abundance from red shiner, which accounted for 57.3% (N=3,3365) of the catch, to river carpsucker (N=144, 2.4%). In contrast, the ninth-most abundant fish, largemouth bass, was represented by only nine specimens. The eight selected species, five of which were native, represented three orders and four families and occupy a variety of trophic levels and different macro-and-microhabitats. These species and their habitat associations are addressed in order of abundance rather than by phylogeny.

It should be noted that the macrohabitat availability data-set was modified to compare it with the species habitat association data. The former information were important for assessing habitat while the latter were an assessment of habitat use by fish. Island comprised over 20% of the macrohabitat availability data, but fish cannot use islands as habitat. The percentages of macrohabitat types, depths, velocities, and substrata were therefore recalculated without islands, and the resulting subset of the habitat availability data were used.

Red shiner

There was a statistically significant association between red shiner and macrohabitat type (D.F. 8, 329; $F=7.30$; $p<0.001$), substrate (D.F. 5, 328; $F=6.15$; $p<0.001$) and velocity (D.F. 9, 329; $F=2.44$; $p<0.0107$). The largest percentage of the total catch of red shiner (37%; N=1,245) was in low-velocity habitats (Figure 40). Red shiner were present in 21% of backwaters (N=21), 44% of debris piles (N=27), 68% of pools (N=25), and 69% of eddies (N=13) sampled during species association-macrohabitat studies.

This species was most closely associated with sand and silt substrata. However, it would probably be invalid to assume that the species avoided larger substrata. Rocky or gravely substrata was most common in the upper reaches of the river, which were also characterized by cooler water of sustained higher velocity. It was most likely the velocity and temperature, rather than the larger substrata, that restricted red shiner in these reaches.

Avoidance by red shiner of relatively high-velocity water, as indicated by this work, was probably not an artifact of the species' longitudinal distribution. Macrohabitats with water velocities comparable to the upper reaches were present at each of the sites during some phase of the study. Red shiner generally avoided high-velocity waters and habitats (D.F.9, 320; $F=2.44$; $p<0.0107$). There were only three samples (of 331) in which red shiner was taken in water > 100 cm/second. In contrast, red shiner occurred in 68% of the macrohabitat samples taken in velocity class 1 (0-10 cm/second), 58% of class 2 (11-20 cm/second), and 48% of class 3 (21-30 cm/second).

Western mosquitofish

Western mosquitofish was found in 100 fewer samples (N=30) than red shiner but was the second-most abundant taxon (N=926) in macrohabitat samples (Figure 41). This species exhibited a significant macrohabitat association (D.F. 8, 329; $F=4.47$; $p<0.0001$) and was most often taken in low-velocity macrohabitats (backwater, isolated pool, and debris piles). The majority of western mosquitofish collections (N=12) and individuals (62%; N=572) were taken in backwater habitats. This species was also found in 60% (N=5) of the

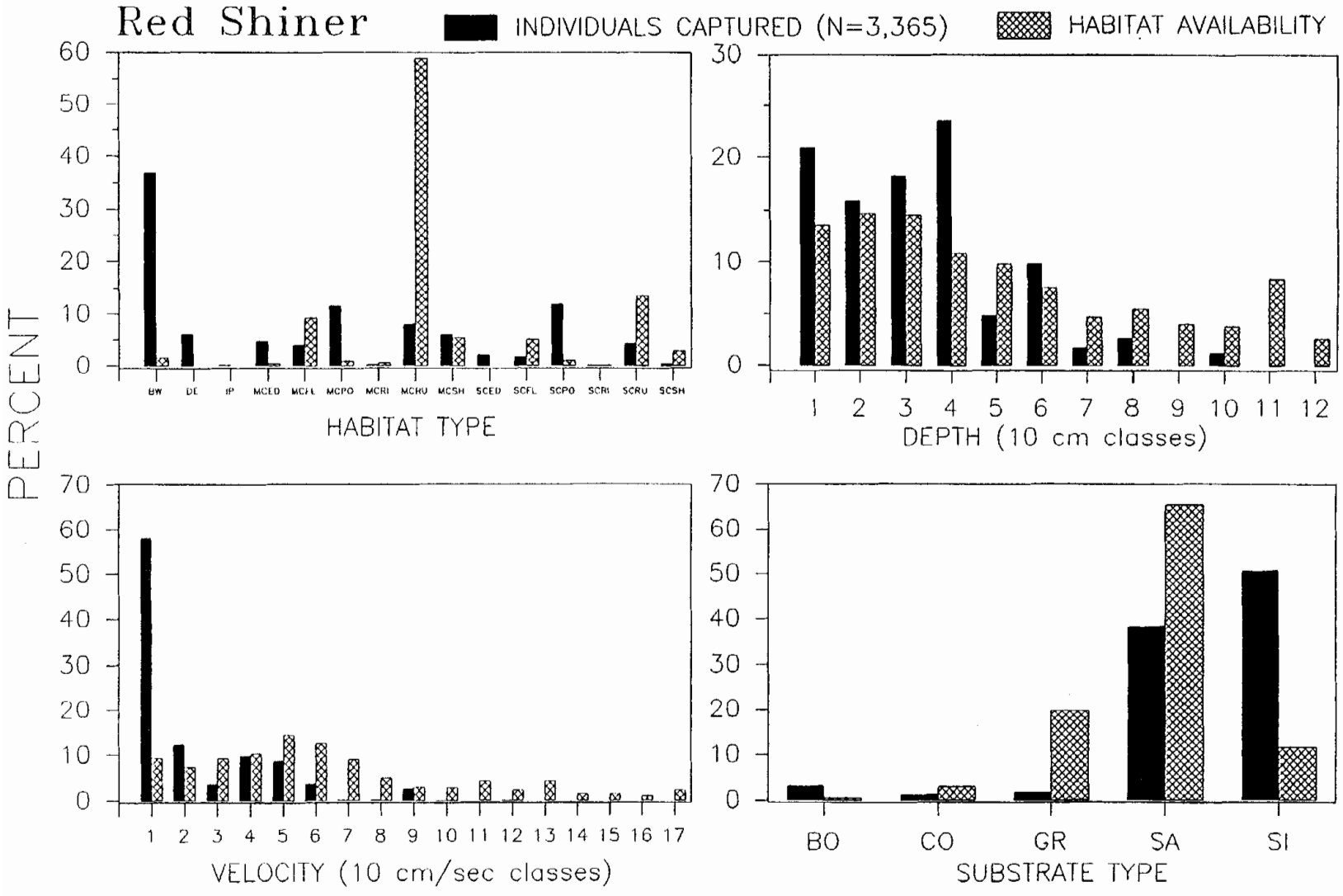

Figure 40. Red shiner macrohabitat association.

