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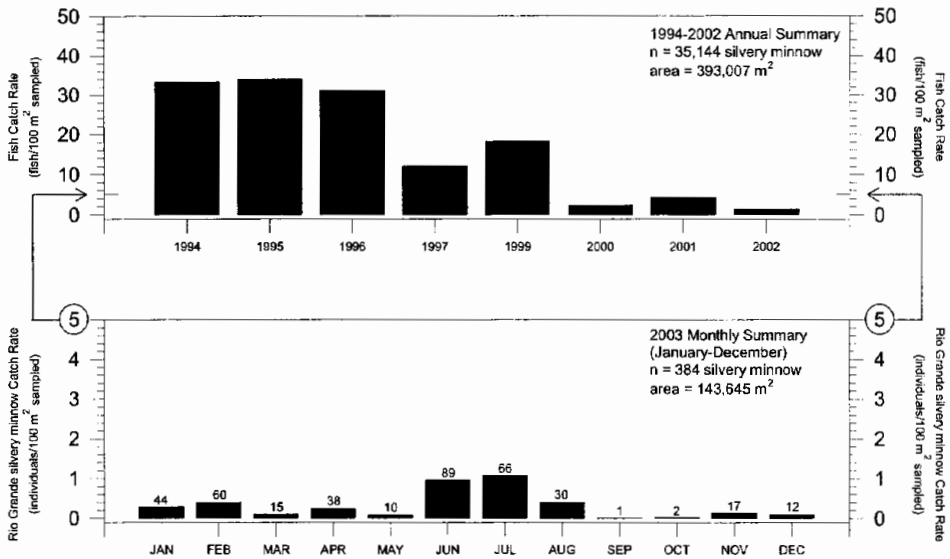
Rio Grande silvery minnow
Population Monitoring Program Results from 2003

Final

A Middle Rio Grande Endangered Species Act Collaborative Program Funded Research Project



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12 April 2004

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Funded through the Middle Rio Grande Endangered Species Act Collaborative Program.

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EXECUTIVE SUMMARY

Rio Grande silvery minnow, *Hybognathus amarus*, has been declining in distribution and abundance in the Rio Grande Basin over the past fifty years. It has been extirpated from the Pecos River and from the vast majority of its historical range in the main stem Rio Grande. The remaining population of this imperiled species resides in a 280 km reach of river between Cochiti Dam and Elephant Butte Reservoir in the Middle Rio Grande of New Mexico. The remnant population of this once widespread taxon has also been steadily declining in abundance despite its listing as a federal endangered species in 1994. Multiple pronounced river drying events over the past decade have eroded the ability of this species to recover in its current range. In addition, fragmentation of its remaining range into four segments (35.9, 65.2, 85.5, and 90.4 km long) by diversion dam structures (Angostura, Isleta, and San Acacia) pose continued threats to the species' long-term persistence.

Analysis of Rio Grande silvery minnow catch rates revealed a significant interaction ($p<0.05$) between mean catch rate and locality. The highest catch rates of silvery minnow were generally recorded at upstream sampling localities in each of the respective reaches (i.e, close to diversion dams). This spatial distribution of individuals was most pronounced in the Angostura and Isleta reaches. Diversion dams allow passive downstream movement of silvery minnow eggs and larvae but block upstream movements of juveniles and adults.

Population monitoring efforts of the fish community in the Middle Rio Grande show that silvery minnow catch rates have declined about three orders of magnitude from 1993 to 2003. Additionally, relative abundance of silvery minnow has declined from about 50% of the total ichthyofaunal community in 1995 to <0.5% in 2003. The number of silvery minnow taken in 2003 was low in all reaches and had declined to the lowest levels ever recorded by September 2003. In 2003, the Angostura Reach yielded the most silvery minnow, followed by the San Acacia Reach, and the Isleta Reach. This was in contrast to previous years of population monitoring where the San Acacia Reach produced the largest catch rates of silvery minnow. Low flow conditions and the diversion of nearly all water at the Isleta Diversion Dam during the summer of 2003 resulted in river drying in downstream reaches and substantial losses of riverine habitat especially in the San Acacia Reach.

River discharge during 2003 was artificially elevated through a short duration reservoir release during May 2003 to induce spawning by Rio Grande silvery minnow. Although a large number of Rio Grande silvery minnow eggs were produced as a result of the flow spike, the production of propagules ultimately resulted in the recruitment of very few Rio Grande silvery minnow to the 2003 year-class. Young-of-year (YOY) individuals rapidly declined in abundance following extended periods of river drying and low flows during summer and autumn of 2003. Comparison of Rio Grande silvery minnow mean October catch rates (1993-1997, 1999-2003) to hydraulic variables measured at two Middle Rio Grande gauges revealed some striking relationships. Elevated and prolonged flows (e.g., >2,000 cfs) during spring were significantly positively correlated ($p<0.001$) and low flows (<200 cfs) were significantly negatively correlated ($p<0.001$) with October Rio Grande silvery minnow catch rates. These results suggest that inundated habitats and overbank flooding produced by prolonged and elevated flows are likely quite important for the successful recruitment of larval Rio Grande silvery minnow.

The cumulative effects of years of channel drying, downstream displacement, river fragmentation, and habitat degradation continue to be manifested by the decline of Rio Grande silvery minnow. The marked and alarming decline in abundance of Rio Grande silvery minnow recorded in 2003 during this population monitoring study provide strong evidence that the problems that led to the precipitous decline of this species have not been remedied. A renewed focus on issues that directly affect the immediate survival of wild populations of Rio Grande silvery minnow is essential. Removal of instream barriers that prevent this species from repopulating upstream reaches, the need to maintain increased and variable flow throughout downstream reaches, and restoration and reconnection of the historical floodplain are paramount issues that need to be resolved to assure the continued persistence of Rio Grande silvery minnow.

INTRODUCTION

Population information on Rio Grande silvery minnow and the associated Middle Rio Grande (Rio Grande between Velarde and Elephant Butte Reservoir, New Mexico) fish community has been gathered regularly since 1987. The first studies were conducted by Platania (1993a) from 1987-1992 to determine spatial and temporal changes in the Middle Rio Grande ichthyofaunal community and provide resolution of species-specific habitat use patterns. An additional purpose of those preliminary studies was to provide information on the conservation status of Rio Grande silvery minnow. Quarterly sampling efforts during 1989 and 1990 revealed that Rio Grande silvery minnow population numbers were extremely low. Based on previous samples, these low numbers indicated a rapid decline of this species in its already greatly reduced range. The 90-95% reduction in the range of Rio Grande silvery minnow and threats to its continued persistence in the Middle Rio Grande were central to this species being listed as endangered by the U. S. Fish and Wildlife Service (U. S. Department of Interior, 1994).

From 1992 until the present, the U. S. Bureau of Reclamation, U. S. Fish and Wildlife Service, New Mexico Department of Game and Fish, and U. S. Army Corps of Engineers have cooperated to fund numerous ichthyofaunal studies in the Middle Rio Grande. Among these studies was long-term monitoring of the distribution and relative abundance of the Middle Rio Grande fish community at numerous sites between Angostura Diversion Dam and Elephant Butte Reservoir (initiated in 1993). While Rio Grande silvery minnow was the primary focus of most efforts, research activities were also designed to provide information on the associated fish community.

The primary objective of the 2003 sampling activities was to monitor the population status of Rio Grande silvery minnow in the Middle Rio Grande, New Mexico. Seasonal and spatial differences in population structure and abundance of Middle Rio Grande fishes were also examined. Annual changes in the distribution, abundance, and composition of all fish species were also assessed. Information obtained from this study will allow a more thorough understanding of the current conservation status and population dynamics of Rio Grande silvery minnow, both of which are important components for the recovery of this species.

STUDY AREA

The headwaters of the Rio Grande are located in the San Juan Mountains of southern Colorado. The mainstem Rio Grande flows 750 km through New Mexico draining an area of about 68,104 km^2 (excluding closed basins). The Rio Chama is the only major perennial tributary of the Rio Grande in New Mexico and confluences with it near the city of Española. Snowmelt from southern Colorado and northern New Mexico provides the majority of water for the Rio Grande, but transmontane diversions from the San Juan River drainage (Colorado River Basin) supplement flow. The highest flow in the Rio Grande generally occurs during spring snowmelt, while the lowest flow usually occurs in late summer and autumn. Low flow in the river from March through October is caused, in part, by diversions into irrigation canals. Summer thunderstorms periodically augment low flow in discrete reaches, but do not ensure that the river channel will remain wetted. Precipitation in the region is low and averages <25 cm/year (Gold and Denis, 1985).

The Middle Rio Grande is defined as the reach between Velarde, New Mexico and Elephant Butte Reservoir (Figure 1). This reach changes considerably through its 364 km length. At high elevations, the Middle Rio Grande is a narrow, canyon-bound coldwater river with large substrata and a salmonid-dominated fish community. In contrast, downstream areas are 50-250 m wide, sand-bottomed, and support a warmwater fish community. The area of interest of this study is a segment of the Middle Rio Grande and encompasses the current range of Rio Grande silvery minnow (i.e., below Cochiti Dam to the inflow of Elephant Butte Reservoir). The Cochiti Reach of the Rio Grande (between Cochiti Dam and Angostura Diversion Dam) passes first through Cochiti Pueblo, then Santo

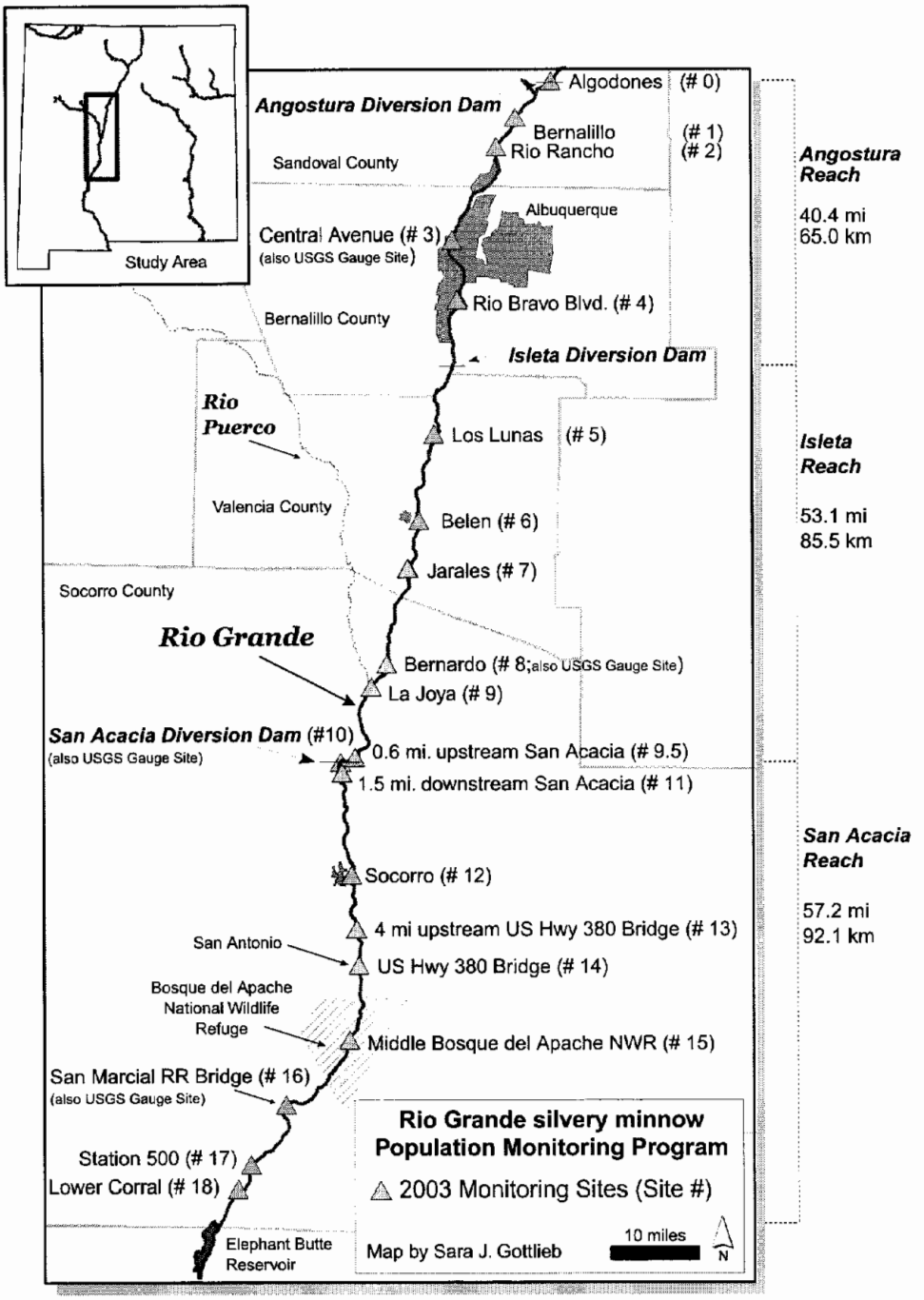

Figure 1. Map of the study area and sampling localities (numbered) for the 2003 Rio Grande silvery minnow population monitoring program. Sampling locality information that corresponds with the numbered localities is provided in Appendix A (Table A-1).

Domingo Pueblo, and finally San Felipe Pueblo; access is currently restricted in this reach precluding fish sampling for this study. The last comprehensive ichthyofaunal surveys of the Rio Grande in the Cochiti Reach documented the presence, at low abundance, of Rio Grande silvery minnow on Santo Domingo and San Felipe pueblos (Platania, 1995). Rio Grande silvery minnow were not taken within the boundaries of Cochiti Pueblo (Platania, 1993b).

Five mainstem reservoirs on the rios Chama and Grande and numerous smaller irrigation diversion dams regulate flow in the Middle Rio Grande. The complex system of ditches, drains, and conveyance channels provide water for extensive irrigated agriculture in the Rio Grande Valley. Cochiti Reservoir, located 76 km above Albuquerque and operational since 1973, is the primary flood control reservoir and largely regulates flow in the mainstem of the Middle Rio Grande.

The section of river from Angostura Diversion Dam to Bernalillo is a transition zone where the river channel becomes more braided, the floodplain widens, and substrata is primarily sand and silt. From Bernalillo downstream to Albuquerque, the river channel often exceeds 100 m in width and lower velocity habitats are more common. Backwaters are more abundant in this reach than between Cochiti and Angostura Diversion dams and substrata larger than sand is generally rare.

Downstream of Albuquerque, the Rio Grande is a wide and meandering river with a predominantly sand substrata, high suspended silt load, and a broad variety of mesohabitats. The mainstem channel is generally wide (100-200 m), <1 m deep, and has a current velocity of <1 m/s. From approximately the middle of Bosque del Apache National Wildlife Refuge to Elephant Butte Reservoir, the river channel is generally less than 50 m wide.

Diel and seasonal discharge varied somewhat but was consistently low, especially in southern reaches of the Middle Rio Grande, during 2002-2003 (Figure 2). There was a general trend of lower flow at downstream locations (i.e., U. S. Geological Survey (USGS) San Acacia Gauge [#08354900] and USGS San Marcial Gauge [#08358400]) compared to those upstream (i.e., USGS Albuquerque Gauge [#08330000]). Flow was continuous in the Angostura Reach in 2003 but very low from July-October. From the middle of March 2003 until late October 2003, extremely low flow and extensive river drying persisted in the Isleta and San Acacia reaches. Summer rains occasionally supplemented low base flows and resulted in brief but elevated instream flow and turbidity levels.

METHODS

This study was structured to monitor populations of Rio Grande silvery minnow and associated fish community at selected sites (Appendix A, Table A-1) in the study area. Monthly sampling efforts allowed for determination of general spatial and temporal changes in population structure and species abundance. Sampling was conducted at 20 sites during each month of 2003 (Appendix B).

Reach names were derived from the diversion structure at the upstream boundary of that reach of river. The Angostura Reach (Angostura Diversion Dam to Isleta Diversion Dam) had five sampling localities and the Isleta Reach (Isleta Diversion Dam to San Acacia Diversion Dam) had six sampling sites. There were nine sampling localities in the San Acacia Reach (San Acacia Diversion Dam to Elephant Butte Reservoir). No sampling was conducted in the Cochiti Reach as this reach of the Rio Grande is sovereign property under the jurisdiction of at least three discrete Native American Pueblos and is not generally accessible.

Fish were collected by rapidly drawing a two-person 3.1 m x 1.8 m small mesh (ca. 5 mm) seine through discrete mesohabitats (usually <15 m). During the spring and summer, a 1m x 1m fine mesh (ca. 1.5 mm) seine was also used to selectively sample shallow low velocity habitats for larval fish. Nearly all fish >15 mm standard length (SL) were released at the site of capture. Retained fish (primarily larval individuals) were fixed in the field in 10% formalin and returned to the laboratory where they were sorted, identified to species, counted, measured (minimum and maximum size; mm

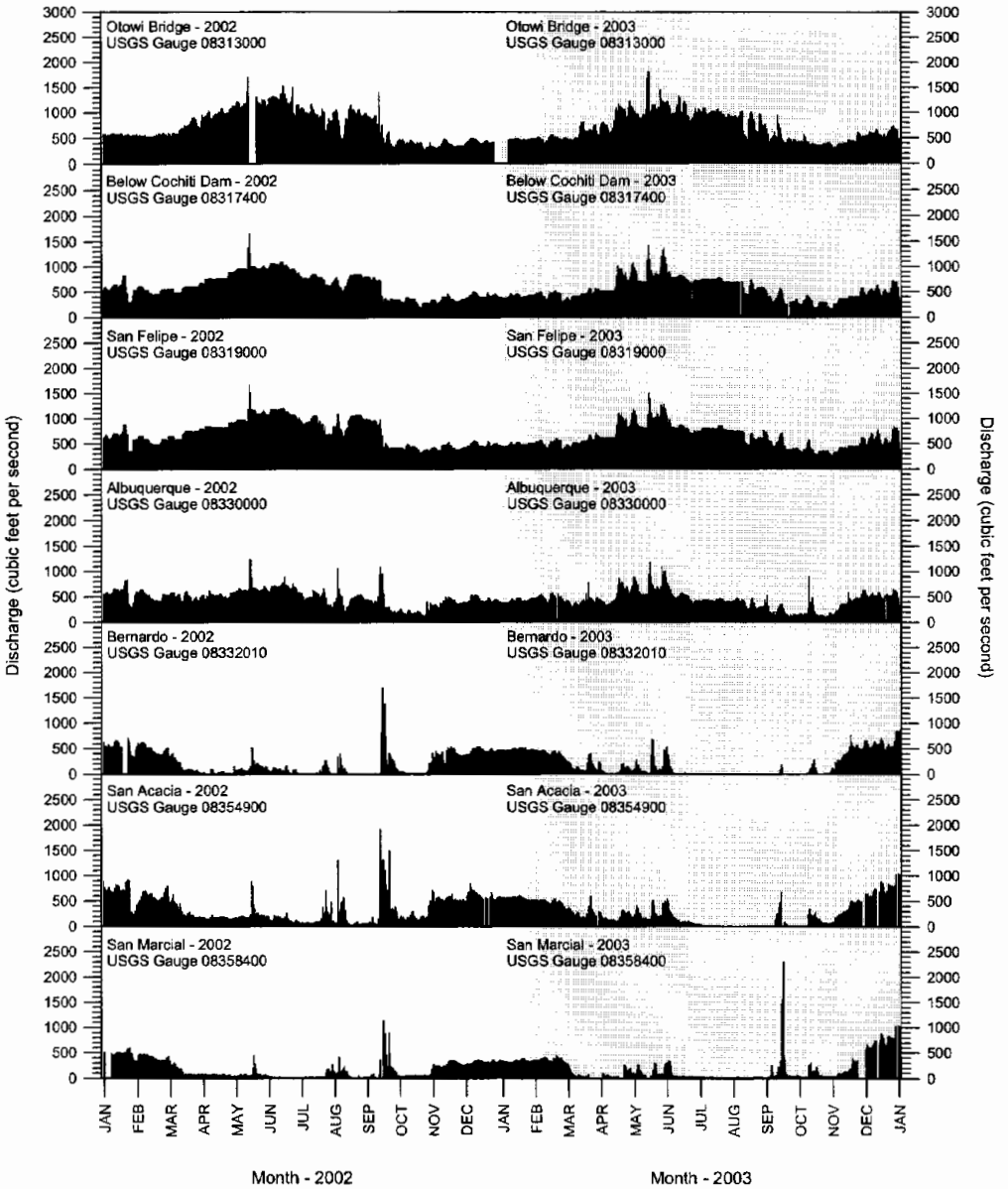

Figure 2. Discharge in the Rio Grande from January 2002 through December 2003 as recorded at seven U. S. Geological Survey (USGS) gauge stations. The Otowi Bridge gauge site is outside of the study area (ca. 25.5 river miles upstream of Cochiti Dam) and provided for reference. Discharge data are provisional and subject to change.

SL), transferred to 70% ethyl alcohol, and catalogued into the Fish Division of the Museum of Southwestern Biology (MSB) at the University of New Mexico. Graphic illustration of fish catch per unit effort are provided for the 10 focal species (the 10 most common taxa that occur throughout the study area) for each collection locality by sampling period (Appendix A; Figures A-1 to A-13). Scientific and common names of fishes in this report generally follow Robins et al. (1991; Table 1). Common names are arranged in phylogenetic order and appear throughout this report in tables, figures, and text.

Moving averages (one and two year) were calculated using mean monthly Rio Grande silvery minnow catch rates over time. Population trends were also evaluated by comparing mean annual and autumnal catch rates over time. Linear regression modeling of estimated abundance and hydraulic variables was used to evaluate inter-annual trends in population fluctuations. Peak discharge and days exceeding certain threshold discharge values (cubic feet per second, cfs) were selected to represent likely spring runoff conditions. Other threshold discharge values (days <200 cfs and days <100 cfs) were selected to represent summer low flow conditions. Samples obtained from isolated pools were not included in data analysis as catch rates in these confined habitats were artificially elevated. Fish CPUE data from all samples were log-transformed ($X'=\ln(X+1)$) based on low observed values and temporal heterogeneity of variance (Zar, 1984). A negative or positive trend in population abundance was defined as occurring when the slope of the regression was significantly different (alpha<0.05) from zero. Two-factor analysis of variance without replication (Sokal and Rohlf, 1995) was used to evaluate differences in mean catch rates between sampling sites over time.

RESULTS

Rio Grande silvery minnow

Population status-2003

The 2003 abundance of Rio Grande silvery minnow at reach-specific collection sites varied within and between seasons. Catch rate of silvery minnow also varied noticeably in and between sampling reaches (Figures 3-5). The Angostura Reach generally produced the highest catch rates for this species but still yielded few silvery minnow in 2003 compared with previous years.

Population monitoring efforts during January yielded the fourth largest monthly cumulative catch of Rio Grande silvery minnow (n=44) during 2003 with half of the individuals (n=22) taken in the San Acacia Reach. Rio Grande silvery minnow were present at 12 of 20 sampling localities during this sampling effort and they were distributed relatively evenly throughout the Middle Rio Grande with the exception of the upper Angostura Reach. More than half (n=8) of the silvery minnow collected in the Angostura Reach were marked (i.e, hatchery reared fish).

A total of 339 seine hauls were made during the February 2003 sampling trip of which 18 contained Rio Grande silvery minnow. All three sampling reaches yielded Rio Grande silvery minnow during the February sampling effort but catch rates for this species were very low at the majority of sites sampled (e.g., <5 individuals collected at 8 of 10 sites). The highest catch rate was recorded at Site 5 where 39 individuals were collected. Rio Grande silvery minnow were only collected from the upper portions of the San Acacia and Isleta river reaches.

Population monitoring sampling in March 2003 resulted in the collection of Rio Grande silvery minnow at seven of 20 collecting localities. This species was present in nine of 346 seine hauls taken in a wide variety of habitats. Catch rates were low throughout all river reaches. Most of the Rio Grande silvery minnow collected were age-1 (n=11) and the remainder were age-2 (n=4).

More Rio Grande silvery minnow were collected in April 2003 (n=38) than March 2003 (n=15). The highest catch rate was in the Angostura Reach at Site 2 (n=31). Marked individuals

Table 1. Scientific and common names and species codes of fish collected in the Middle Rio Grande during the 2003 Rio Grande silvery minnow population monitoring program.

Scientific Name	Common Name	Code
Order Clupeiformes		
Family Clupeidae	herrings	
Dorosoma cepedianum	gizzard shad	(GZS)
Order Cypriniformes		
Family Cyprinidae	carps and minnows	
Cyprinella lutrensis	red shiner [1]	(RDS)
Cyprinus carpio	common carp [1]	(CCA)
Hybognathus amarus	Rio Grande silvery minnow [1]	(RGM)
Pimephales promelas	fathead minnow [1]	(FHM)
Platygobio gracilis	flathead chub [1]	(FHC)
Rhinichthys cataractae	longnose dace [1]	(LND)
Family Catostomidae	suckers	
Carpiodes carpio	river carpsucker [1]	(RCS)
Catostomus commersoni	white sucker [1]	(WHS)
Ictiobus bubalus	smallmouth buffalo	(SMB)
Order Siluriformes		
Family Ictaluridae	bullhead catfishes	
Ameiurus melas	black bullhead	(BBH)
Ameiurus natalis	yellow bullhead	(YBH)
Ictalurus punctatus	channel catfish [1]	(CCT)
Pylodictis olivaris	flathead catfish	(FCT)
Order Cyprinodontiformes		
Family Poeciliidae	livebearers	
Gambusia affinis	western mosquitofish [1]	(MOS)
Order Perciformes		
Family Percichthyidae	temperate basses	
Morone chrysops	white bass	(WHB)

[1] focal taxa represent the most abundant species present in recent Middle Rio Grande collections and species illustrated in monthly plots of data.

Table 1. Scientific and common names and species codes of fish collected in the Middle Rio Grande during the 2003 Rio Grande silvery minnow population monitoring program (continued).

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

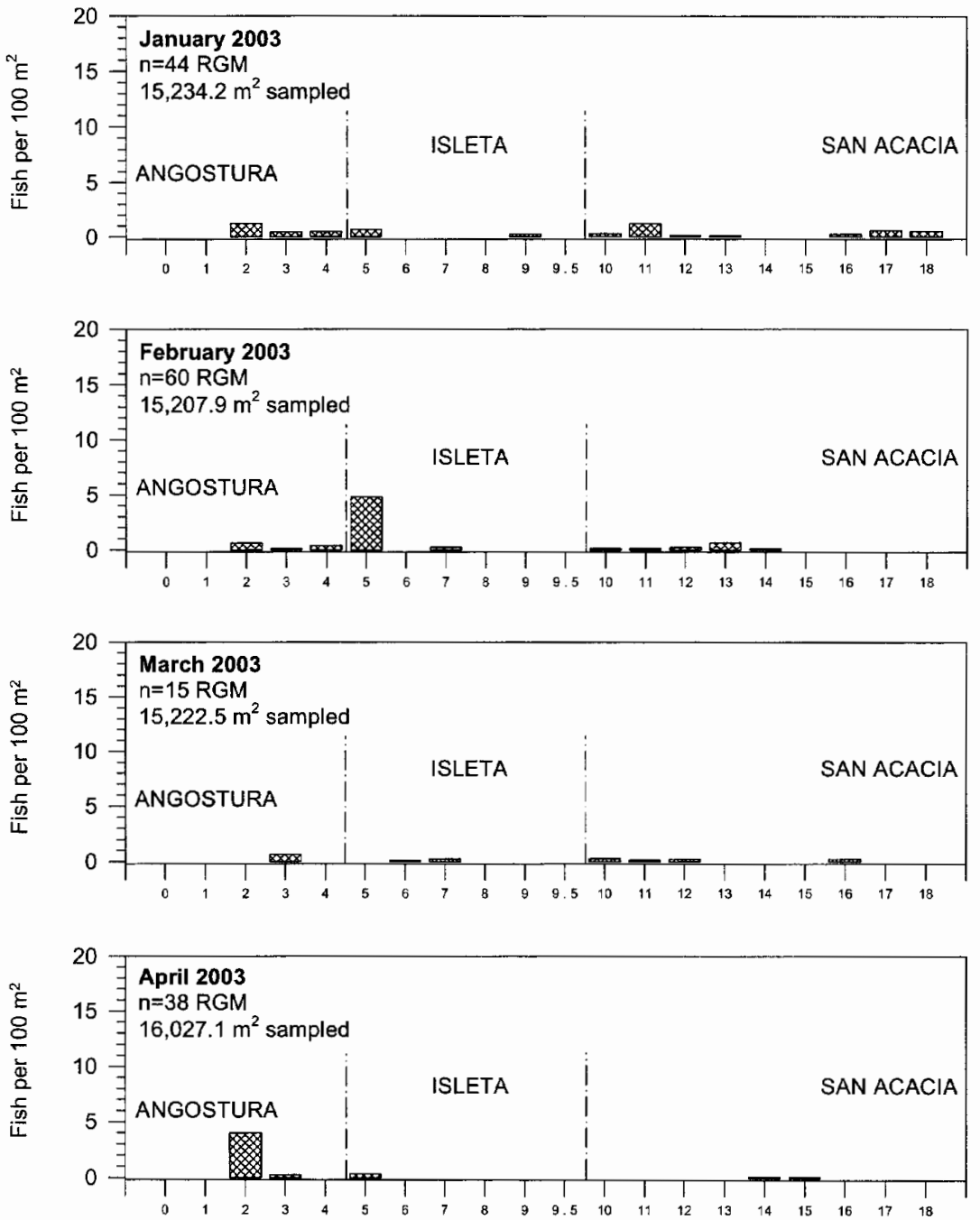

Figure 3. Rio Grande silvery minnow (RGM) catch rates (CPUE) from January-April 2003 for each collection locality in the Middle Rio Grande.

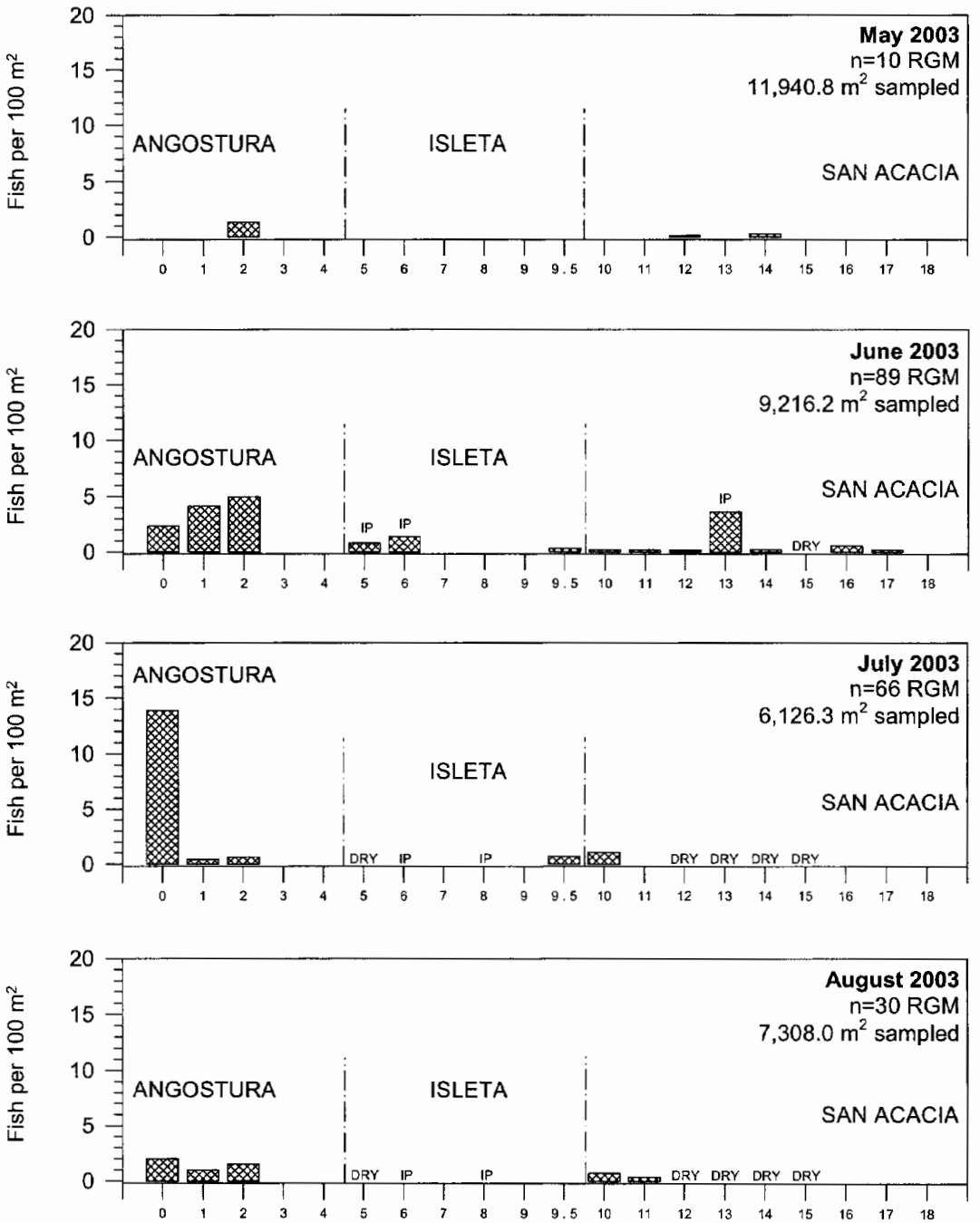

Figure 4. Rio Grande silvery minnow (RGM) catch rates (CPUE) from May-August 2003 for each collection locality in the Middle Rio Grande. Sites where the river had dried (DRY) or where only isolated pools (IP) remained are indicated.

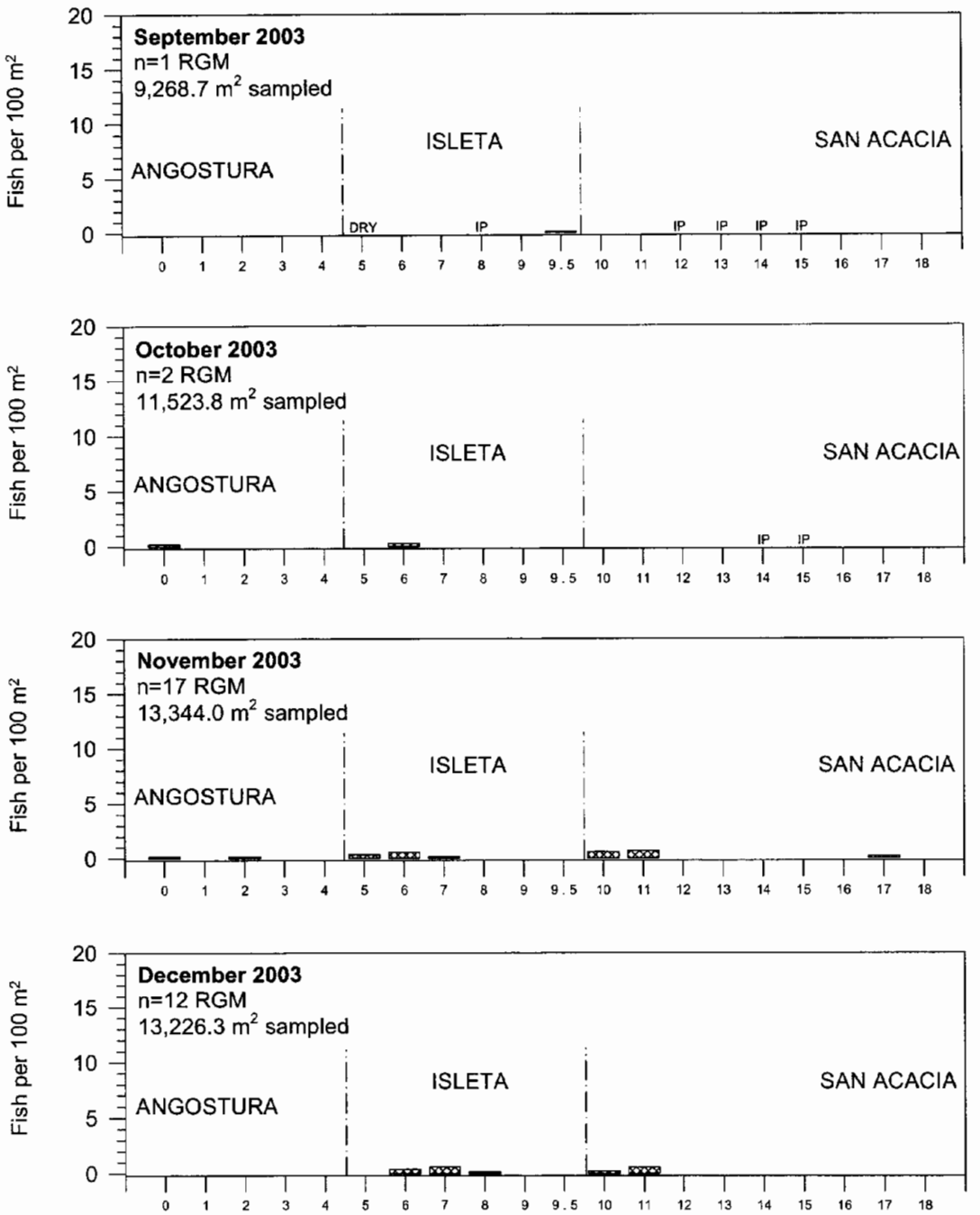

Figure 5. Rio Grande silvery minnow (RGM) catch rates (CPUE) from September-December 2003 for each collection locality in the Middle Rio Grande. Sites where the river had dried (DRY) or where only isolated pools (IP) remained are indicated.

comprised 24% (8 of 33) of the total catch in the Angostura Reach. Rio Grande silvery minnow was collected in only five of 20 sampling sites during the April 2003 sampling effort.