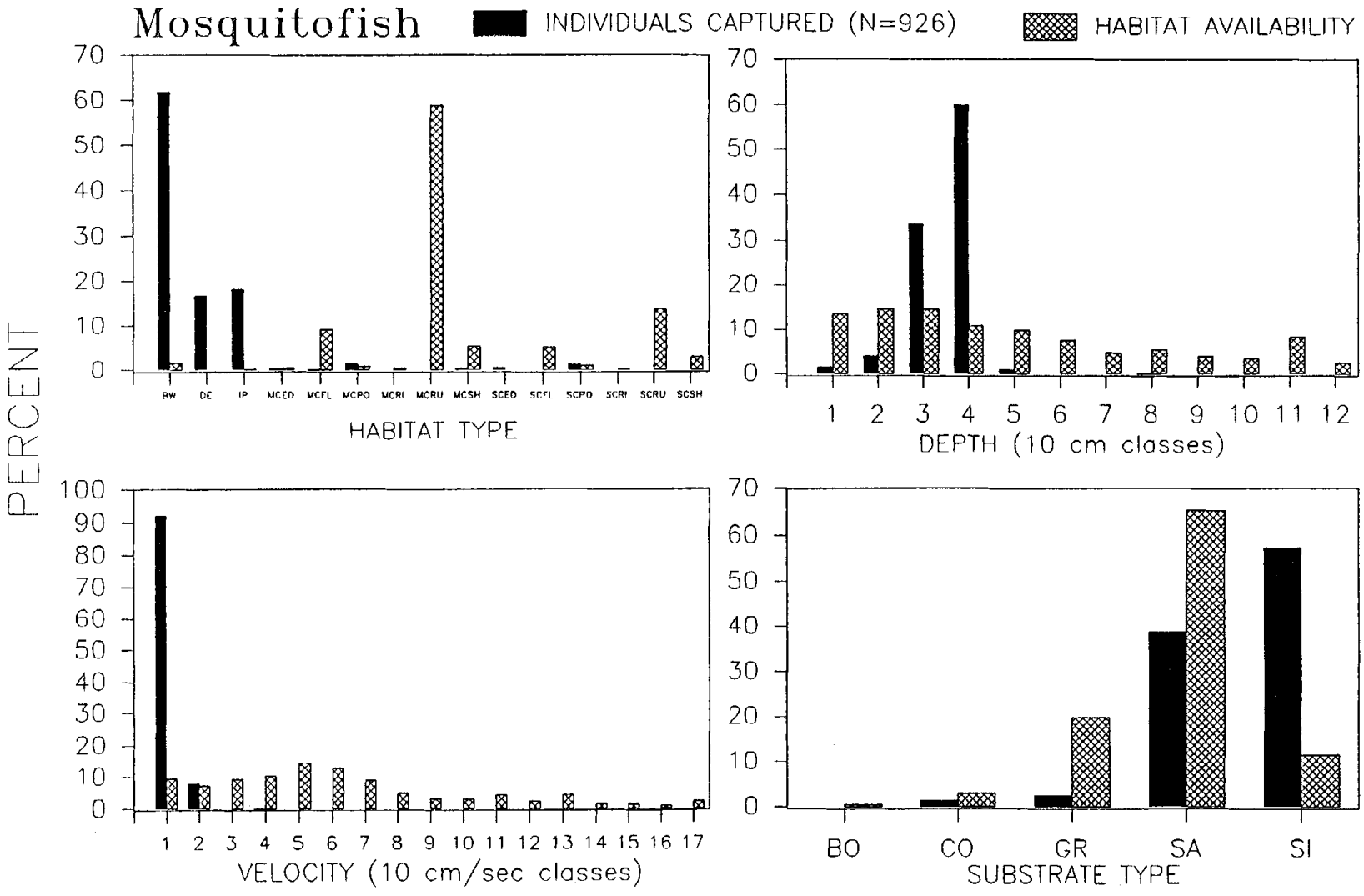

Figure 41. Western mosquitofish macrohabitat association.

isolated pools and 18.5% (N=5) of the debris piles sampled and was relatively abundant (N=168, 153 respectively) in those habitats.

Western mosquitofish tended to occur most often in shallow water (<40 cm deep), over sand or silt substrate types, and water with reduced velocity. A total of 851 (92%) of the individuals and 90% of the samples which contained western mosquitofish was taken in water of velocity class 1. Of the remaining 75 western mosquitofish collected, 74 were collected in water with class 2 velocity. No specimens were taken in water with velocity >41 cm/second.

Flathead chub

The third-most abundant species, flathead chub, had the second-highest frequency of occurrence in macrohabitat collections. A total of 621 flathead chub was collected in 80 samples (Figure 42). This species exhibited a significant association with habitat type (D.F. 8, 320; $F=3.22$; $p<0.0016$). It had a higher frequency of occurrence in run habitat but was numerically more common in low-velocity habitats (backwater and pool). This apparent inconsistency of habitat association was reflective of the habitat preference of different ontogenetic stages of flathead chub. Juvenile and young-of-year flathead chub tended to occupy lower velocity habitats (pool and backwater) while adults were more frequently found in higher velocity water (run). This apparent preference for low-velocity water by young and juvenile was also illustrated in the velocity histogram.

Flathead chub showed a greater tendency than most of the other eight species being discussed to be found over gravel or larger substrata (20%). When adult flathead chub were present, these substrate types were most frequently associated with run or riffle habitats with relatively high water velocity.

Longnose dace

Longnose dace also occurred in habitats characterized by higher velocity water and associated gravel or cobble substrata (Figure 43). The majority of the samples (63%; N=24) and individuals (55%; N=156) of this species were taken in these habitat types. This species was also affiliated with main channel pool and debris habitats, both of which, while characterized by low-velocity water, were adjacent to fast moving water. Adult longnose dace were most often associated with high-velocity water while juveniles occurred in a variety of lower-velocity class waters.

Physiological, morphological (reduced swim bladder and body shape), and behavioral characters of this species allow it to exploit high-velocity water habitats while expending little energy. Our measurements determined mean water column velocity and were not indicative of the point velocity for this benthic species. Longnose dace live in the interstices of rocks at or below the boundary layer where water velocity was significantly different from the mean of the water column.

Fathead minnow

Fathead minnow occurred in low-velocity waters and associated habitats. There was a significant association between this species and macrohabitat types (D.F. 8, 321; $F=6.14$; $p<0.0001$). This species was associated with backwaters, isolated pool, eddy, and pool habitats. Of the 245 individuals captured, the largest number, percentage, and frequency of occurrence (N=90, 37%, 12) were in backwater habitat (Figure 44). Fathead minnow was