Population monitoring in May 2003 occurred soon after the initiation of Rio Grande silvery minnow spawning (15-20 May artificial flow spike). The cumulative number of individual silvery minnow collected in May 2003 (n=10) was low and no age-0 individuals were collected. The lack of young-of-year fish likely indicated that larvae were still too small to be captured effectively. Rio Grande silvery minnow catch rate in May 2003 was, as in April 2003, highest in the Angostura Reach. Rio Grande silvery minnow was present in samples at three of 20 sampling localities compared with 16 of 20 localities in 2002. Rio Grande silvery minnow were absent from the Isleta Reach samples.

The June 2003 population monitoring trip yielded more Rio Grande silvery minnow (n=89) than any of the previous 2003 sampling trips. Young-of-year (= age-0) Rio Grande silvery minnow were collected in all river reaches and comprised about 97% of the cumulative silvery minnow catch. Catch rate of this species was highest in the Angostura Reach. Elevated catch rates in the Isleta and San Acacia reaches were only recorded in sections of the river that were drying and had been reduced to a series of isolated pools. Increased concentrations of fishes in these restricted habitats (isolated pools) resulted in higher than normal catch rates for all taxa fish present, including Rio Grande silvery minnow. Site 15 was the first sampling locality to dry in 2003.

The July 2003 sampling results highlighted the uneven distribution and abundance of Rio Grande silvery minnow in the Middle Rio Grande. The largest site-specific silvery minnow catch rate was recorded in the Angostura Reach (Site 0) where 52 age-0 fish were collected. Stream drying became much more pervasive during July 2003 resulting in complete drying at five sites and leaving only isolated pools at two additional sites. Remaining sites in the Isleta and San Acacia reaches experienced very low flows.

The August 2003 sampling trip produced less than half of the number of Rio Grande silvery minnow taken during July 2003. Individuals were collected in only in the Angostura Reach and portions of the upper San Acacia Reach that had not dried. The largest collections of Rio Grande silvery minnow were in the Angostura Reach although their abundance ranged from 5-10 individuals at each site. Very few Rio Grande silvery minnow were taken in collections in the San Acacia Reach and none in the Isleta Reach. Age-0 Rio Grande silvery minnow comprised 100% of the total catch (of this species) in August 2003.

Monitoring of Rio Grande silvery minnow during September 2003 yielded only a single individual even though over 9,000 m^2 of aquatic habitat at 20 sites was sampled. Many of the sampling sites were still either dry or comprised of only isolated pools. The September 2003 sampling effort yielded the lowest catch rate of the federally endangered Rio Grande silvery minnow since sampling began in 1993.

The October 2003 sampling effort also produced very few Rio Grande silvery minnow (n=2) and one of the lowest catch rates of this species ever recorded. The river had become reconnected between many of the sampling sites but sites 14-15 were comprised of isolated pools. Higher flows during sampling may have reduced the catch rate somewhat because of the increased area of available habitat in the Isleta and San Acacia reaches.

Rio Grande silvery minnow were collected in greater numbers in November 2003 (n=17) than in October 2003 but were still very rare. Rio Grande silvery minnow were taken in all three reaches and collected at eight of the 20 sampling localities. The highest catch rates were recorded at sites in the upper portions of the Isleta and San Acacia reaches. In November 2003, 53% (n=9) of the cumulative silvery minnow catch was from the San Acacia Reach.

The number of Rio Grande silvery minnow collected in December 2003 was the fourth lowest recorded (n=12) during 2003 and was comprised only of age-0 individuals. Four of the five sampling sites that produced Rio Grande silvery minnow in December had also yielded individuals in November. None of the sites that yielded silvery minnow during December 2003 resulted in the collection of more than four individuals of this species.

A month-by-month summary of Rio Grande silvery minnow catch rates provides reference to trends in relative abundance observed during 2003 (Table 2). The effects of stocking programs during late 2002 and 2003 were most apparent in the Angostura Reach. Young-of-year silvery minnow produced in this reach, either by wild or hatchery reared fish, moved upstream following spawning but their overall abundance declined notably by autumn sampling efforts. River drying throughout most of the Isleta and San Acacia reaches during 2003 resulted in decreased relative abundance of fishes and concentrated those that remained in a few fragmented habitats that maintained some low volume of flow during summer.

Catch rates of Rio Grande silvery minnow in 2003 were generally highest in the Angostura Reach and approximately equal in the Isleta and San Acacia reaches. The Angostura Reach yielded the most silvery minnow (n=224) in 2003 (Figure 6), followed by the Isleta Reach (n=79), and San Acacia Reach (n=81). However, higher catch rates of young-of-year and the addition of hatchery fish to the Angostura Reach primarily drove this pattern. Overall catch rates for all reaches were very low and indistinguishable by autumn. Age-0 individuals comprised nearly the entire silvery minnow catch from June to December and were most abundant in June and July (Figure 7). Catch rates of Rio Grande silvery minnow, in all reaches, decreased following summer spawning although inter-month variation was moderate. Monthly catch rates of Rio Grande silvery minnow have continued to decline since 2002 despite temporary increases following 2003 spawning.

A temporal and spatial comparison of Rio Grande silvery minnow collections revealed a significant interaction ($p<0.05$) of mean catch rate with month and locality (Figure 8). The highest catch rates of Rio Grande silvery minnow, in all three river reaches, were generally recorded at or near upstream sampling localities in each respective reach. This spatial distribution of individuals was most pronounced in the Angostura and Isleta reaches. Downstream collecting localities within a specific river reach generally produced very few Rio Grande silvery minnow and also had a lower level of variation between samples compared with upstream localities.

Population trends-1993 to 2003

Rio Grande silvery minnow catch rate, plotted as seasonal collections, has declined since systematic sampling began in 1993 (Figures 9 and 10). Catch rates have declined two to three orders of magnitude within the last decade with the largest declines occurring after 1999. Despite seasonal fluctuations in the abundance of this species, recent samples indicate a severe decline over the last two years (Figure 11) particularly in areas subjected to the greatest river drying (e.g., downstream of Escondida, NM; Figure 12). October population monitoring samples illustrate that the magnitude of decline (as measured logarithmically) has been substantial (Figure 13). Catch rate data demonstrated that 2003 population level of Rio Grande silvery minnow was lower in October 2003 than had been previously recorded. The overall trend in population decline was also evident for annual Rio Grande silvery minnow catch rates (Figure 14).

Hydrological variables that represent different flow conditions were compared at upstream and downstream USGS gauging stations of the Middle Rio Grande (Table 3). Extended periods of higher flows were recorded in 1993, 1994, 1995, 1997, and 1999. These years were notably different in both the magnitude and duration of higher flows compared with 1996 and 2000-2003. While there were slightly fewer high flow days at the downstream station compared with the upstream station, the number of low flow days at the downstream stations was markedly higher for every year analyzed.

Multivariate analysis of October catch rates of Rio Grande silvery minnow from 1993-2003 revealed significant associations with hydraulic variables. Regression results based on several hydraulic variables were not presented for the Albuquerque gauge (days>4,000 cfs) and the San Marcial gauge (days>3,000, and >4,000 cfs) because of high autocorrelation (coefficient >0.95) with other variables. Regression analysis of Rio Grande silvery minnow October catch rates revealed significant relationships with several hydraulic variables. At the Albuquerque gauge, catch rate

Table 2. Summary of the monthly catch of Rio Grande silvery minnow, by site and reach, during the 2003 Rio Grande silvery minnow population monitoring program. Numerals in parenthesis, a subset of the total catch, are the number of individual silvery minnow in that sample that were marked with VIE tags (=hatchery reared [stocked] fish).

REACH Site Number Site Name	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
ANGOSTURA REACH													
0 Angostura Dam	---	---	---	---	---	13	52	10	---	1 (1)	1	---	77 (1)
1 Bernalillo	---	---	---	---	---	26	1	5	---	---	---	---	32
2 Rio Rancho	8 (1)	4	---	31 (6)	7 (6)	33	4	9	---	---	1	---	97 (13)
3 Central Ave (Abq)	3 (3)	1 (1)	5 (3)	2 (2)	---	---	---	---	---	---	---	---	11 (9)
4 Rio Bravo (Abq)	4 (4)	3 (3)	---	---	---	---	---	---	---	---	---	---	7 (7)
Angostura Reach Total	*15 (8)*	*8 (4)*	*5 (3)*	*33 (8)*	*7 (6)*	*72*	*57*	*24*	*---*	*1 (1)*	*2*	*---*	*224 (30)*
ISLETA REACH													
5 Los Lunas	5	39 (2)	---	3	---	1	---	---	---	---	2	---	50 (2)
6 Belen	---	---	1	---	---	2	---	---	---	1	3	3	10
7 Jarales	---	2	2	---	---	---	---	---	---	---	1	4	9
8 US Hwy 60 Bernardo	---	---	---	---	---	---	---	---	---	---	---	1	1
9 South of Bernardo	2	---	---	---	---	---	---	---	---	---	---	---	2
9.5 North of San Acacia	---	---	---	---	---	2	4	---	1	---	---	---	7
Isleta Reach Total	*7*	*41 (2)*	*3*	*3*	*---*	*5*	*4*	*---*	*1*	*1*	*6*	*8*	*79 (2)*
SAN ACACIA REACH													
10 San Acacia Dam	2	1	2	---	---	1	5	4	---	---	3	1	19
11 S of San Acacia	7 (1)	1	1	---	---	1	---	2	---	---	5	3	20 (1)
12 Socorro	1	2	2	---	1	1	---	---	---	---	---	---	7
13 North of US Hwy 380	1	6	---	---	---	4	---	---	---	---	---	---	11
14 US Hwy 380	---	1	---	1	2	1	---	---	---	---	---	---	5
15 Bosque del Apache	---	---	---	1	---	---	---	---	---	---	---	---	1
16 San Marcial	2	---	2	---	---	3	---	---	---	---	---	---	7
17 South (16 mi) of San Marcial	5	---	---	---	---	1	---	---	---	---	1	---	7
18 South (19 mi) of San Marcial	4	---	---	---	---	---	---	---	---	---	---	---	4
San Acacia Reach Total	*22 (1)*	*11*	*7*	*2*	*3*	*12*	*5*	*6*	*---*	*---*	*9*	*4*	*81 (1)*
MONTHLY TOTALS	*44 (9)*	*60 (6)*	*15 (3)*	*38 (8)*	*10 (6)*	*89*	*66*	*30*	*1*	*2 (1)*	*17*	*12*	*384 (33)*
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL

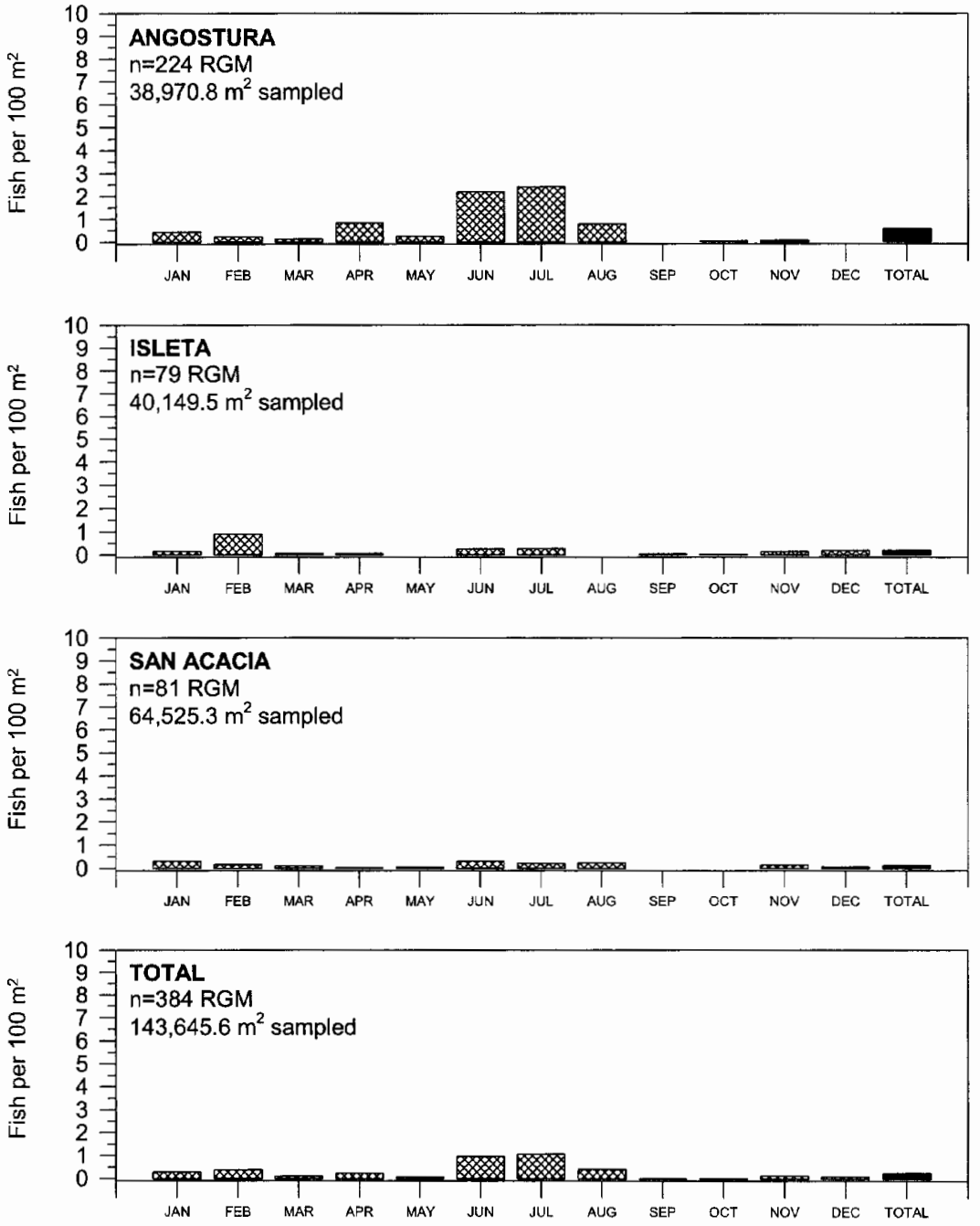

Figure 6. Rio Grande silvery minnow (RGM) catch rates (CPUE) by river reach for reach 2003 monthly sample in the Middle Rio Grande.

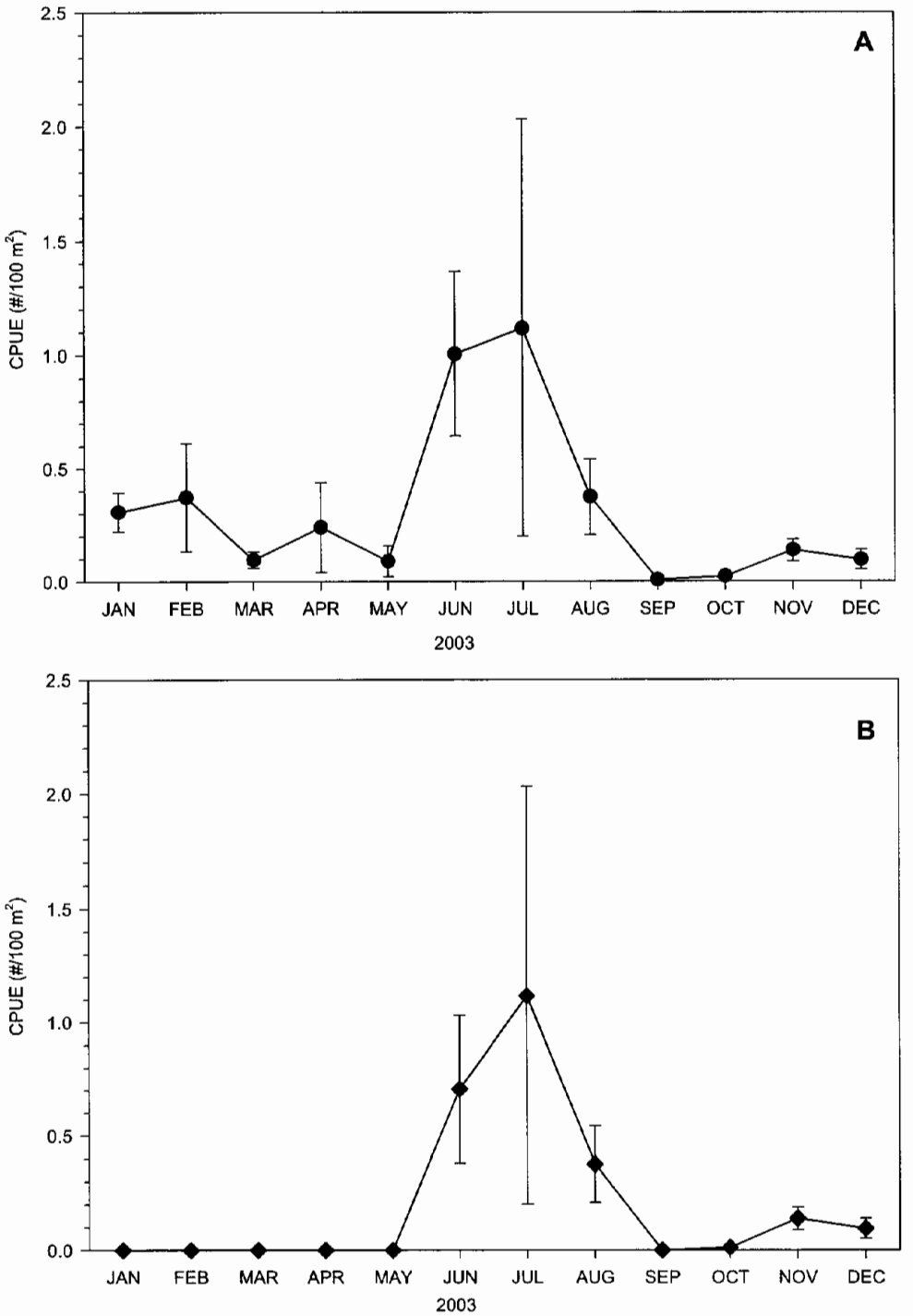

Figure 7. Inter-month fluctuations in catch rates of silvery minnow during 2003 (**A**=all age-classes including age-0 [circle]; **B**=age-0 only [diamond]). Symbols represent mean value for all sites sampled (n=20); bars represent the standard error.