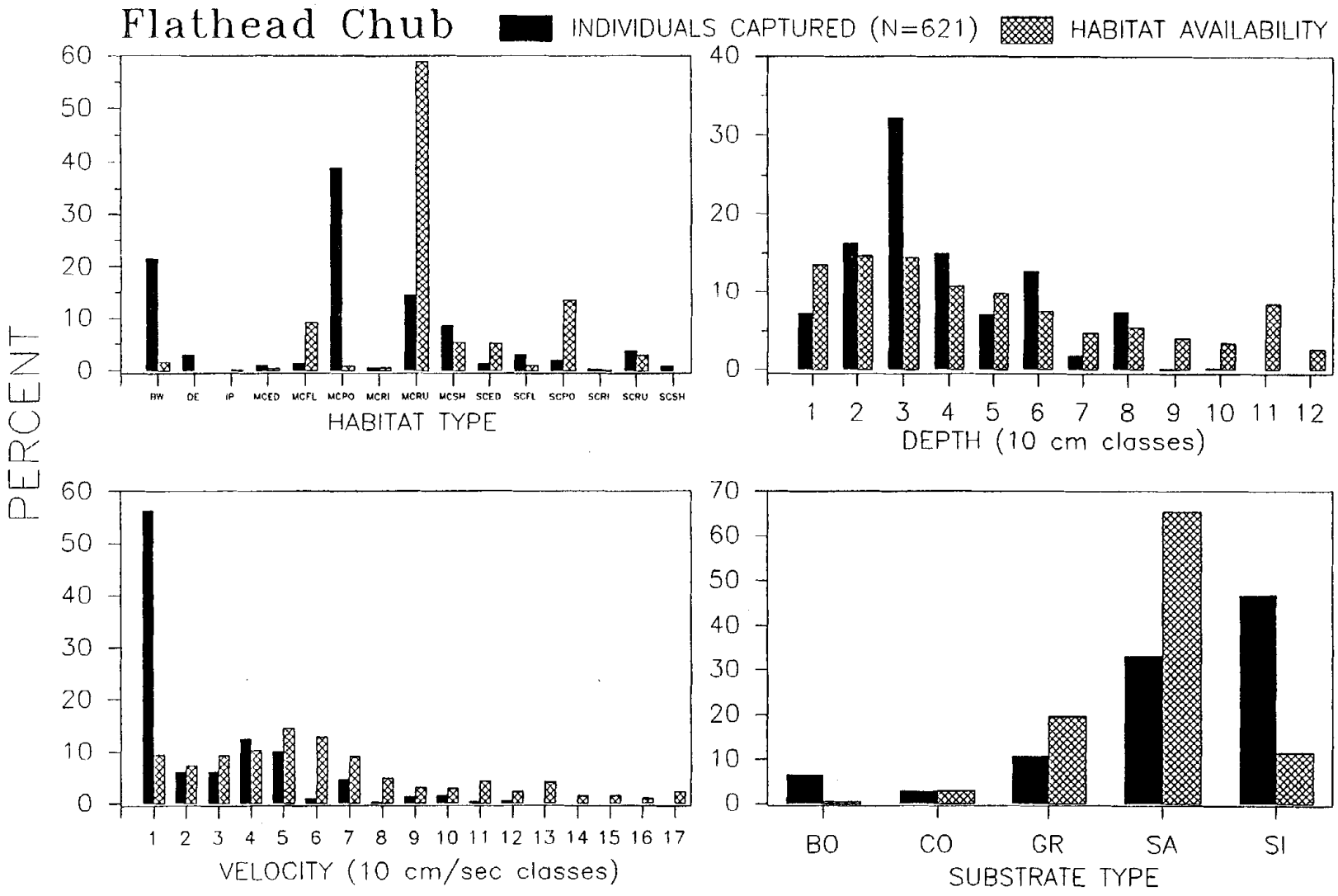

Figure 42. Flathead chub macrohabitat association.

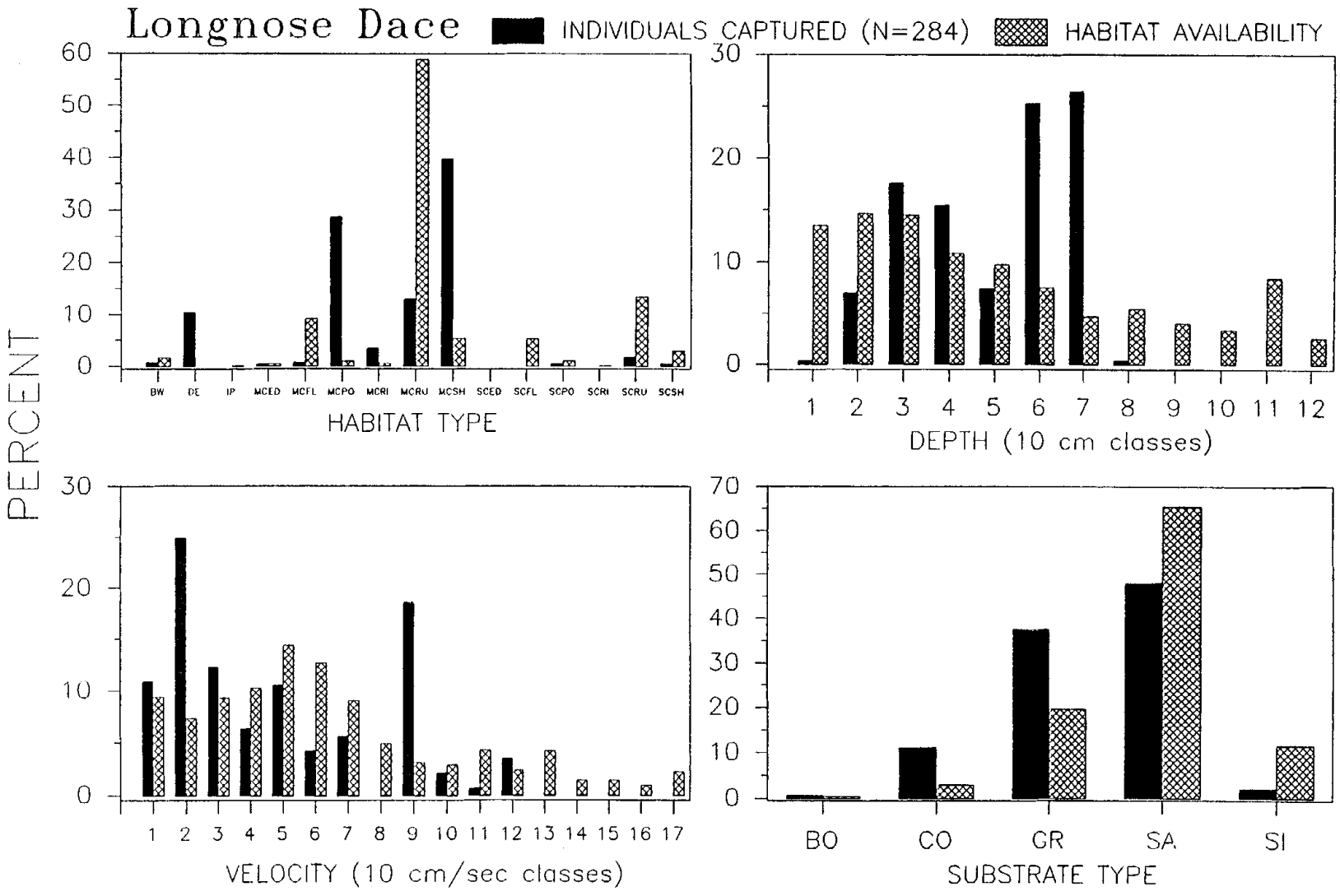

Figure 43. Longnose dace macrohabitat association.