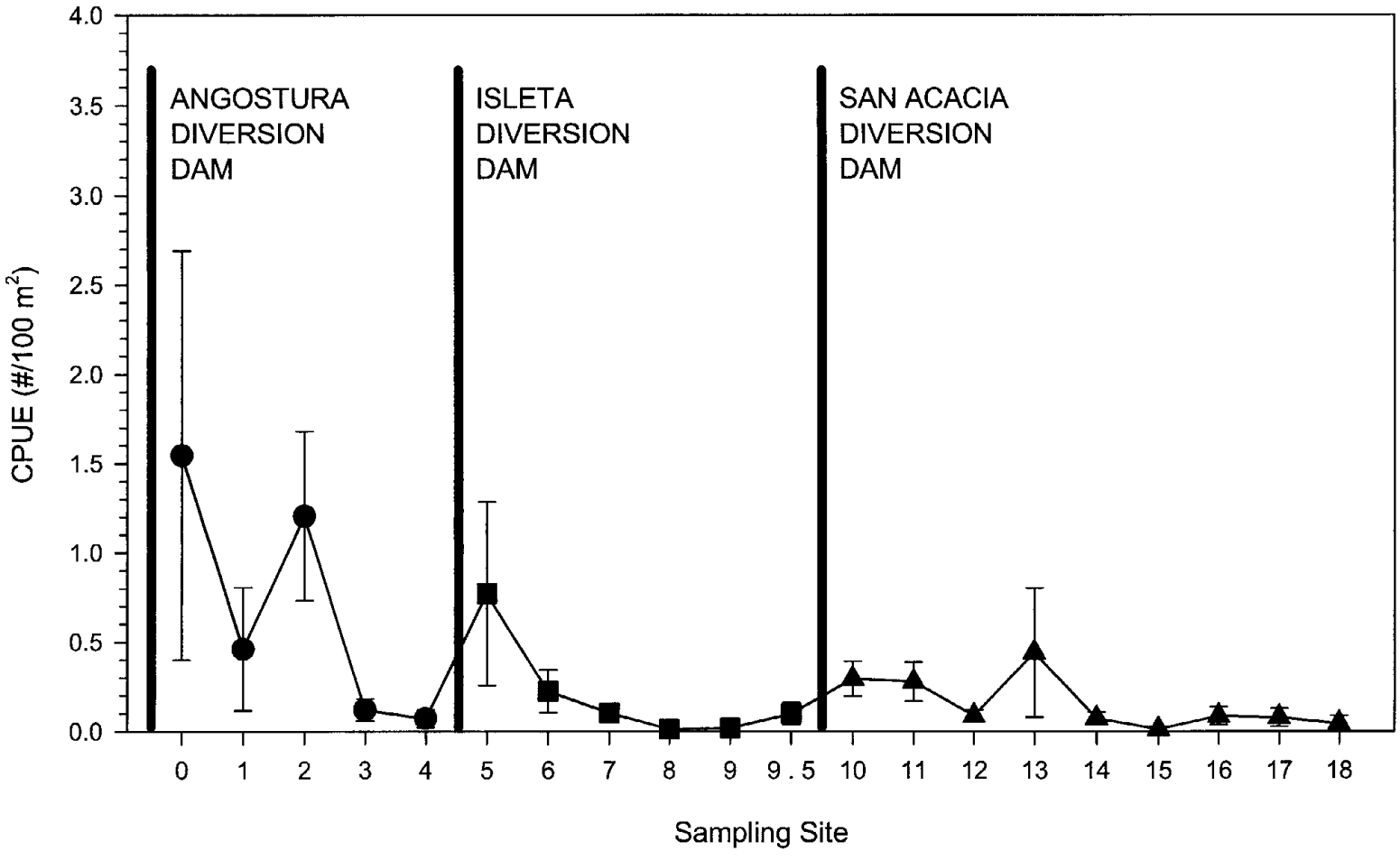

Figure 8. Inter-site comparison of Rio Grande silvery minnow catch rates (CPUE) by sampling locality (20 sites) and river reach (Angostura=circle, Isleta=square, San Acacia=triangle) during 2003. Symbols represent mean values for all sampling months (n=12) and bars represent the standard error.

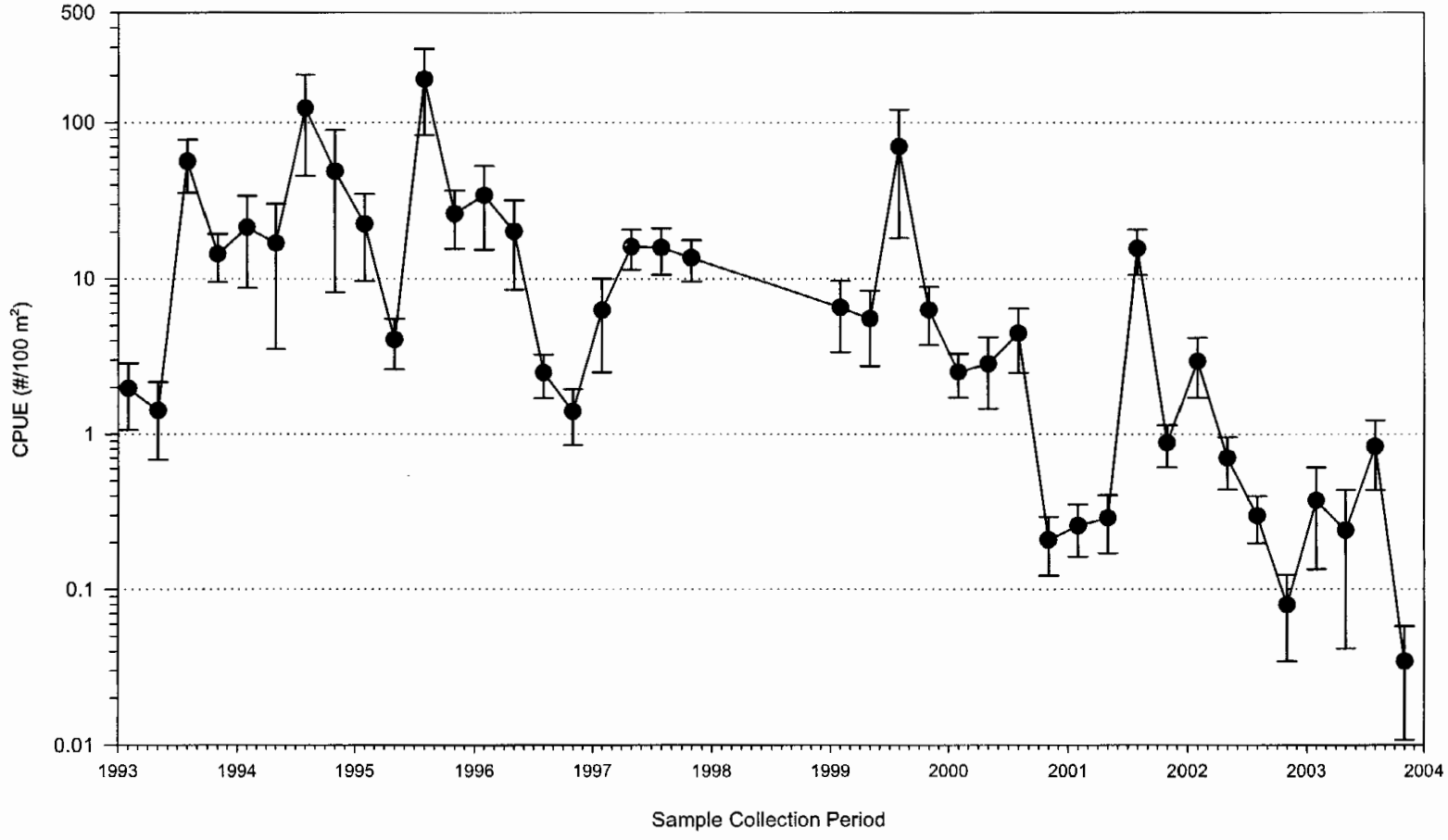

Figure 9. Time sequence of Rio Grande silvery minnow catch rates (1993-1997, 1999-2003) at population monitoring program collection sites. Solid circles indicate sample means for each survey and capped-bars represent the standard error. Dotted horizontal lines represent different orders of magnitude.

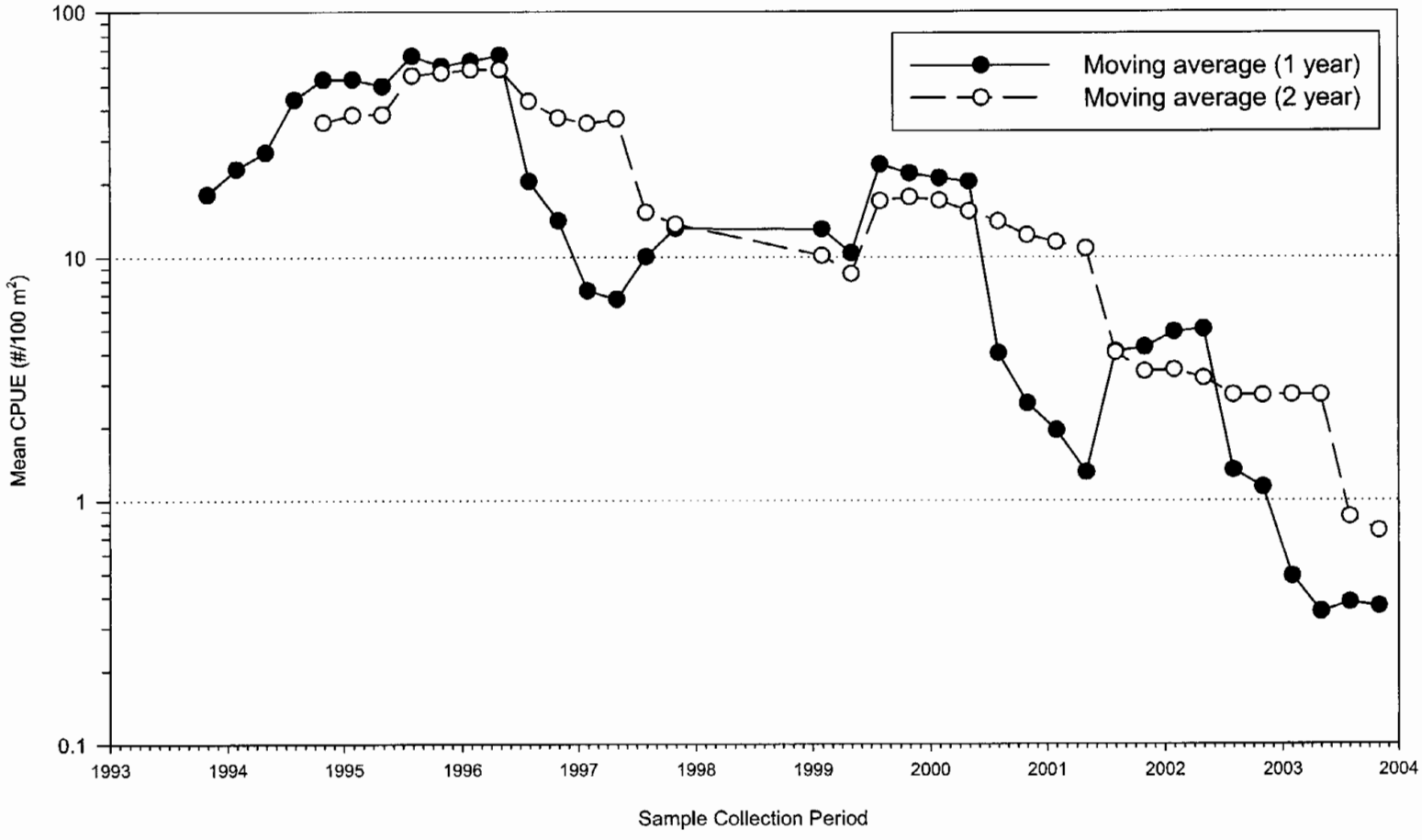

Figure 10. Moving averages (1 year and 2 year) of Rio Grande silvery minnow catch rates (1993-1997, 1999-2003) at population monitoring program collection sites. Dotted horizontal lines represent different orders of magnitude.

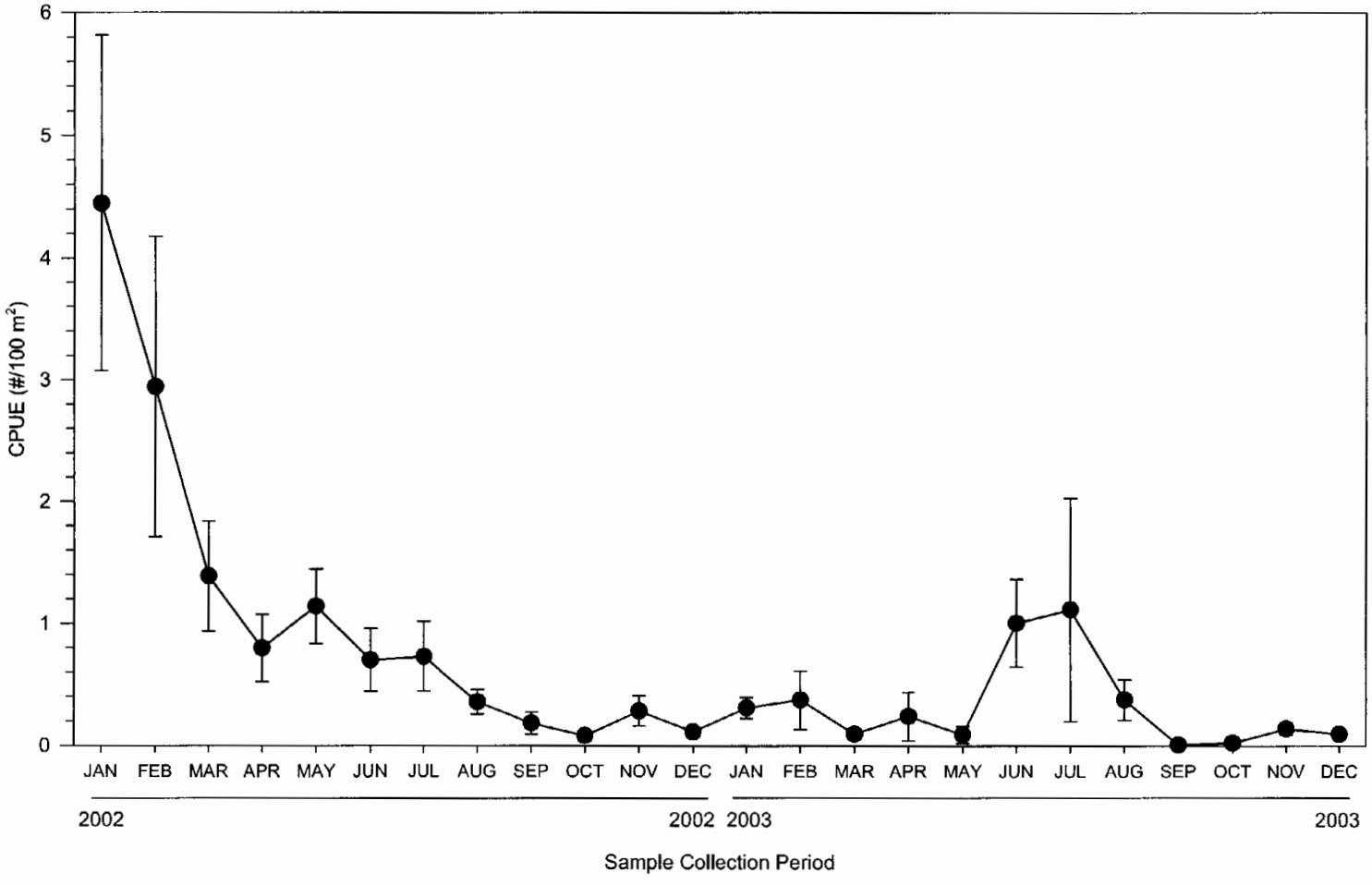

Figure 11. Monthly catch rates of Rio Grande silvery minnow during 2002 (January-December) and through December 2003 at population monitoring program collection sites. Solid circles indicate monthly means (n=20 sites per month) and capped-bars represent the standard error.

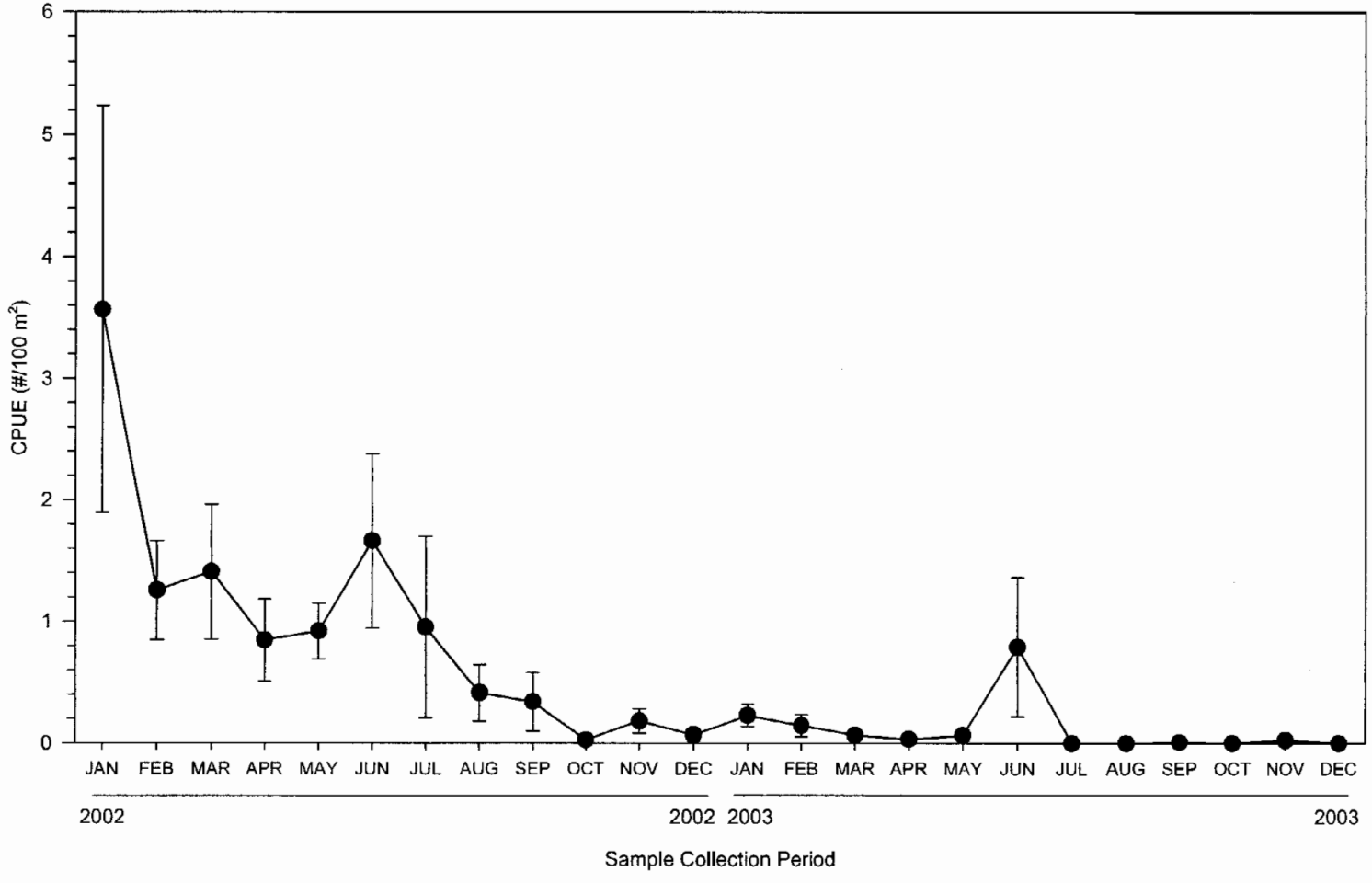

Figure 12. Monthly catch rates of Rio Grande silvery minnow during 2002 (January-December) and through December 2003 at population monitoring program collection sites downstream of Escondida, NM. Solid circles indicate monthly means (n=7 sites per month) and capped-bars represent the standard error.