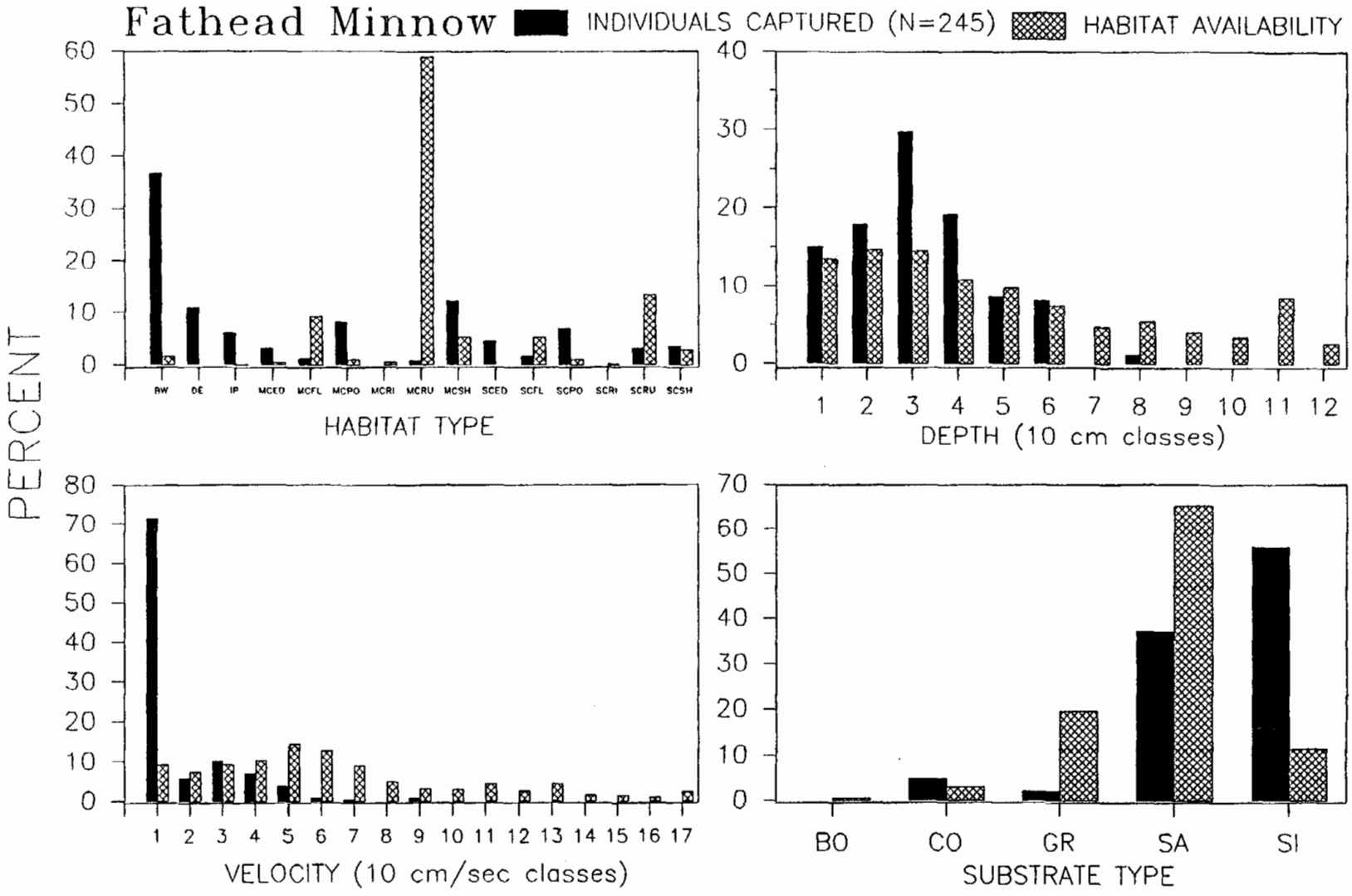

Figure 44. Fathead minnow macrohabitat association.

taken in 12 of 27 (44%) backwaters sampled during this phase of the survey. There was a negative association with higher-velocity habitats such as flat, run, and riffle.

Most individuals (N=214; 87%) were collected in water $\leq$30 cm/second. Only three specimens, in three samples, were collected in water with a velocity >70 cm/second. Low-velocity macrohabitats were often depositional areas where the substrate was silt or sand. This species was collected over gravel or cobble substrata in < 10% of the samples.

White sucker

A total of 161 white sucker was collected in 19 macrohabitat samples. This species was relatively widespread in its habitat usage and did not exhibit statistically significant (D.F. 8, 328; F=1.88; $p<0.0623$) association with any of the macrohabitat parameters. White sucker was found in six macrohabitats but was most abundant in backwater and debris habitats (Figure 45). About 45% of the individuals (N=72) were collected in four of 27 (15%) backwaters sampled. Although this species was less abundant in debris piles (N=46) than backwaters (N=72), it was taken in about the same frequency (N=5) and percentage of samples (19%).

White sucker was found in a variety of different velocity-class waters (0-110 cm/sec) and over four substrate classes. It was most common (96.6%) in low-velocity water ($\leq$50 cm/sec), which corresponded to its association with backwater and debris piles. Most specimens (N=123; 76%) of white sucker were collected over silt and sand substrata. However, about 22% of the samples containing white sucker were taken over rocky (cobble or gravel) substrata. These latter substrate types were relatively rare in the lower reaches of the river.

Channel catfish

The frequency of occurrence of channel catfish in the 11 macrohabitats where it was taken, ranged from one to six. It was most often encountered in main channel run habitats (N=6) and was most abundant in secondary channel pools (N=73; 47%). This species did not exhibit a statistically significant preference (D.F. 8, 329; F=2.63; $p<0.0083$) for habitat or the other associated parameters, thus suggesting a wide physical niche. It was encountered over a broad realm of macrohabitats (N=10), velocities (classes 1-6), depths (N=9), and substrata (Figure 46).

A sample of 67 channel catfish, which represented 44% of the total catch, was collected from a secondary channel pool with silt substrate, water between 31-40 cm deep, and a mean velocity of 5 cm/second (velocity class 1). This collection dominated and biased the statistical analysis of the channel catfish data-set. The next largest collection of channel catfish (N=12) was taken in a 49 cm deep secondary channel run debris pile.

River carpsucker

River carpsucker, the least abundant of fish species of those analyzed (N=8) in the macrohabitat-association study, was taken in 19 samples and represented by 144 specimens (Figure 47). This species was collected six times each in pool, run, and backwater habitats. It was also most common in pools (N=44), backwaters (N=41), and flats (N=38). The other habitat where river carpsucker was collected was run (N=21). Run habitat was generally represented by higher velocity water, while pools, backwaters, and flats were characterized by low-velocity and sand or silt substrata.

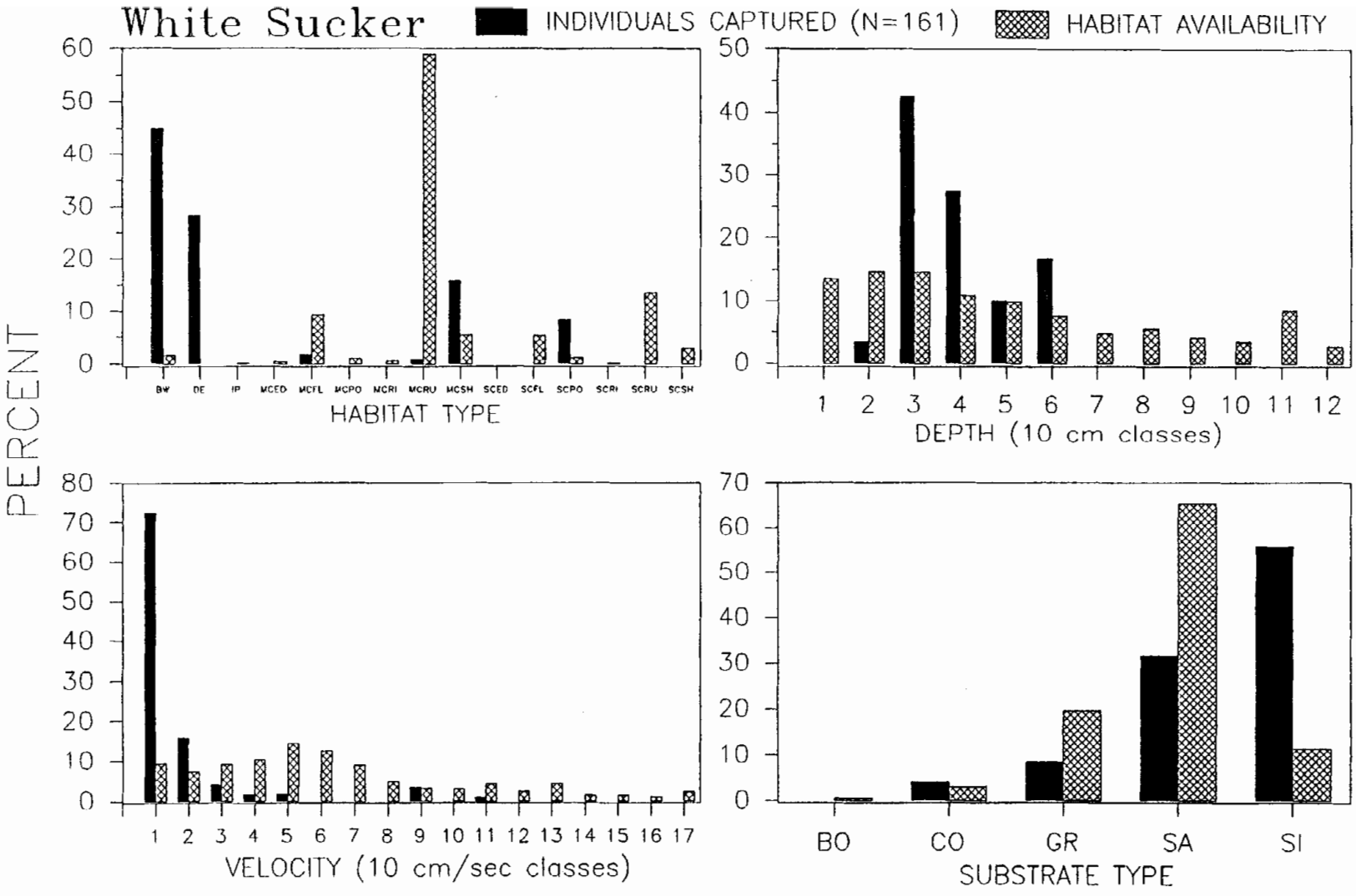

Figure 45. White sucker macrohabitat association.