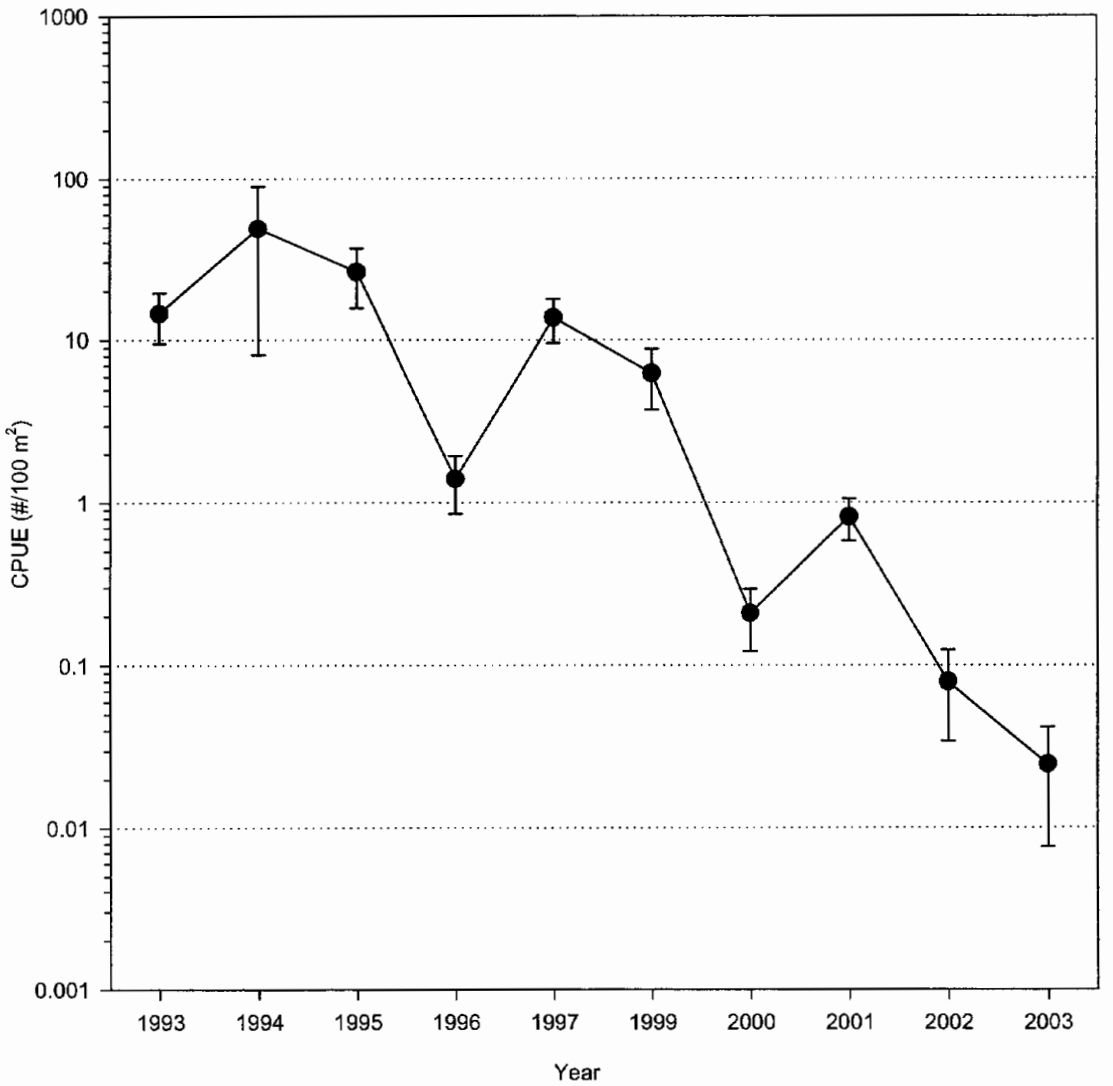

Figure 13. Rio Grande silvery minnow catch rates (CPUE) during October, at all sampling sites, by sampling year (1993-1997, 1999-2003). Solid circles indicate means and capped-bars represent the standard error. Dotted horizontal lines represent different orders of magnitude.

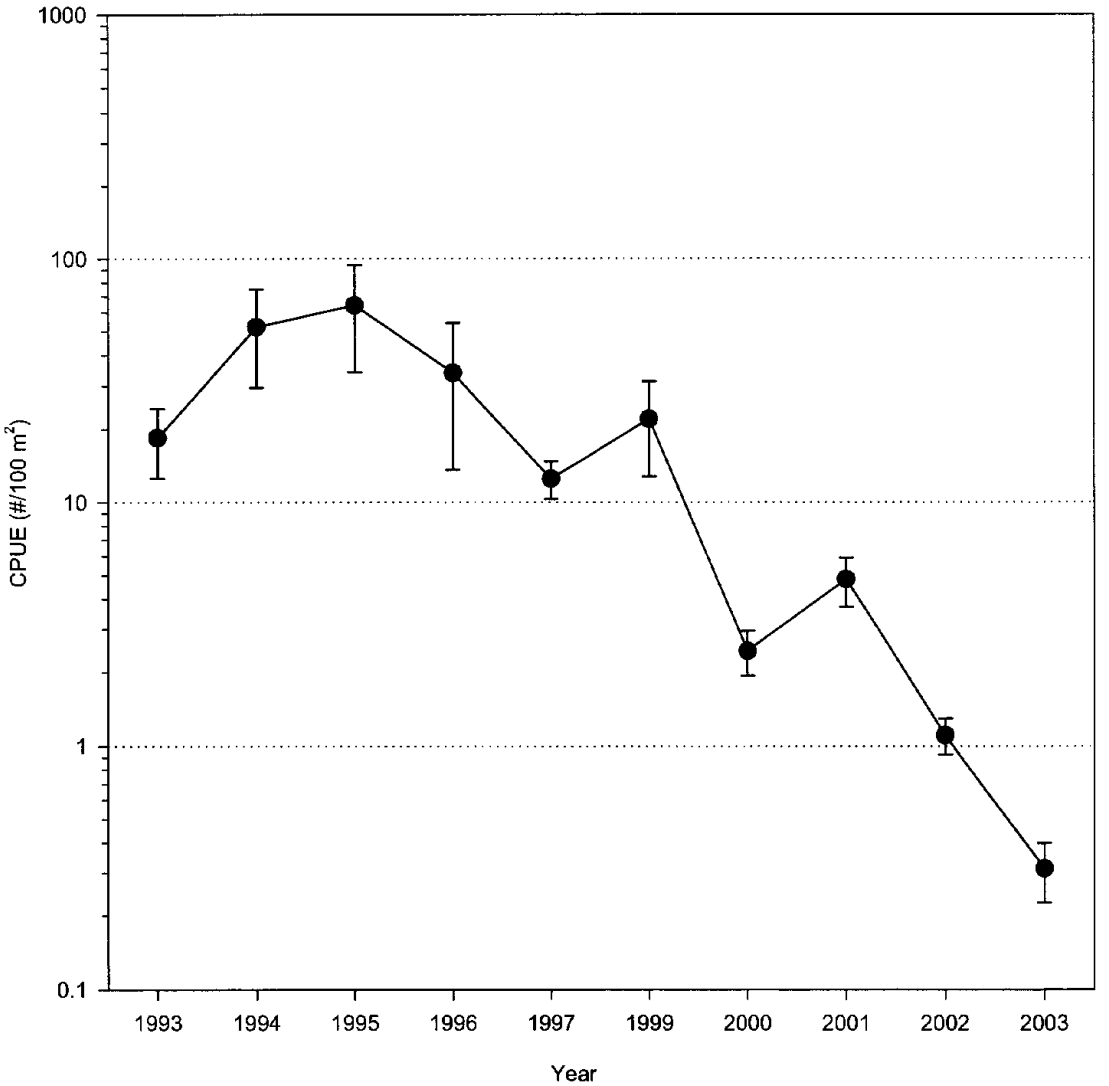

Figure 14. Annual Rio Grande silvery minnow catch rates (CPUE), at all sampling sites, by sampling year (1993-1997, 1999-2003). Solid circles indicate means and capped-bars represent the standard error. Dotted horizontal lines represent different orders of magnitude.

Table 3. Seven hydrograph variables used in correlation analyses for Albuquerque (A) and San Marcial (B) gauging stations. *Discharge values are presented in cubic feet per second (cfs).

(A) USGS 08330000-Rio Grande at Albuquerque, NM

Year	Max. discharge (May-June)	# days (May-June) discharge: >1,000	>2,000	>3,000	>4,000	# days (all year) discharge: <200	<100
1993	7,000	61	61	59	49	0	0
1994	6,250	61	61	60	48	0	0
1995	6,370	61	61	61	57	0	0
1996	1,770	5	0	0	0	2	0
1997	5,980	61	51	43	35	0	0
1999	4,550	61	57	30	13	0	0
2000	1,500	21	0	0	0	0	0
2001	4,760	50	21	2	2	0	0
2002	1,240	2	0	0	0	5	0
2003	1,260	4	0	0	0	42	0

(B) USGS 08358400-Rio Grande Floodway at San Marcial, NM

Year	Max. discharge (May-June)	# days (May-June) discharge: >1,000	>2,000	>3,000	>4,000	# days (all year) discharge: <200	<100
1993	5,590	60	55	40	27	58	36
1994	5,440	61	61	47	22	69	51
1995	4,800	61	61	55	28	39	17
1996	1,690	1	0	0	0	164	152
1997	4,320	54	42	35	15	25	17
1999	4,840	53	26	13	4	71	37
2000	1,470	0	0	0	0	167	98
2001	2,430	20	2	0	0	141	96
2002	446	0	0	0	0	216	191
2003	351	0	0	0	0	229	181

increased significantly ($p<0.001$) with maximum discharge and all combinations of number of days with discharge (cfs) exceeding a threshold value (Figure 15). The relationship that explained the most variation (93%) in mean catch rate was number of days discharge >3,000 cfs. At the San Marcial gauge, mean October catch rate of Rio Grande silvery minnow increased significantly with maximum discharge and several of the combinations of number of days with discharge (cfs) exceeding a threshold value (Figure 16). The relationship that explained the most variation (93%) in mean catch rate was number of days discharge >2,000 cfs. Additionally, there was a strong negative relationship between the number of low flow days (either <200 cfs or <100 cfs) and mean October catch rate of Rio Grande silvery minnow.

Mesohabitat associations

Mesohabitats sampled in the Middle Rio Grande were classified during field sampling and given unique codes to identify their hydraulic features (Table 4). The overall distribution of mesohabitats did not differ notably between reaches although there were some exceptions. Backwaters and isolated pools were more commonly sampled in the Isleta and San Acacia reaches while riffles were more commonly sampled in the Angostura Reach (Figure 17). It is important to stress that a wide variety of habitats were sampled to provide a balanced monitoring program of the Middle Rio Grande ichthyofaunal community and all life stages of Rio Grande silvery minnow. The actual habitats occupied by Rio Grande silvery minnow were diverse and included all of the habitats sampled with the exception of riffles (Figure 18). Habitats that were occupied most frequently were backwaters and shoreline runs.

Fish Community

Population status-2003

The 2003 ichthyofaunal community in the Middle Rio Grande between Angostura Diversion Dam and Elephant Butte Reservoir was numerically dominated by cyprinids (Table 5). The native ichthyofauna consisted of seven species (red shiner, Rio Grande silvery minnow, fathead minnow, flathead chub, longnose dace, river carpsucker, and smallmouth buffalo) represented by between 13 and 59,406 individuals. Smallmouth buffalo (n=13) was the least abundant native fish and Rio Grande silvery minnow (n=384) the second least collected native taxon. Rio Grande silvery minnow was the least abundant of the 10 focal taxa used in the community composition analysis. Red shiner was the most abundant native species collected (n=59,406) followed by fathead minnow (n=11,340), river carpsucker (n=2,862) and flathead chub (n=2,109). The most abundant introduced species were western mosquitofish (n=21,982), white sucker (n=1,236) channel catfish (n=995), yellow bullhead (n=834), and common carp (n=558). The nine remaining nonnative fish species were present at much lower numbers (i.e., n<25) than were the aforementioned nonnatives.

Rio Grande silvery minnow comprised a small fraction of the total ichthyofaunal community in 2003. This percentage has dropped precipitously over the past decade (Figure 19). Rio Grande silvery minnow has comprised <5% of the ichthyofaunal community since 2000 and its relative abundance of the total catch was lower (0.4%) in 2003 than had ever been previously recorded. The magnitude of change in catch rates of Rio Grande silvery minnow is particularly evident when compared to overall fish catch rates (all species) over the past decade (Figure 20). While the rank abundance of most fish species in the Middle Rio Grande has remained relatively constant over the past decade, Rio Grande silvery minnow has declined from being one of the most abundant species in the early to mid-1990s to being one of the least abundant species and the least regularly collected native taxa by 2003 (Table 6).

There were notable seasonal changes in the relative abundance of the ten most abundant fish species during 2003 (Figures 21-23). Catch of all species increased during spring or summer. The highest catch rate of red shiner was recorded in July although the abundance of this taxon was

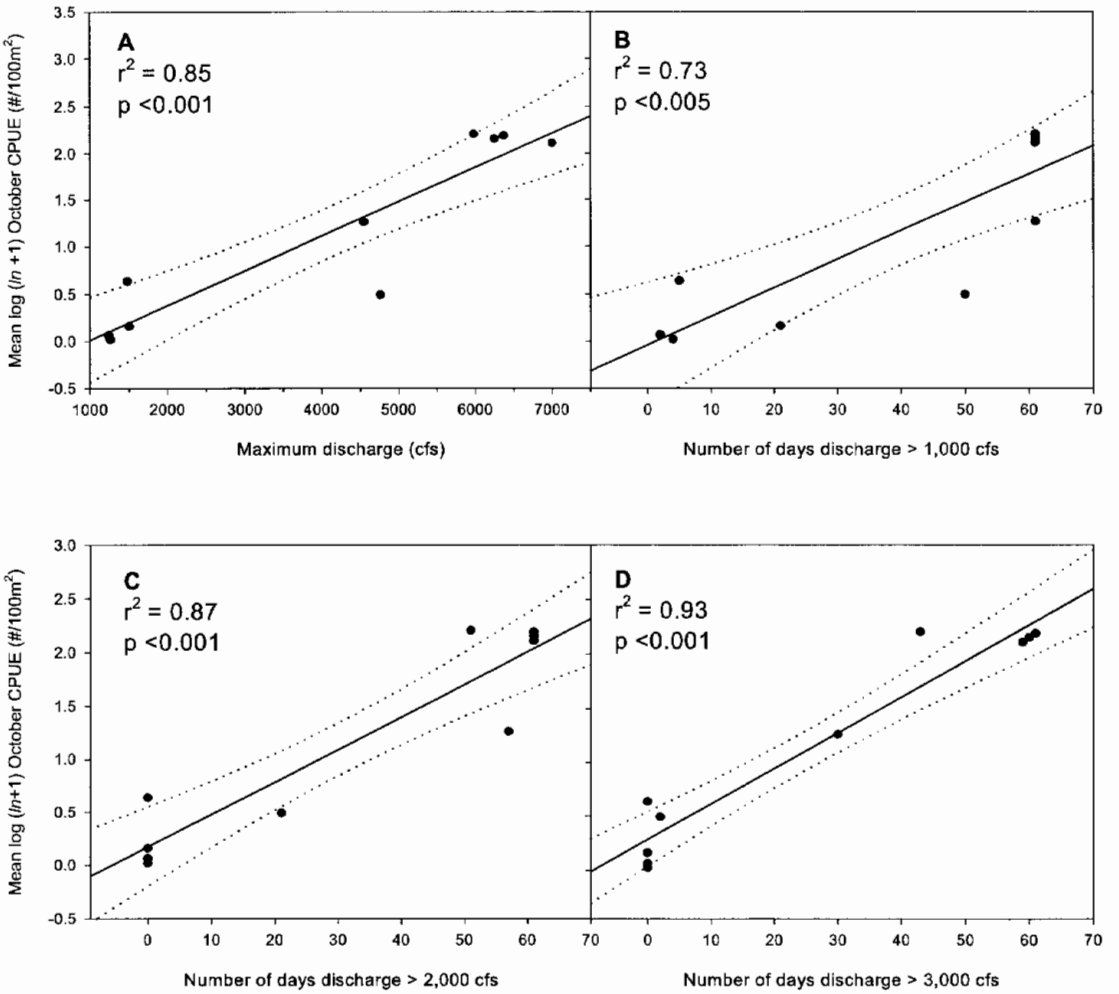

Figure 15A-D. Regression analysis of Rio Grande silvery minnow log-transformed mean October catch rates (1993-1997, 1999-2003) and different hydraulic variables (see Table 3) for USGS Gauge #08330000 (Rio Grande at Albuquerque, NM). Graph shows regression line (solid) and 95% confidence intervals (dotted).