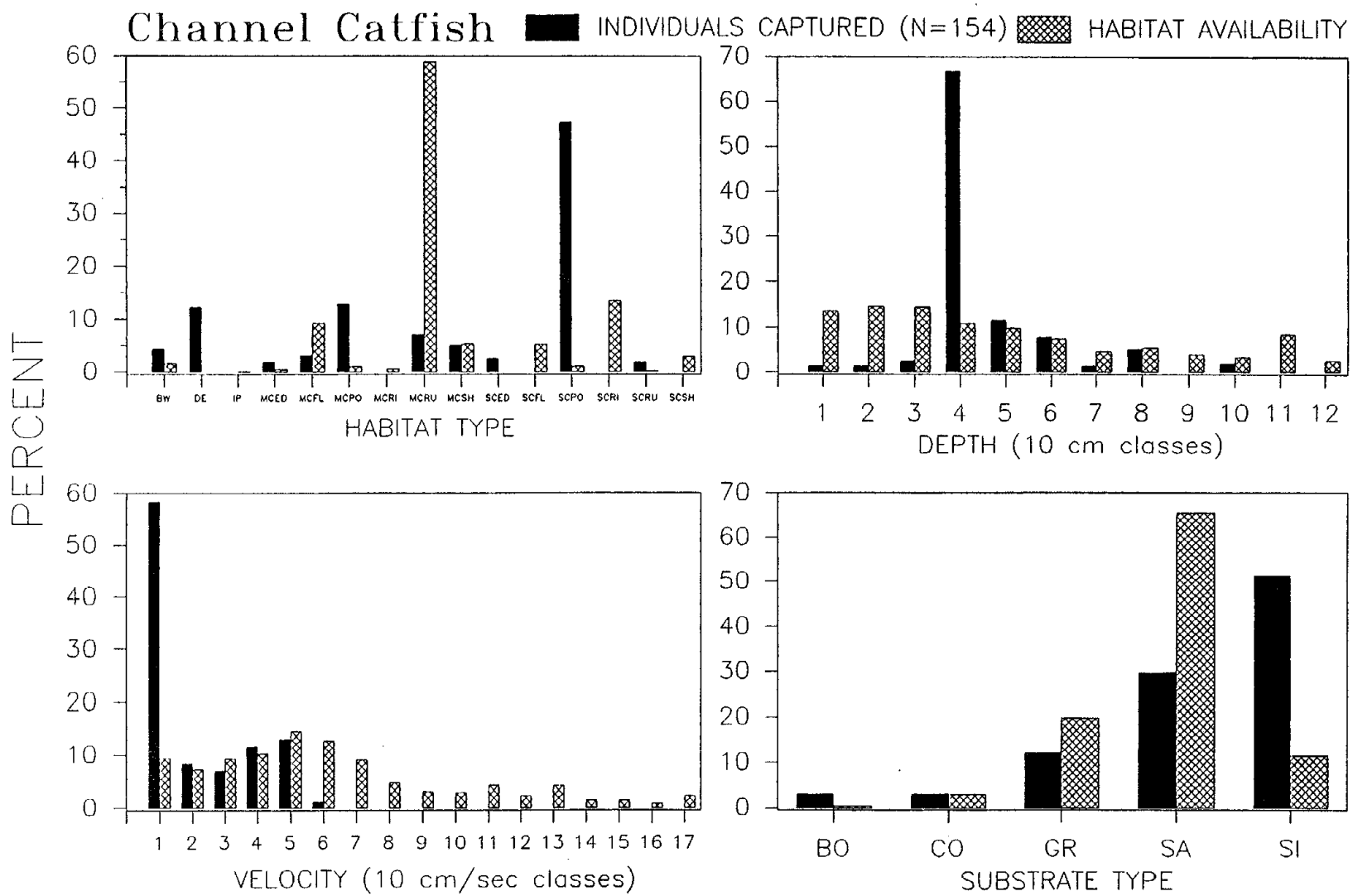

Figure 46. Channel catfish macrohabitat association.