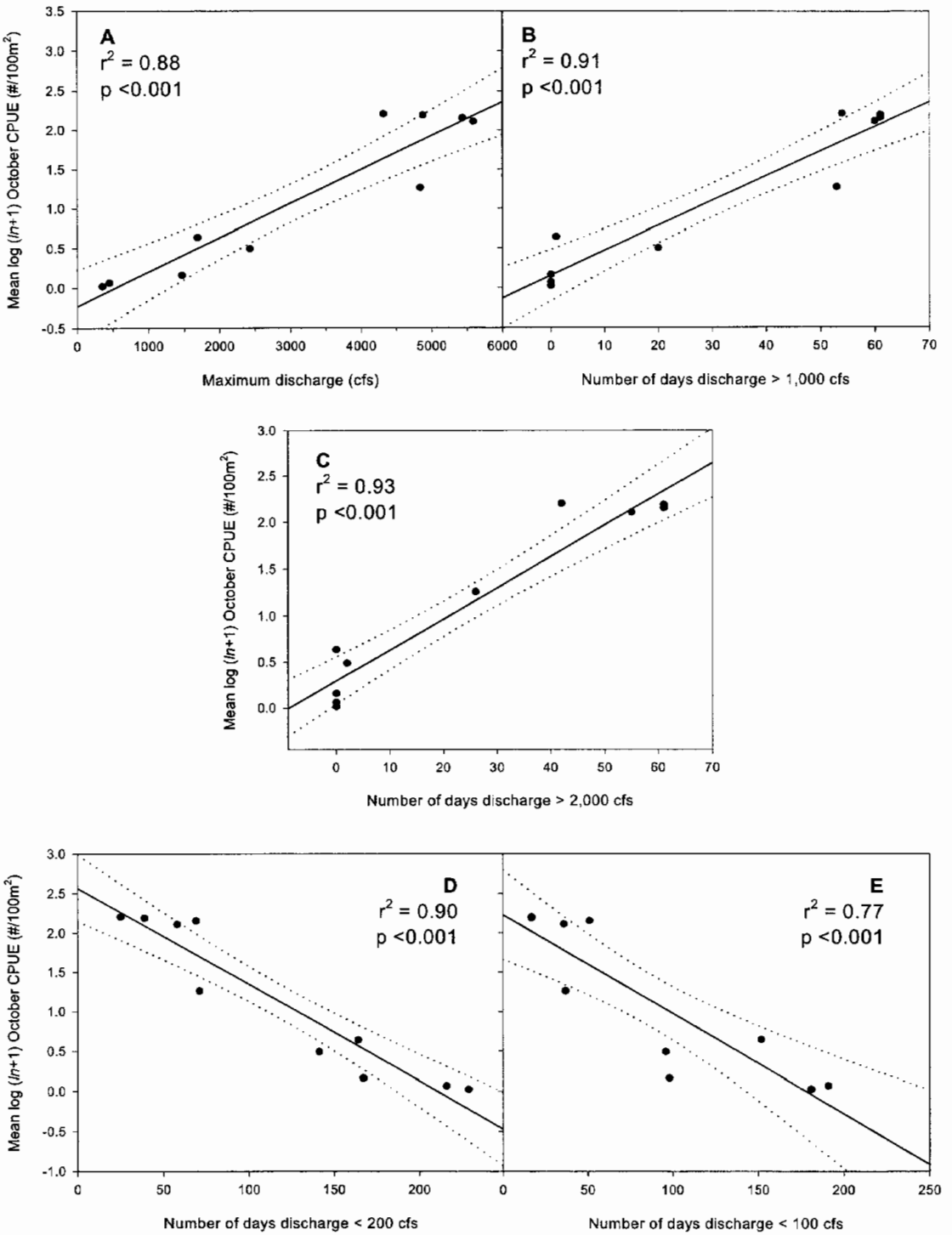

Figure 16A-E. Regression analysis of Rio Grande silvery minnow log-transformed mean October catch rates (1993-1997, 1999-2003) and different hydraulic variables (see Table 3) for USGS Gauge #08358400 (Rio Grande Floodway at San Marcial, NM). Graph shows regression line (solid) and 95% confidence intervals (dotted).

Table 4. Codes used for mesohabitat type classification in the Middle Rio Grande.

MESOHABITAT TYPES	
Primary	
MC	**Main channel-** the section of the river which carries the majority of the flow; there can be only one main channel.
SC	**Secondary channel-** all channels not designated as the main channel; there can be zero or several secondary channels at a site.
BW	**Back water-** a body of water, connected to the main channel, with no appreciable flow; often created by a drop in flow which partially isolates a former channel.
IP	**Isolated pool-** a pool which is not connected to the main or secondary channel; frequently a former backwater which is no longer connected to the main or secondary channel.
RIFFLE	**Riffle-** a shallow and high velocity habitat where the water surface is irregular and broken by waves; generally indicates gravel-cobble substrate.
DEBRIS	**Debris-** any habitat that has associated organic cover (e.g., grasses, woody vegetation etc.) within all or part of the total surface area sampled.
Secondary	
PO	**Pool-** the portion of the river that is deep and with relatively little velocity compared to the rest of the channel.
RU	**Run-** a reach of relatively fast velocity water with laminar flow and a non-turbulent surface.
SH	**Shoreline-** usually a shallower, lower velocity area that is adjacent to shore. This designation precedes other mesohabitat types (i.e. SHRU= shoreline run or SHRI= shoreline riffle).

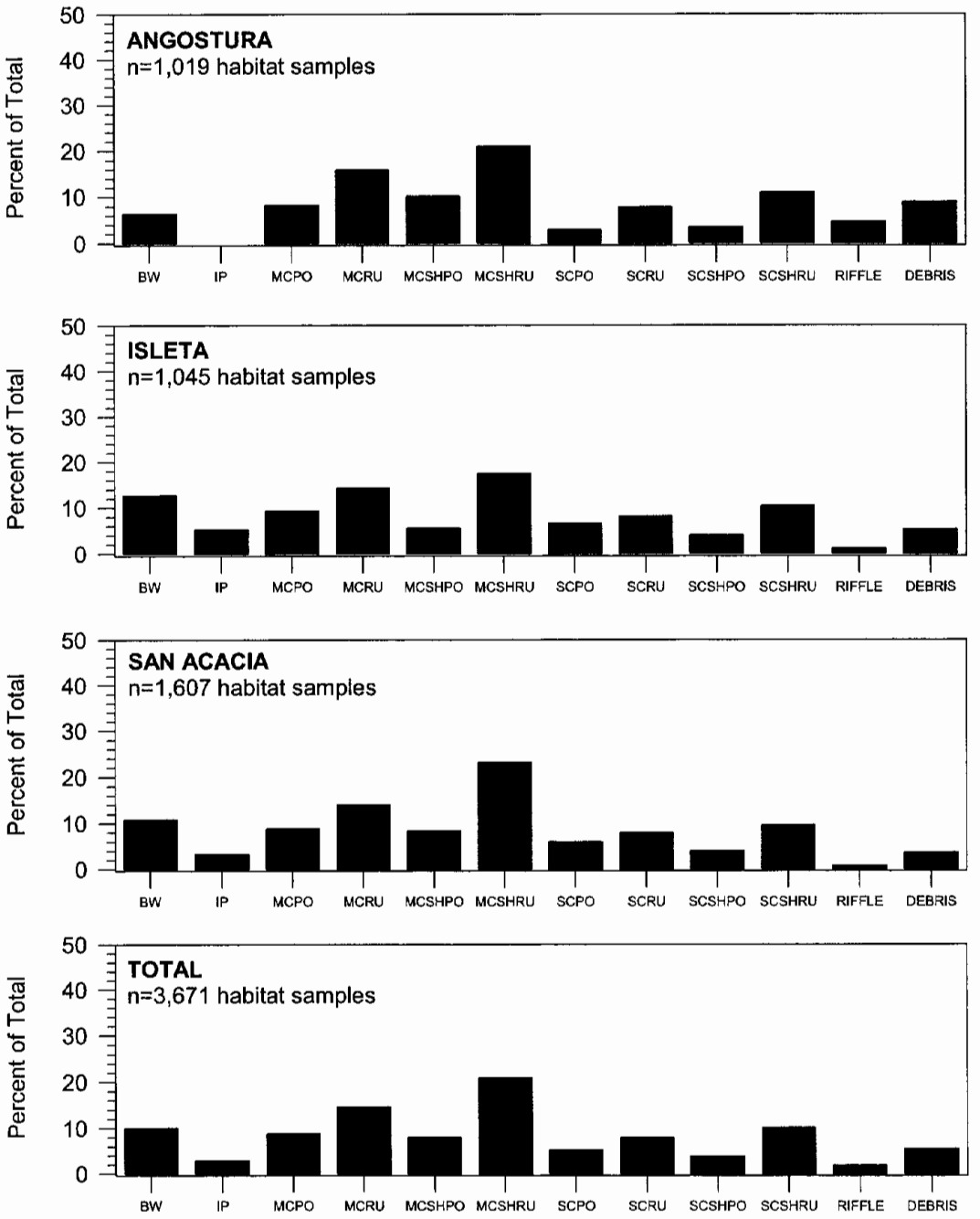

Figure 17. Percent total of mesohabitats (see Table 4 for codes) sampled in the Middle Rio Grande as part of population monitoring during 2003 for each river reach and the annual total.

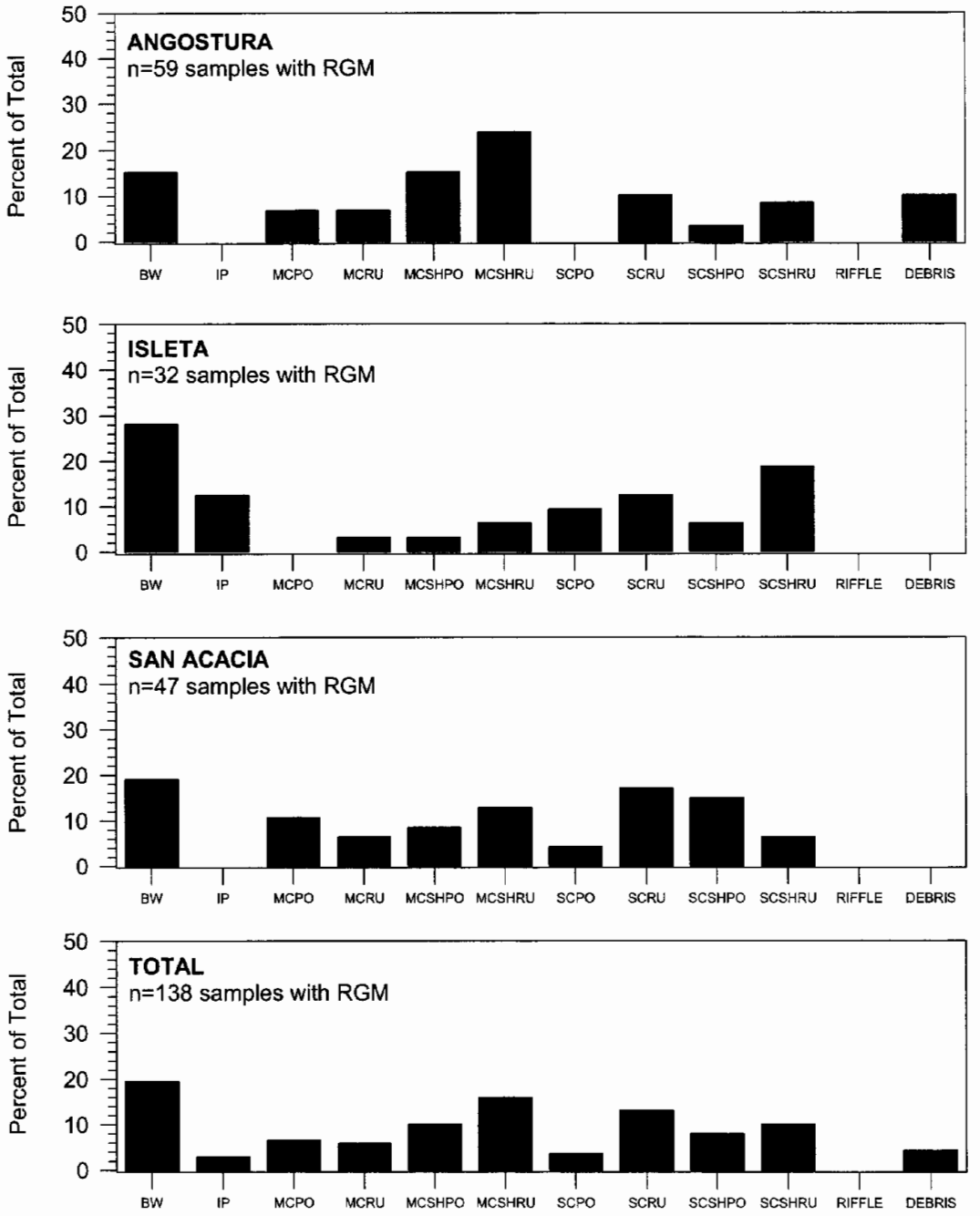

Figure 18. Percent total of mesohabitats (see Table 4 for codes) occupied by Rio Grande silvery minnow (RGM) in the Middle Rio Grande as part of population monitoring during 2003 for each river reach and the annual total.

Table 5. Summary of the 2003 Rio Grande silvery minnow population monitoring program fish collections.

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT OF % OF TOTAL	FREQUENCY OF OCCURRENCE[2]	% FREQUENCY OCCURRENCE[2]
HERRINGS					
gizzard shad	I	6	<0.01	5	25
CARPS AND MINNOWS					
red shiner *	N	59,406	57.98	20	100
common carp *	I	558	0.55	20	100
Rio Grande silvery minnow *	N	384	0.38	20	100
fathead minnow *	N	11,340	11.07	20	100
flathead chub *	N	2,109	2.06	18	90
longnose dace *	N	681	0.66	13	65
SUCKERS					
river carpsucker *	N	2,862	2.79	20	10
white sucker *	I	1,236	1.21	14	70
smallmouth buffalo	N	13	0.01	5	25
BULLHEAD CATFISHES					
black bullhead	I	2	<0.01	2	10
yellow bullhead	I	834	0.81	9	45
channel catfish *	I	995	0.97	20	100
flathead catfish	I	1	<0.01	1	5
LIVEBEARERS					
western mosquitofish *	I	21,982	21.46	20	100
TEMPERATE BASSES					
white bass	I	2	<0.01	2	10
SUNFISHES					
green sunfish	I	2	<0.01	2	10
bluegill	I	4	<0.01	4	20
largemouth bass	I	7	<0.01	2	10
white crappie	I	9	<0.01	6	30
PERCHES					
yellow perch	I	23	0.02	5	25
TOTAL		102,456	100	20	100

[1] N = native; I = introduced
[2] Frequency and % frequency of occurrence are based on n=20 sample sites
* indicates one of the 10 focal taxa used in all community composition figures

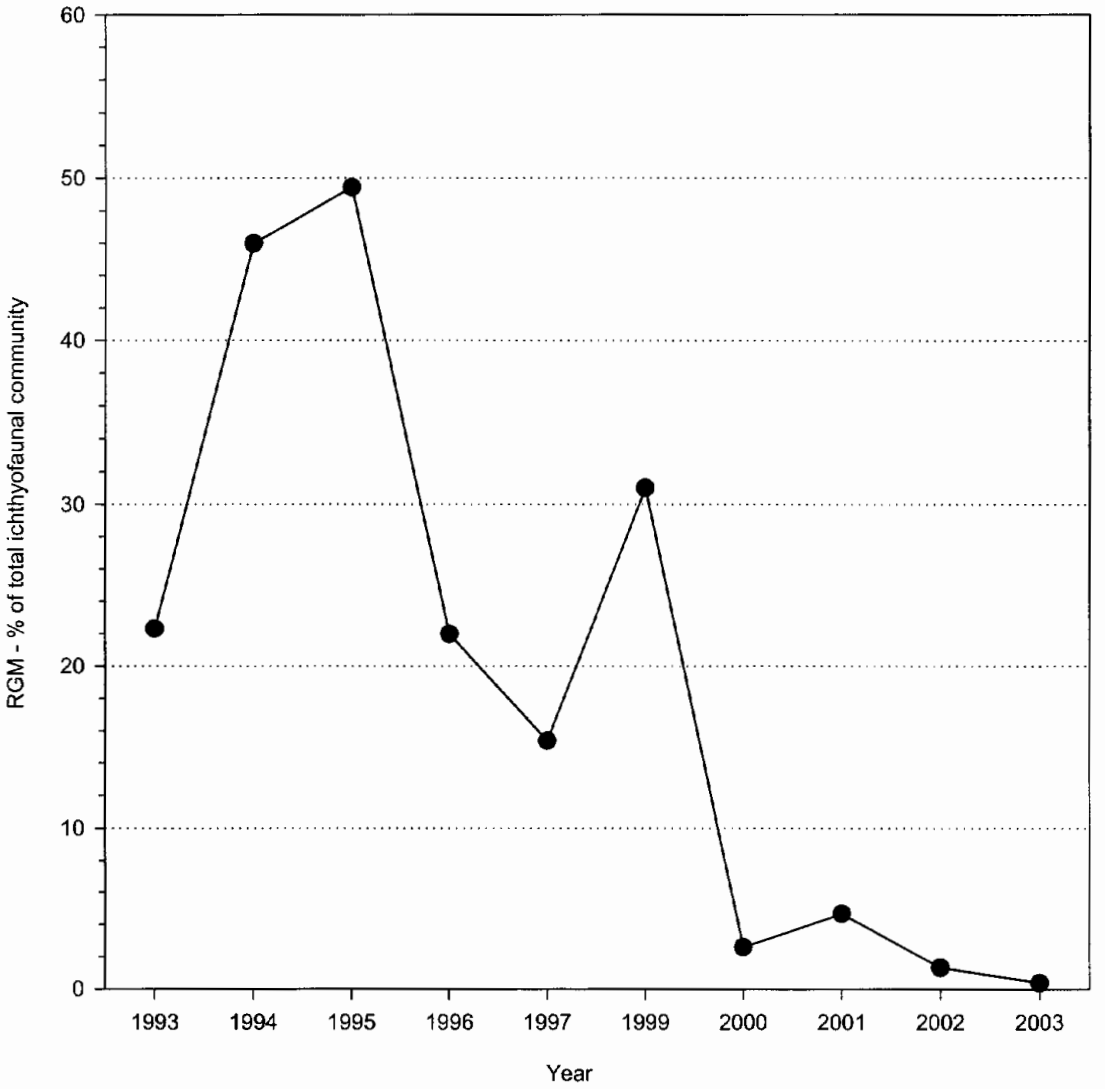

Figure 19. Relative abundance of Rio Grande silvery minnow as a percentage of the total ichthyofaunal community by sampling year (1993-1997, 1999-2003).