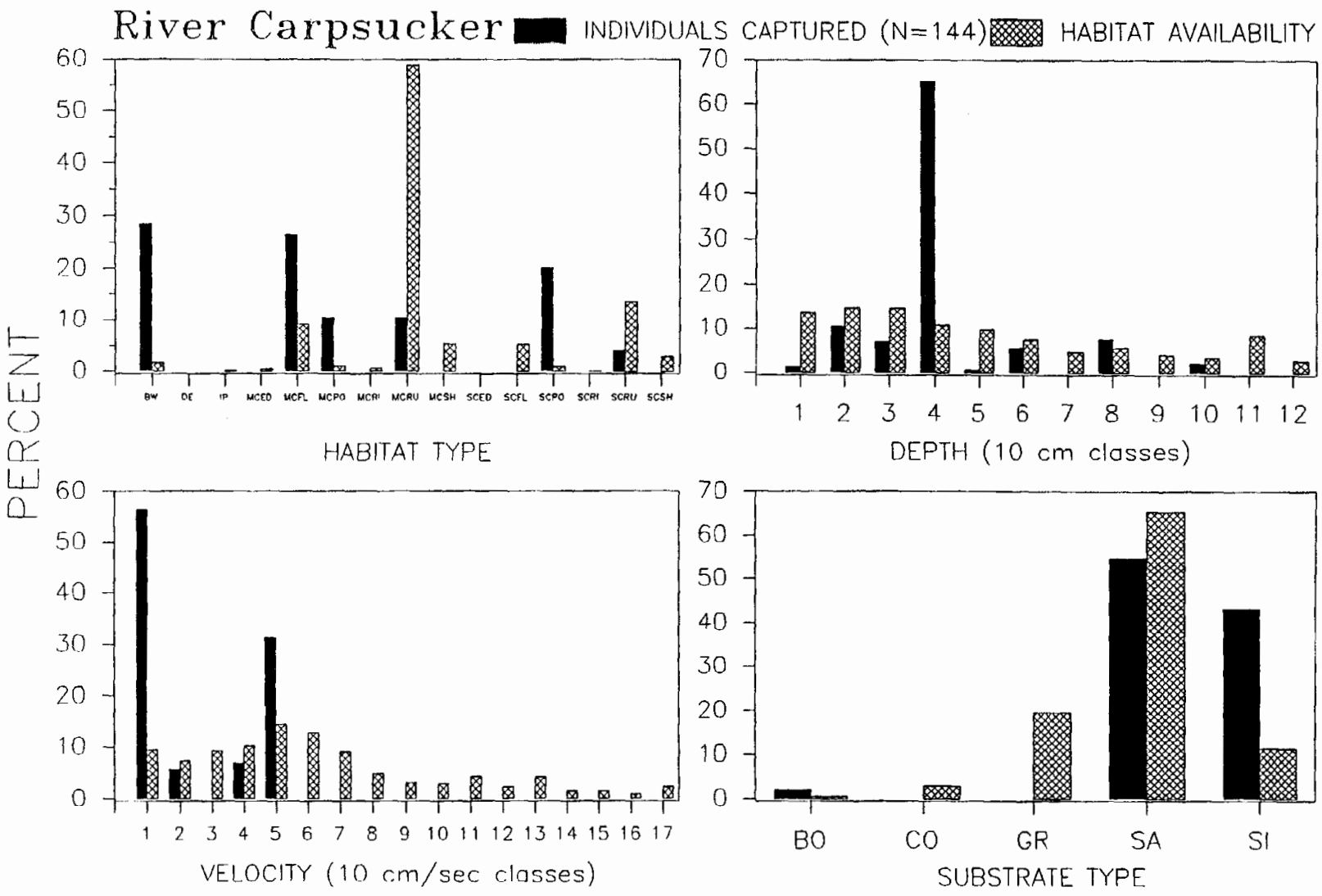

Figure 47. River carpsucker macrohabitat association.

Over 83% of the river carpsucker was taken in water <50 cm deep. Of those 65% were in water 40-49 cm deep. This species was not collected in water velocity >50 cm/second and was most common (N=81; 56%) in velocity class 1 water. It was almost exclusively (N=141; 98%) associated with sand and silt substrata.

DISCUSSION

This study had two major goals: to provide an overview of the ichthyofaunal community in the Rio Grande between Velarde and Elephant Butte Reservoir, and to determine macrohabitat association of those fishes. The inventory data established the distribution, relative abundance, and range of the fish in the study area. Macrohabitat availability data provided a longitudinal assessment of habitat distribution and abundance. Species-habitat association information provided baseline data concerning which macrohabitats were selected by which species.

Inventory

The inventory portion of the study yielded results similar to those reported by Platania (1991a) on his 1984 survey of the Rio Grande between Velarde and Belen. That work showed that the ichthyofaunal community was comprised of 20 species but dominated by three native taxa, each accounting for about 20% of the catch. The six most-abundant species, four native and two introduced, comprised from 5.8 to 22.3% of the community (Platania 1991b).

The current study (1987-1990) encompassed a larger study area than Platania (1991b) but yielded similar results for species composition. Of the 26 species collected in this survey, all but two of those reported previously by Platania (1991b) were taken. Five of the six-most abundant species in the 1984 study were numerically dominant in the 1987-1990 inventory samples.

The most notable differences between these two studies were the substantial increase in abundance of several species and the concurrent population decreases of other members of the ichthyofaunal community. In 1984, red shiner was the second-most abundant species and accounted for 21% of the catch. In the current study it was the dominant species, by number and frequency of occurrence, comprising 53% of the total catch and being taken in 75 of 88 (85%) collections. Additionally, in this study red shiner was 35% more abundant than the second-most abundant species (Rio Grande silvery minnow), whereas in 1984 there was a cumulative 2.1% difference between the three most-abundant species. The six most common fish in this study comprised 94% of the total catch but were 82% in 1984. The changes in fish populations may reflect normal increases or decreases in population levels or may indicate large population abundance cycles resulting from stressed environmental conditions.

Museum records of 1940-1950 Rio Grande fish collections portray a different fish community than currently exists. The fish fauna was comprised almost exclusively of native species in relatively equal numbers. Rio Grande chub and speckled dace were abundant in many collections downstream of Albuquerque and Rio Grande bluntnose shiner and phantom shiner were sporadically common. Speckled dace, Rio Grande bluntnose shiner, and phantom shiner no longer occur in the study area, and the range of the Rio Grande chub has shifted to upstream reaches of the drainage. Flathead chub and Rio Grande silvery minnow were often the first and second-most abundant fish in historic collections while red shiner was not common in or absent from samples taken during that period. Of the 88 inventory samples

taken in the current study, red shiner was the most abundant species in 58% (N=51) of the collections compared with 8% (N=7) and 7% (N=6) for Rio Grande silvery minnow and flathead chub, respectively.

The hiatus in systematic fish collections from the Rio Grande between 1950-1980 makes it difficult to determine the timing of changes in the ichthyofaunal community. However, comparison of the limited data do indicate 1950-1980 as a period of considerable change in the Rio Grande fish community. Rio Grande bluntnose shiner, historically one of the more abundant members of the ichthyofaunal community, was known to occur from near Abiquiu downstream to El Paso, Texas. The largest collections of this species were from directly below mainstream irrigation diversion dams. Examination of its historic distribution and abundance patterns indicated that its decline was concurrent with the establishment of mainstream dams and massive irrigation of adjacent lands, as well as with the increased human population in the Rio Grande Valley. These human activities contributed to the fragmentation of the range of the species and possibly to its extirpation. Factors which probably contributed to the decline and ultimate demise of Rio Grande bluntnose minnow may now be affecting Rio Grande silvery minnow.

Between the completion of the Bernalillo to Elephant Butte Reservoir inventory (1988) and the conclusion of macrohabitat sampling (1992), there was an apparent decline in abundance of the Rio Grande silvery minnow. This species comprised 25% of the specimens collected between Bernalillo and Elephant Butte Reservoir in 1987-1988 and was abundant at the dam-face of irrigation diversions. Sampling conducted during the macrohabitat phase (1989-1992) of this study at several sites where Rio Grande silvery minnow was previously abundant failed to produce any individuals.

Bestgen and Platania (1991) assumed that the data they had collected on the distribution and abundance of Rio Grande silvery minnow were indicative of "normal" population levels. It now appears that Bestgen and Platania (1991) may have collected data on the Rio Grande silvery minnow near a peak of an abundance cycle. The preceding three years (1985-1988) of almost continuous flow in the Rio Grande may have provided suitable conditions for it and other species to expand both in abundance and distribution. The macrohabitat work coincided with the beginning of a dry-cycle and the de-watering of extensive reaches of the Rio Grande. Our macrohabitat sampling of these reaches, after desiccation, yielded considerably fewer fish and no specimens of Rio Grande silvery minnow.

Drying of the river results in two discrete types of isolated habitats. The reaches directly below diversions typically remain wet due to dam seepage and provide habitat and refuge for fish. These areas are often the last to retain water and are frequently inhabited by large aggregations of fish. Disconnected pools scattered throughout the river receive no surface inflow and, depending on their location, size, and the duration of the drying event, will usually become completely dry, resulting in the death of all fish inhabitants. If these isolated pools are reconnected to the main river by increased flows, those individuals that survive may proceed through their normal life cycles. However, it is also possible that they might subsequently die due to disease or malnutrition caused by living under sub-optimal conditions. Their spawning activities might also be disrupted, with serious results to the population as most of these taxa are 2-3 year-lived species.

The study area contains two dams and three major irrigation diversion structures. The irrigation diversions (Angostura, Isleta, and San Acacia) effectively divide the river and range of the Rio Grande silvery minnow into four discrete reaches. While individuals may be transported downstream, actively or by drift, they are not able to move upstream above the

dams. Information obtained from studies on Rio Grande silvery minnow indicated that it is a spring-summer spawner that lays semi-buoyant eggs which will drift downstream (Platania, pers. obser.). The eggs hatch in 24-36 hours (depending on water temperature), at which time the larvae continue to drift. After a few days, the larvae appear to select low velocity habitats to continue development. This selection of low-velocity habitats may be related to the warmer water temperature, the smaller number of predators, and the availability of food.