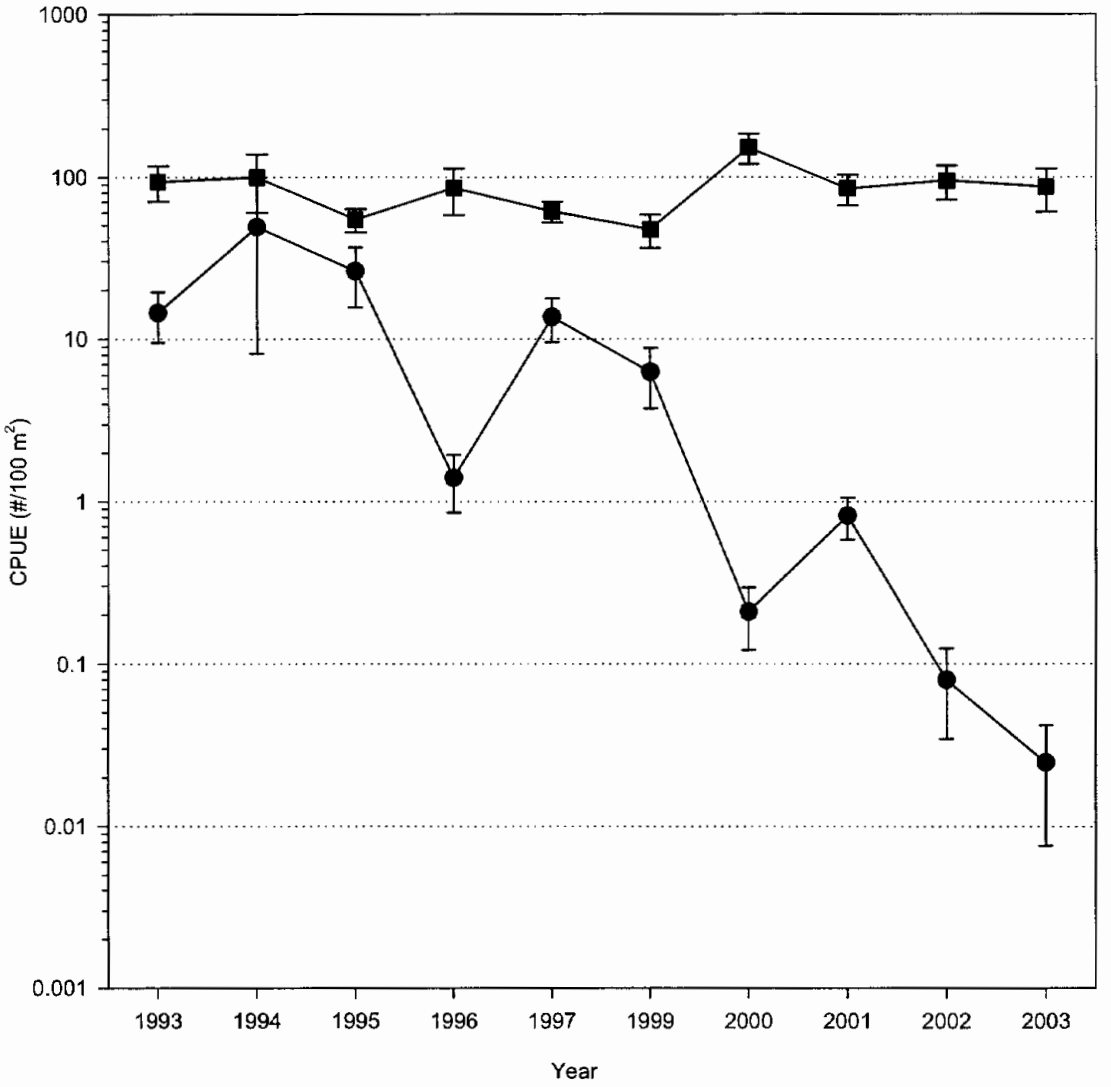

Figure 20. Catch rates (CPUE) of Rio Grande silvery minnow (circles) and the total ichthyofaunal community (squares) during October, at all sampling sites, by sampling year (1993-1997, 1999-2003). Solid circles or squares indicate means and capped-bars represent the standard error. Dotted horizontal lines represent different order of magnitude.

Table 6. Summary of annual rank abundance of species collected every year in the Rio Grande from 1993-1997 and 1999-2003.

SPECIES	1993	1994	1995	1996	1997	1999	2000	2001	2002	2003
HERRINGS										
gizzard shad	10	13	11	8	11	8	12	11	13	14
CARPS AND MINNOWS										
red shiner	1	2	2	1	1	1	1	1	1	1
common carp	11	8	10	10	8	9	9	6	10	10
RG silvery minnow	***2***	***1***	***1***	***2***	***2***	***2***	***6***	***5***	***8***	***11***
fathead minnow	4	7	8	5	6	7	5	3	2	3
flathead chub	6	6	5	7	9	6	8	9	7	5
longnose dace	9	10	9	11	10	10	10	10	9	9
SUCKERS										
river carpsucker	5	5	6	4	4	3	4	4	4	4
white sucker	3	3	3	3	3	11	3	8	5	6
BULLHEAD CATFISHES										
black bullhead	17	15	15	16	13	12	17	17	16	16
yellow bullhead	12	14	14	12	17	15	13	14	11	8
channel catfish	7	4	7	9	8	4	7	7	6	7
LIVEBEARERS										
western mosquitofish	8	9	3	6	5	5	2	2	3	2
TEMPERATE BASSES										
white bass	14	11	12	17	15	14	15	12	15	16
SUNFISHES										
bluegill	16	17	16	15	16	17	16	16	14	15
largemouth bass	15	16	17	14	12	16	14	15	16	13
white crappie	13	12	13	13	14	12	11	13	12	12

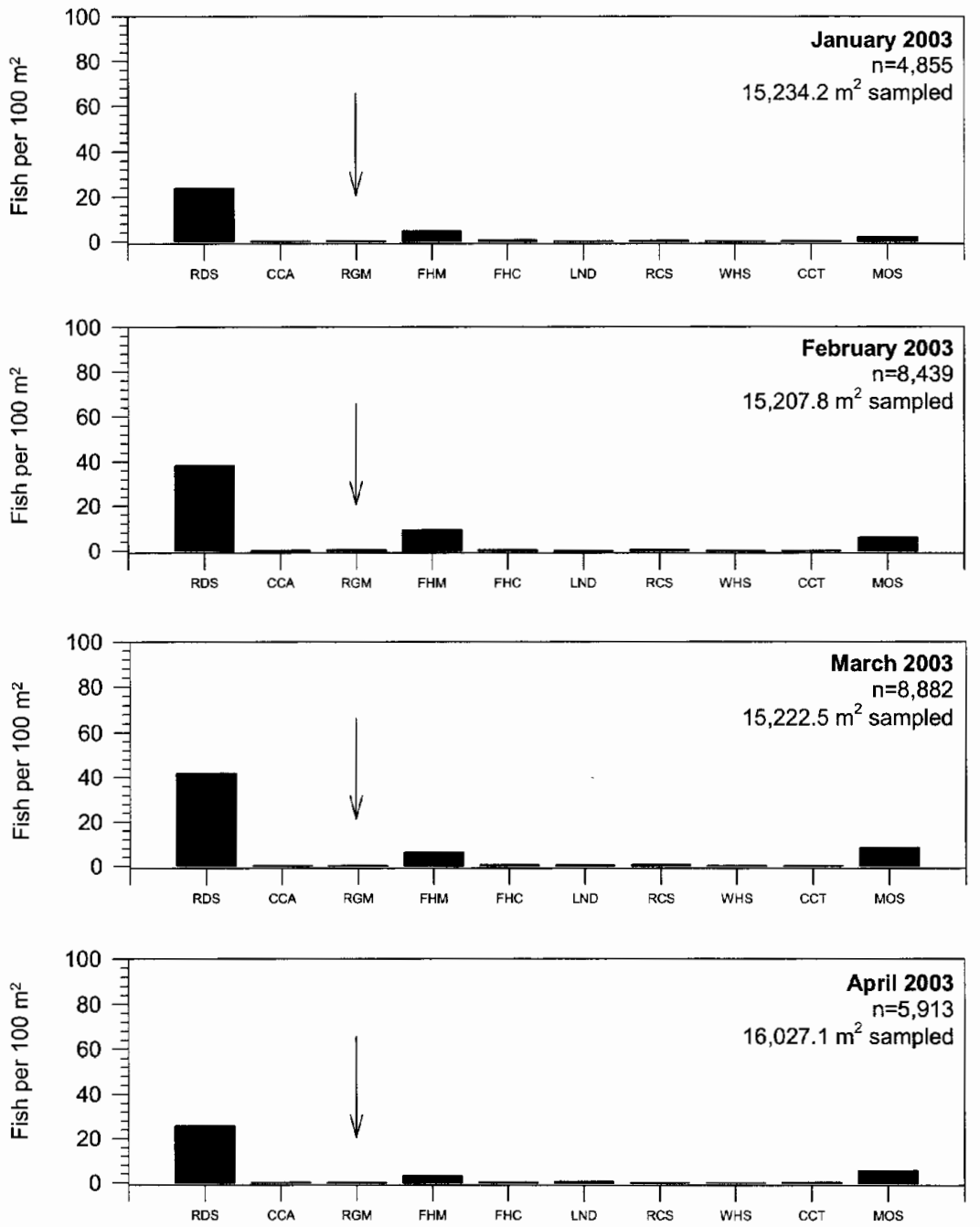

Figure 21. Fish catch rates (CPUE) from January-April 2003 for each focal species (see Table 1 for species codes) in the Middle Rio Grande. An arrow indicates the Rio Grande silvery minnow (RGM) histogram bar.

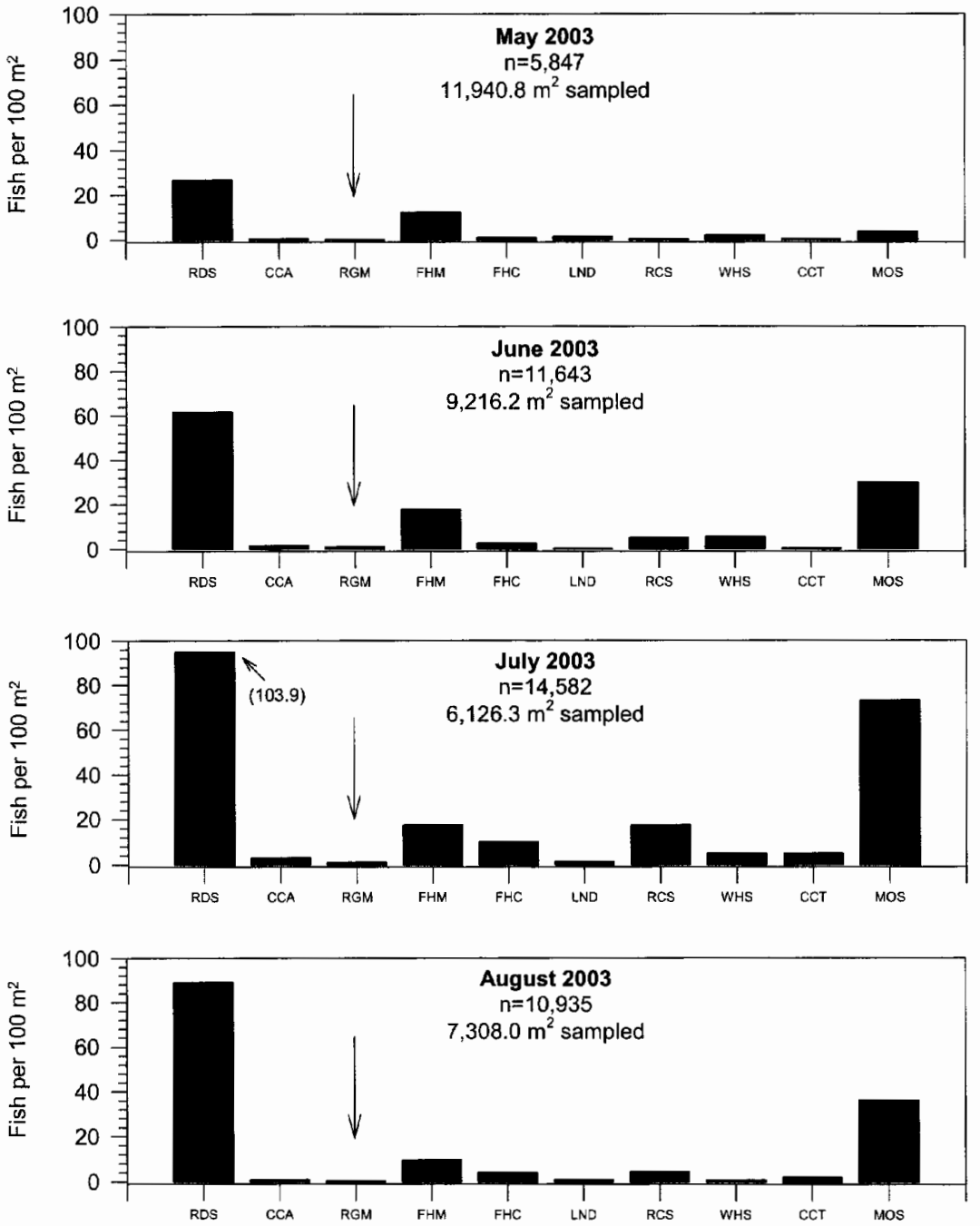

Figure 22. Fish catch rates (CPUE) from May-August 2003 for each focal species (see Table 1 for species codes) in the Middle Rio Grande. An arrow indicates the Rio Grande silvery minnow (RGM) histogram bar. *Note: Scale different for July 2003 histogram.

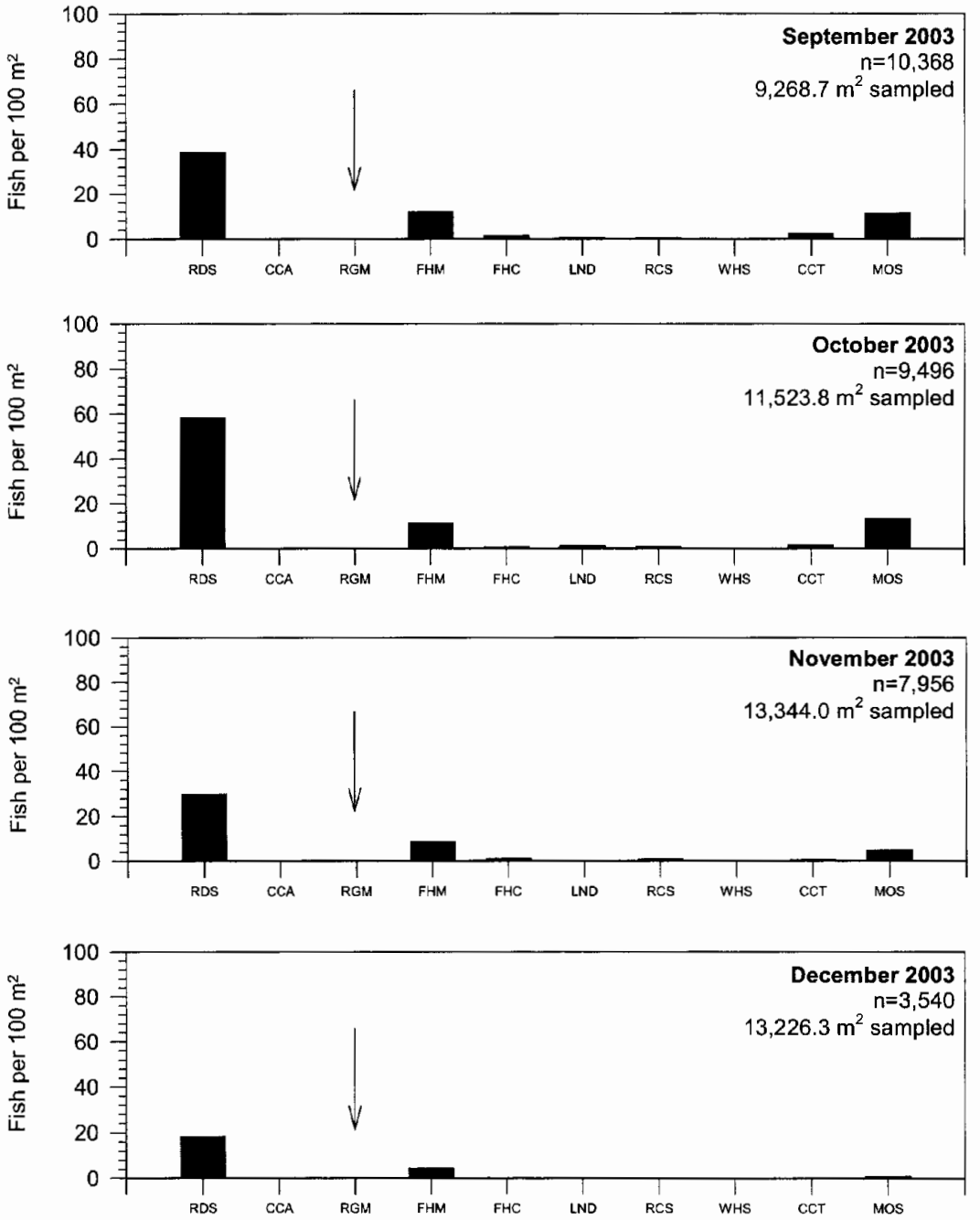

Figure 23. Fish catch rates (CPUE) from September-December 2003 for each focal species (see Table 1 for species codes) in the Middle Rio Grande. An arrow indicates the Rio Grande silvery minnow (RGM) histogram bar.

high throughout the year. Other fish species whose catch rates peaked in July were common carp, flathead chub, river carpsucker, channel catfish, and western mosquitofish. Fathead minnow and white sucker were most abundant during the June sampling trip. Rio Grande silvery minnow abundance in samples increased briefly in June and July but rapidly declined during subsequent months. Abundance of most species began to decline by September 2003 and stabilized during the remainder of the year. A detailed accounting of species-specific temporal abundance revealed similar trends and documented the season-specific presence of certain nonnative taxa (e.g., gizzard shad, smallmouth buffalo, yellow perch; Table 7).

Besides temporal variation in the relative abundance in the fish community, there were also longitudinal differences in the abundance of fish species (Figure 24). Red shiner, fathead minnow, and western mosquitofish catch rates were highest in the Isleta Reach and lowest in the San Acacia Reach. Catch rate of river carpsucker was highest in the Angostura Reach and lowest in the San Acacia Reach. Longnose dace and white sucker exhibited a similar pattern of higher catch rates in the Angostura Reach compared to the Isleta or San Acacia reaches. Rio Grande silvery minnow was most abundant in the Angostura Reach but overall catch rates differed little between river reaches.

Relative abundance of all fish species in 2003 fluctuated for each of the river reaches (Figure 25). An increase in the relative abundance of fish occupying the three river reaches was discerned in June and July samples but declines were generally most apparent by September or October. Notable increases in fish catch rate occurred in June in the Angostura and Isleta reaches but not until July in the San Acacia Reach. Isleta Reach fish catch rates were high from June through September primarily because of the large number of red shiner, fathead minnow, and western mosquitofish collected there. Overall catch rates for all reaches peaked in July.

Catch rates of individual taxa in the study reaches varied extensively by sampling period (Figures 26-28). Fish catch rates in the Angostura Reach were low for most of the focal species except red shiner, river carpsucker, and western mosquitofish. Rio Grande silvery minnow catch rates, low throughout 2003, were collected from at least one Angostura Reach site during almost every monthly sampling trip. Red shiner was most common in samples taken in June until the end of 2003. White sucker abundance peaked in June and July following spawning by this species. Western mosquitofish was most abundant in June-August Angostura Reach samples. Relative abundance of most other focal species in the Angostura Reach peaked during July and declined to pre-spawning levels by September.

Fish catch rates in the Isleta Reach, like the Angostura Reach, also peaked in June and July. Red shiner, fathead minnow, and western mosquitofish were clearly the most abundant species in samples throughout the year. Flathead chub reached its highest catch rate in the Middle Rio Grande during July in the Isleta Reach. Rio Grande silvery minnow abundance in the Isleta Reach was low throughout the year but a small number of individuals was collected in this reach during all but two sampling months. Red shiner abundance was relatively high throughout the year and the two largest collections were taken from June-September. Channel catfish was generally more prevalent in the Isleta Reach than in the other reaches and was most abundant in the July and August samples.