If Rio Grande silvery minnow is eliminated from a reach, that section may be repopulated either by the downstream drift of eggs and young or the upstream movement of reproducing adults. Both of these mechanisms have been observed, suggesting the means by which Rio Grande silvery minnow has survived in a highly modified and often largely desiccated system.

Sections of the Rio Grande were historically ephemeral but river reaches did not remain dry for extended periods. More important, these "natural barriers," which prevented upstream movement of fish and resulted in fragmentation of the range of Rio Grande silvery minnow, did not have the impact of the current diversions. Presently, when a fish species is lost from an upstream reach, mainstem diversions prevent re-colonization by downstream populations. This scenario may provide a partial explanation for the extirpation of endemic Middle Rio Grande fishes (Rio Grande bluntnose shiner, Rio Grande shiner, and phantom shiner) if one assumes that the life-history aspects of those fishes were comparable to the Rio Grande silvery minnow and there was a similar pattern of river desiccation and impeded upstream movement.

While the inventory phase of the current study indicated that the ichthyofaunal assemblage of the Rio Grande between Velarde and Elephant Butte Reservoir was comprised primarily of native fishes, the loss of several native taxa, unevenness in abundances of fish species, and continued survival of selected fishes commands concern.

Macrohabitat

Numerous factors need to be considered when evaluating the macrohabitat association findings of this study. A total of 331 macrohabitat samples were made but only 187 resulted in the collection of fish. The limited number of samples that contained fish and the relatively small number of specimens per sample required that collection information from throughout the study area be combined. The infrequent statistically significant associations between species and habitat parameters (N=4) was not the result of this merger but of the low frequency of occurrence and small number of fish.

The analysis was performed on the entire data-set. It was not practical to delete samples that did not contain fish because those data were frequently as important as those that contained fish. For example, the absence of western mosquitofish from samples taken in high velocity waters indicated this species' preference for low-velocity habitats.

Another factor that skewed the data-set was the presence of multiple ontogenetic stages of numerous species. Adults of one taxon were frequently sympatric (in a particular habitat) with young-of-year of one or several other species. This problem was compounded by the disproportionate abundance of fish in various life stages. Differences in abundance between earlier life stages (larval and juvenile) and reproducing adults were sometimes logarithmic. In analysis of the data, all specimens were assigned the same importance.

Finally, the merging of the data-set may have obscured habitat associations as the merged data no longer represented the longitudinal succession of physical parameters of the river or the longitudinal distribution of the fishes. For example, the majority of white sucker

(93%) was collected from the upper three macrohabitat sites where it was a numerically dominant component of the ichthyofaunal community. Those sites were characterized by relatively high velocity water and rocky substrate and there appeared to be a highly correlated species-habitat association. At lower macrohabitat sites, white sucker was uncommon. Where collected, it was found in a variety of velocity classes over several substrata and showed no statistically significant habitat association. That white sucker did not select the same habitat variables at lower sites as at upper sites (high velocity and rocky substrata) may initially suggest that there was not a species-habitat correlation. However, the macrohabitat availability data established that the preferred habitat of white sucker in the upper reach was relatively rare in the lower reach. The limited habitat may have been the reason for the rarity of white sucker in the lower reach. In addition, factors such as water temperature may have been equally important in determining the species' longitudinal distribution as habitat. The marriage of the species habitat correlated data from the upper reach and uncorrelated data from the lower reach obscured the habitat association of white sucker.

Matthews and Hill (1980) attempted to discern habitat use and association patterns of plains fish in an unstable southwestern river (Canadian River, Oklahoma). They reported that the 19-species assemblage was dominated by four taxa comprising 99.5% of the total catch. This compares to six species in this study accounting for 94% of the catch. Three of the four species that dominated their study (red shiner, plains minnow [Hybognathus placitus], and western mosquitofish) were present or represented by congeners in this research program.

While there were differences in the habitat use by the three species, Matthews and Hill (1980) found no stable patterns of habitat partitioning. The species exhibited adaptability and changed macrohabitats as environmental conditions changed. Our macrohabitat data appear to suggest that members of the current Rio Grande ichthyofaunal assemblage have wide ecological tolerances which allowed them to occupy a variety of macrohabitats, depending on the prevailing conditions. The pattern of fish dispersal to numerous macrohabitats during high flows and convergence to isolated macrohabitats during low flow periods, as reported by Matthews and Hill (1980), was evident in our macrohabitat collections. Our limited number of statistically significant associations lends additional support to the hypothesis that while habitat partitioning and association may play an important role in the structuring of fish communities in stable environments, it is of lesser importance in rivers such as the Rio Grande that exhibit such a wide range of environmental conditions.

ACKNOWLEDGMENTS

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MANAGEMENT RECOMMENDATIONS

The Middle Rio Grande is subject to numerous river maintenance activities and water management practices that may be adversely affecting native fishes. Although it is beyond the scope of this work, the timing and distribution of water in the Middle Rio Grande are critical considerations in fish management in this system. The U.S. Bureau of Reclamation, the principal federal agency responsible for carrying out maintenance activities, initiated this study to characterize the physical habitats and fishes of the Middle Rio Grande and determine species habitat associations. Determining species-habitat associations would allow the Bureau of Reclamation to correlate construction impacts on habitats with consequent effects to the fish community. It was hoped, with this information, that some of the negative impacts of maintenance activities could be mitigated by creating specific habitats to compensate for those that had been modified. Under ideal circumstances, creation of habitat would result in enhancement of specific fish populations. The data gathered during this study did not provide the high level of species-habitat correlation necessary to meet the all of the aforementioned objectives. However, data from this study do provide valuable information on the types, distribution, and abundance of fish and habitats in the Rio Grande between Velarde and Elephant Butte Reservoir (1987-1992).

The nine sites sampled in the 364-km reach of the Middle Rio Grande exhibited longitudinal changes in macrohabitat types and physical parameters (depth, velocity, and substrate). In addition to data recorded on habitat availability, information was also obtained on the distribution and abundance of fish species and their habitat associations. These two data-sets allowed for cursory correlations between fish distribution and availability of habitat.

These collections produced information on habitat availability and species-habitat associations in the upper Rio Grande during two seasons (winter and summer) over a six-month period and in the lower Rio Grande during four winter and summer seasons over two years. The sampling schedule allowed for discrimination between pre- and post spawning periods of habitat availability and species-habitat associations but did not propose to address other, more comprehensive questions relating to flow-habitat and species-habitat associations at different ontogenetic stages. Both habitat availability and fish-habitat association can change dramatically over relatively short time periods. This is especially true in arid ecosystems where habitats are, by nature, ephemeral. The data collected during this study were useful in providing general direction for future research activities.

The Middle Rio Grande, below Cochiti Dam, is a highly regulated system maintained by the Bureau of Reclamation for the purposes of providing for the efficient transport of water and sediment to Elephant Butte Reservoir to meet New Mexico's water obligation to Texas (under the Rio Grande Compact), to conserve surface and groundwater in the basin, and to reduce aggradation of the river "floodway." The Bureau of Reclamation recognizes the Rio Grande as a dynamic riverine system with invaluable riparian habitat. They identified six river maintenance activities (bank stabilization, river training, sediment removal, vegetative control, snag removal, and levee maintenance) that they undertake to meet their mandated goals that affect the physical character of the river.

The Bureau of Reclamation achieves bank stabilization in the Rio Grande through revetments, curve reshaping, and vegetative plantings. Jetty jacks are selectively placed in the river to help accrue river sediment, deflect flows, and reduce bank erosion. Groins, root wads, and boulders are also used to prevent bank erosion. River training involves building training and freeboard dikes to influence flow alignment and control and manage overbank

flows. Sediment control is employed to increase channel capacity and is confined primarily to the San Marcial reach, the headwaters of Elephant Butte Reservoir, and at the mouths of arroyos. Vegetative control and snag removal consists of mechanical removal of plant material and is employed on bars or instream structures that inhibit or deflect flows towards levees. Chemical control of vegetation may be used only as a last resort. Levee maintenance is undertaken in areas where over-topping or breaching is probable and may employ one or more of the aforementioned activities. The question this study on the fishes and habitats in the Middle Rio Grande could be used to address was what effects Bureau of Reclamation activities have on the fish community and how could adverse impacts be ameliorated.

River modification activities produce physical alterations that could result in direct or indirect biological impacts. Direct impacts are caused when physical change eliminates suitable habitat for a species resulting in a decrease in that species' range and abundance. Species are impacted indirectly when habitat alterations allow for the increase of sympatric predators or competitors and there is a corresponding decrease in range and abundance of the species or community of concern. The competitors and predators can be native and non-native fishes.

Several concerns regarding Rio Grande fishes have been previously addressed in this report with one of the more important considerations being the effects of non-native fishes on the native fish community. Non-native fishes, which can be subdivided into two categories (game and non-game), can impact native species through physical displacement, reproductive displacement (hybridization), or predation. Population fluctuations in fishes are generally closely associated with the timing and duration of flows. Slight variations in anthropogenetic river management activities may provide a competitive advantage to one group or the other.

The six Bureau of Reclamation river maintenance activities generally strive to reduce river channel meandering and maintain the water carrying capacity of the channel. Discussed below are the potential impacts of each activity on the fish community and management recommendations (•) that might help to ease those impacts.

Bank Stabilization

Allowing the river to meander naturally may result in loss of property and the possible breaching of flood control levees, riverside drains, and canals. However, the magnitude and extent of meandering varies throughout the Middle Rio Grande and in some areas might present no immediate danger to personal property or riverside facilities. In several locations where the bank has been artificially stabilized, affected habitat is relatively homogenous. Natural river meandering provides fish with a greater variety of habitats by creating important low velocity regions which may also act as refugia during periods of low flow.

The mechanisms (revetment, curve shaping, groins, jetty jacks, vegetative plantings) used for bank stabilization are selected based on the severity of the problem and channel conditions and have differential impacts on the biotic community. Revetment and curve shaping, selected to alleviate imminent bank erosion problems, are the most drastic measures and have the most immediate impacts on the aquatic community. In effect, these activities result in a localized partial lining of the Rio Grande. Groins are instream earthen and rip-rap structures constructed to prevent bank erosion. These structures increase the instream surface area and create high and low velocity habitat but do not necessarily result in increased cover for native species. Jetty jacks and vegetative plantings induce the river to maintain its existing alignment and are selected when conditions are appropriate. To allow for vegetative

establishment, plantings must be initiated long before bank erosion has reached a critical stage. Vegetative plantings is the least disruptive of the bank stabilization activities. In addition to protecting shorelines, vegetative material increases productivity and if washed away by the river provides valuable instream cover.

- Allow the river to meander in reaches where there would be no or limited impact to people or riverside facilities. On river bends that must be stabilized, attempt to select natural methods (vegetative cover). When revetment and curve shaping are the only options, provide for the maximum allowable arc in the river to reduce water velocity and incising.

- Limit the number and location of instream structures to sites where breaching of the channel will cause immediate and substantial impact. Attempt to vegetate banks of groins and dikes to provide instream cover for aquatic organisms.

- Concentrate construction activities during low-flow periods (preferably zero-flow) to minimize impacts to the aquatic community.

River training

Training and freeboard dikes are similar mechanical river training devices used to help redirect the river channel and protect items in the Rio Grande floodplain. Training dikes are normally built in conjunction with revetment works. Freeboard dikes are primarily off stream activities where impacts to the biotic community of the Rio Grande would probably be minimal and related to impacts to the riparian zone. The construction of freeboard dikes parallel to the river channel guide peak flow in an alternate direction.

The impacts of these structures on the fish community has not been documented. However, because the function of river training is to prevent natural meandering of the river, this activity reduces the creation of habitats that form in dynamic lotic systems.

An additional Rio Grande training activity is pilot channeling. This is a disruptive activity employed in reaches where the riverbed sediment has impeded the natural flow. Pilot channeling requires mechanical removal of large quantities of substrate material, which may then be disposed of at an upland locality or redeposited instream. Pilot cuts through sand plugs that block the river channel allow flowing water to erode the plug and restore channel capacity. Pilot cuts allow the river to remove sediment deposits with natural flows. These activities are principally found in the lower Rio Grande between San Marcial and Elephant Butte Reservoir and therefore, the upstream native fish community realizes no direct beneficial effects from this activity. If sediment deposits were not removed, the lowest reach of the river may evolve towards a lentic system. For a short distance upstream of the obstruction, the river would widen and deepen and the fish community may shift from one comprised of native riverine species to non-native, piscivorous, gamefishes.

- Attempt to remove as much sediment as possible during low-flow (or zero-flow) periods so as to minimize the impact of pilot channeling activities. Dispose of spoil material at upland sites, preferably outside of the flood-plain, so that it does not wash back into the river. Investigate using flow spikes to transport material and keep the channel open.

Sediment Control

Sediment control is typically employed in response to arroyo input resulting from thunderstorms. Sufficient sediment displacement into the main channel may create islands or bars, result in the redirection of the channel, and threaten floodplain structures. Sediment control attempts to remove the arroyo plugs prior to the establishment of vegetation. However, at some sites, a rip-rap revetment is placed on the opposite river bank to allow the river flows to remove the arroyo plugs with minimal or no mechanical removal.

The alluvial fan inputs in the lower reaches of the Middle Rio Grande are sometimes composed of sediment types (gravel, rubble, cobble) that are relatively rare in that stretch of the river. Often associated with these small and disjunct patches of substrate is a fish community or species (ex. flathead chub and longnose dace) more characteristic of upstream reaches, where those habitat types are abundant. The removal of those macrohabitats results in the displacement of species with the strongest habitat-association. Without these isolated patches of habitat, those species with the closely correlated to habitats will cease to exist in specific reaches.

Sediment deposition from arroyos may be an important mechanism of island building in the lower reaches of the Middle Rio Grande. The elimination of downstream islands, which form near the mouths of arroyos, considerably reduces habitat diversity. Islands provide relief from the homogeneity of main channel runs which characterize the lower Rio Grande. Numerous macrohabitat types (shoreline, run, eddy) and other physical parameters (low velocity, shallow water) are associated with islands. In addition, instream cover is frequently found immediately adjacent to islands.

- Leave islands and fluvial fans, especially in reaches where the river channel is wide, until it has been demonstrated that the river's course will change and there will be a demonstrable impact to floodplain structures.

Vegetative Control

Control of vegetation on bars is accomplished through two mechanisms. Mechanical control is the primary method employed and is accomplished through mowing and plowing. Chemical control involves the application of a herbicide and is rarely used. The concern by the Bureau of Reclamation is that the presence of vegetation on bars reduces the river channel capacity and enables debris dams to form during high flows. As discussed under the sediment control section, island and bar habitats make important contributions to habitat and species diversity.

- Leave vegetation and islands in place until it has been proven that there will be a demonstrable impact to floodplain structures.

- Investigate less environmentally disruptive techniques such as encouraging vegetative growth that would not inhibit high flows.

Snag removal

Snag removal is used when large instream structures (trees) threaten bridges and diversion dams and obstruct or deflect flows. Fish are associated with both large and small instream structures, both of which are rare in the Rio Grande. In this study, woody structures, where found, frequently had large clusters of smaller debris (tumbleweeds)

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