The 2003 relative abundance of red shiner in the San Acacia Reach was high during July and August but declined rapidly by September and remained moderately low throughout the rest of the year. Rio Grande silvery minnow catch rates in the San Acacia Reach were approximately equal to those recorded in the Isleta Reach. There was no discernible difference in the number of Rio Grande silvery minnow collected following May spawning. This was probably caused by extensive stream drying in this reach and presumably substantial losses of young-of-year. The abundance of Rio Grande silvery minnow in autumn was similar to values recorded in the Angostura and Isleta reaches. The abundance of other fish species (common carp, fathead minnow, flathead chub, river carpsucker, channel catfish, and western mosquitofish) in the San Acacia Reach peaked in June and July 2003. The only species whose abundance increased in August 2003 in the San Acacia Reach was channel catfish.

Table 7. Summary of the monthly 2003 Rio Grande silvery minnow population monitoring program fish collections.

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
HERRINGS													
gizzard shad	---	1	---	---	---	1	2	2	---	---	---	---	6
CARPS AND MINNOWS													
red shiner	3,602	5,822	6,363	4,136	3,208	5,967	6,362	6,514	4,684	5,042	5,196	2,780	59,406
common carp	9	15	9	18	54	143	188	59	17	25	8	13	558
RG silvery minnow	44	60	15	38	10	89	66	30	1	2	17	12	384
fathead minnow	704	1,412	943	510	1,471	1,641	1,078	704	953	757	917	250	11,340
flathead chub	83	61	60	70	117	249	616	313	146	126	185	83	2,109
longnose dace	7	5	76	112	186	26	87	75	48	31	21	7	681
SUCKERS													
river carpsucker	55	108	89	42	48	475	1,079	344	139	123	231	129	2,862
white sucker	4	6	22	29	251	507	304	64	6	24	12	7	1,236
smallmouth buffalo	---	---	---	---	---	2	3	8	---	---	---	---	13
BULLHEAD CATFISHES													
black bullhead	---	1	---	1	---	---	---	---	---	---	---	---	2
yellow bullhead	---	1	---	1	2	4	5	2	5	807	6	1	834
channel catfish	26	16	23	62	56	38	304	163	105	38	89	75	995
flathead catfish	---	---	---	---	---	---	1	---	---	---	---	---	1
LIVEBEARERS													
western mosquitofish	318	928	1,281	893	444	2,764	4,481	2,649	4,264	2,508	1,271	181	21,982
TEMPERATE BASSES													
white bass	1	---	---	---	---	---	1	---	---	---	---	---	2
SUNFISHES													
green sunfish	---	2	---	---	---	---	---	---	---	---	---	---	2
bluegill	1	---	1	---	---	---	---	---	---	1	1	---	4
largemouth bass	---	---	---	---	---	1	---	2	---	4	---	---	7
white crappie	1	1	---	1	---	1	---	1	---	2	---	2	9
PERCHES													
yellow perch	---	---	---	---	---	5	5	5	---	6	2	---	23
TOTAL	8,439	8,439	8,882	5,913	5,847	11,643	14,582	10,935	10,368	9,496	7,956	3,540	102,456

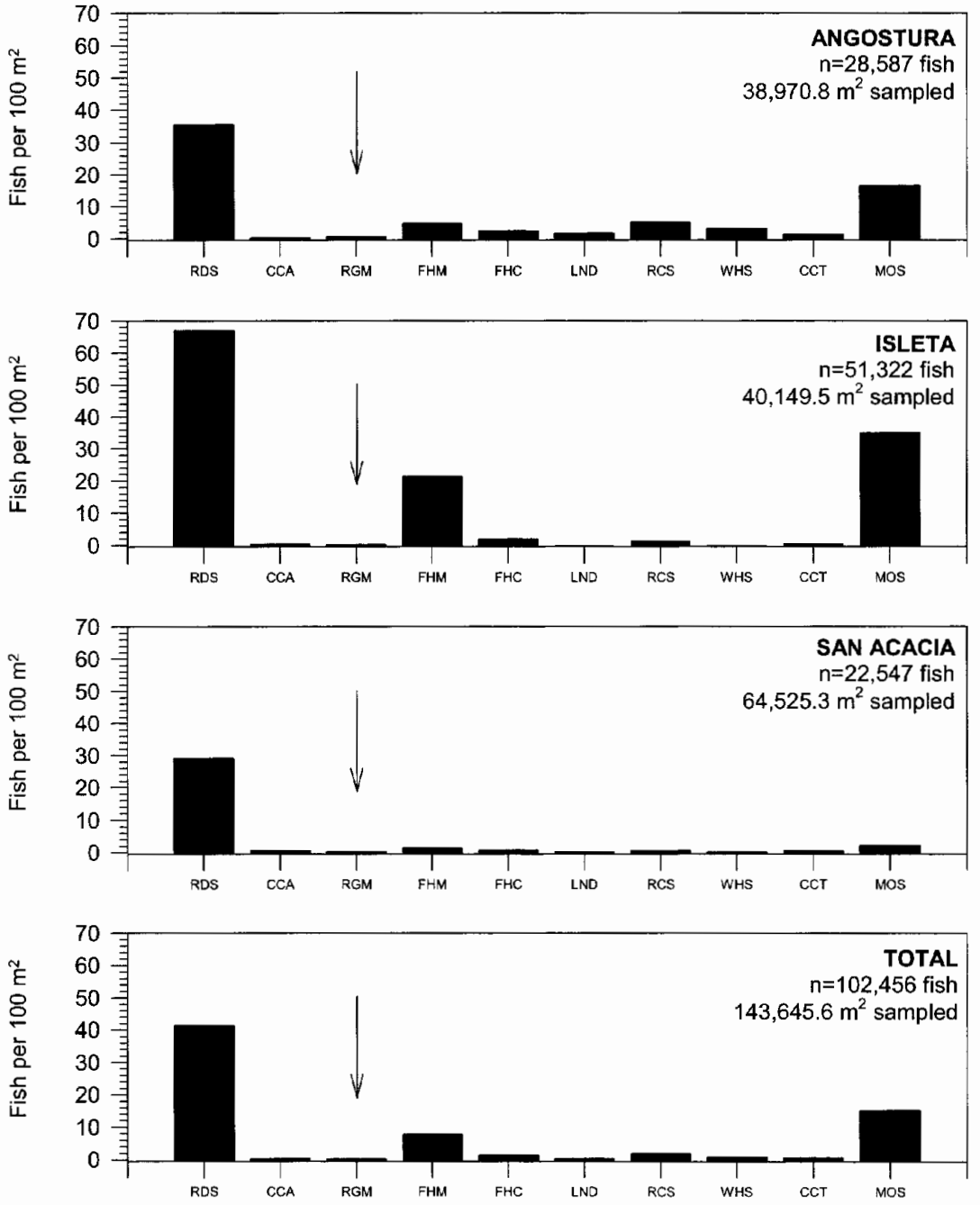

Figure 24. Fish catch rates (CPUE) by river reach for each focal species (see Table 1 for species codes) in the Middle Rio Grande during 2003. An arrow indicates the Rio Grande silvery minnow (RGM) histogram bar.

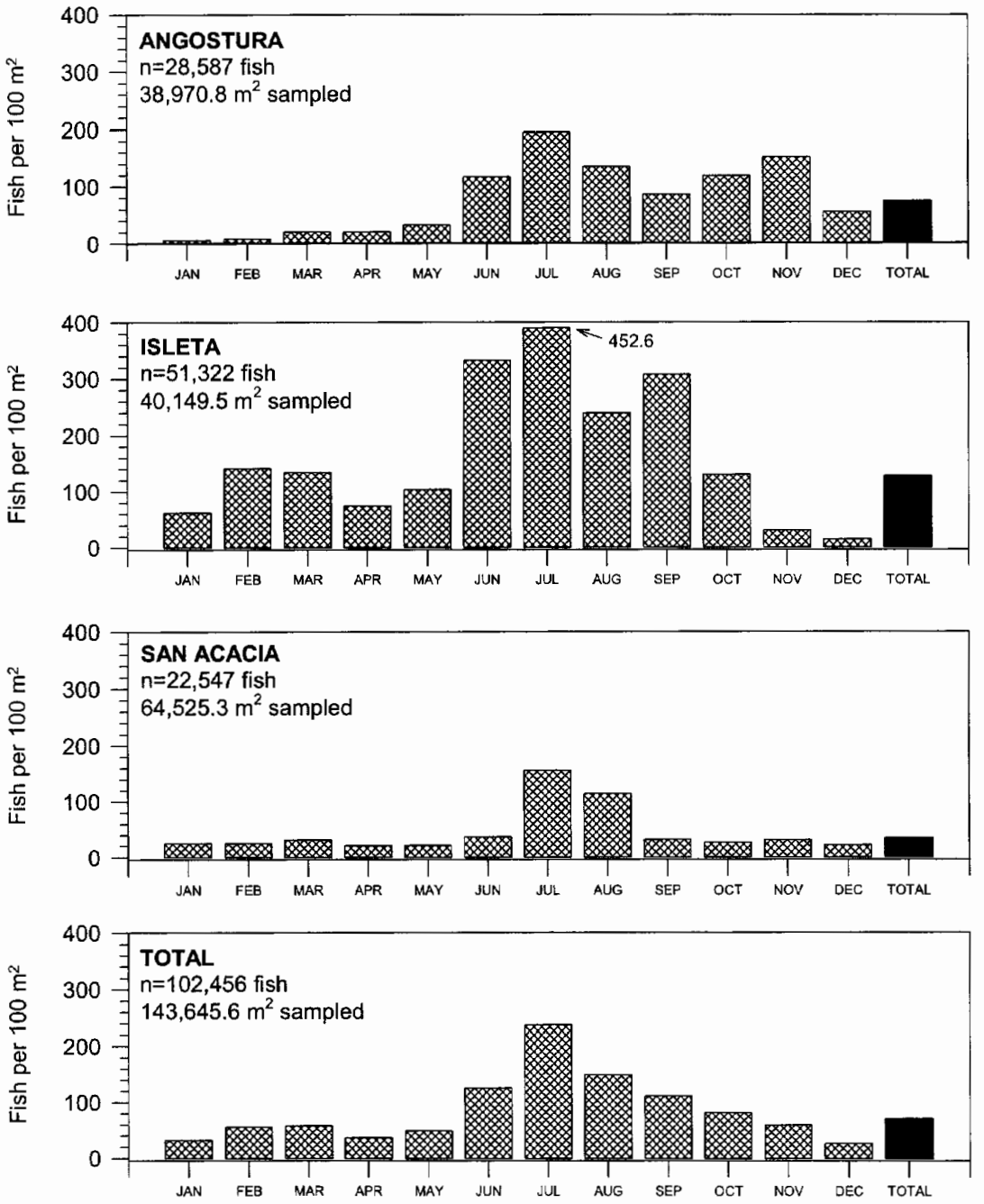

Figure 25. Fish catch rates (CPUE) by river reach for each sampling period in the Middle Rio Grande during 2003.

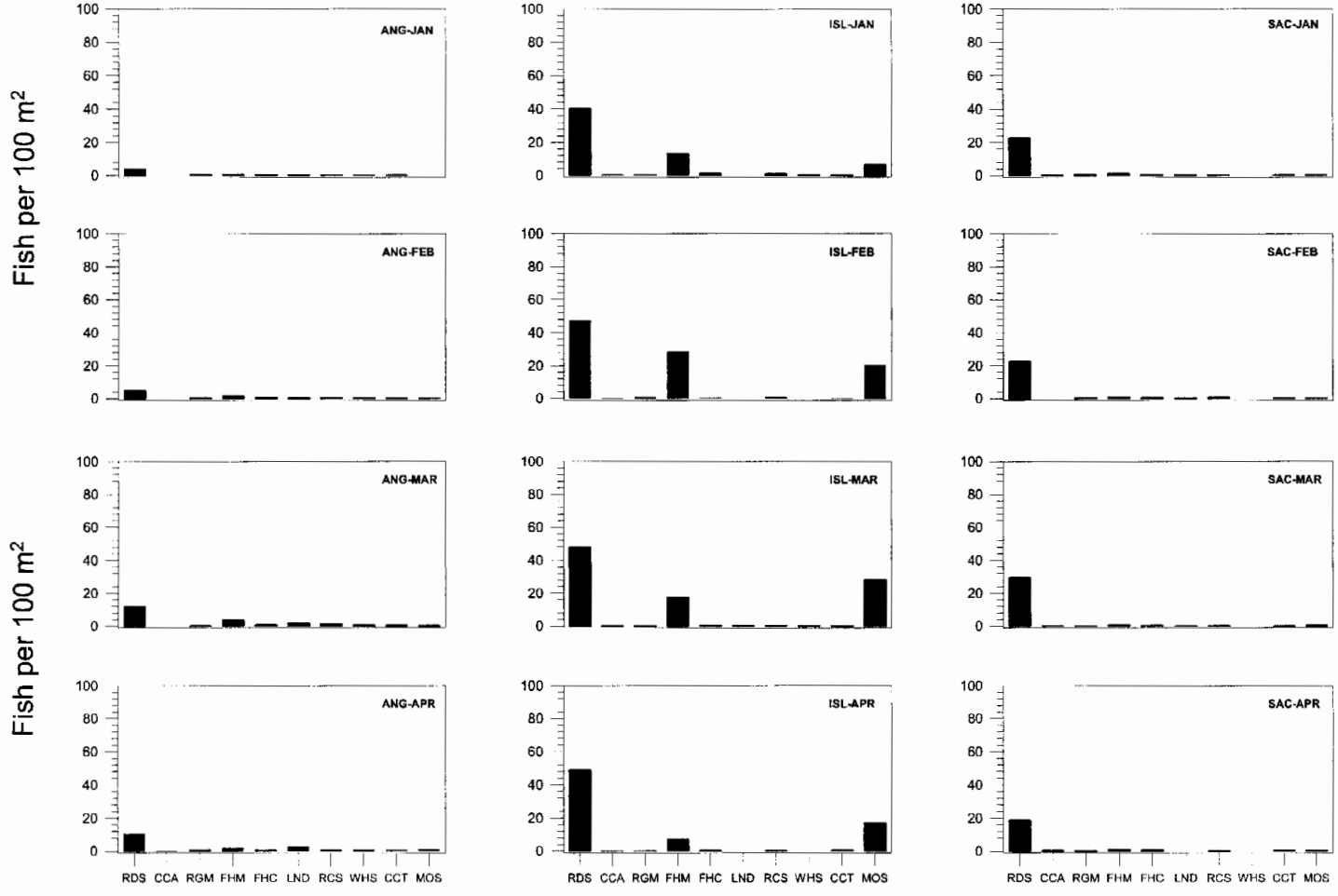

Figure 26. Fish catch rates (CPUE) by river reach from January-April 2003 for each focal species (see Table 1 for species codes) in the Middle Rio Grande (ANG=Angostura, ISL=Isleta, and SAC=San Acacia).

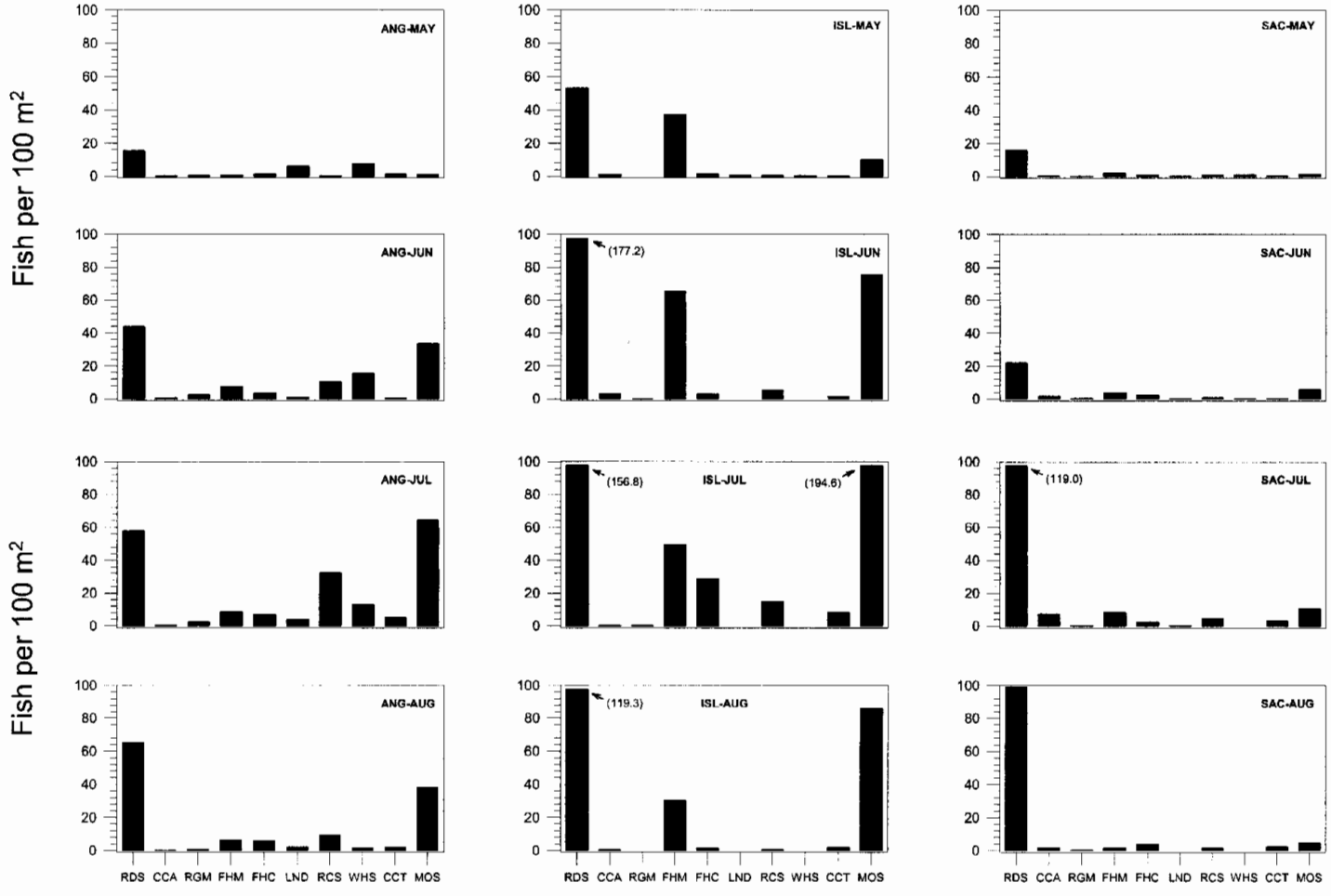

Figure 27. Fish catch rates (CPUE) by river reach from May-August 2003 for each focal species (see Table 1 for species codes) in the Middle Rio Grande (ANG=Angostura, ISL=Isleta, and SAC=San Acacia).

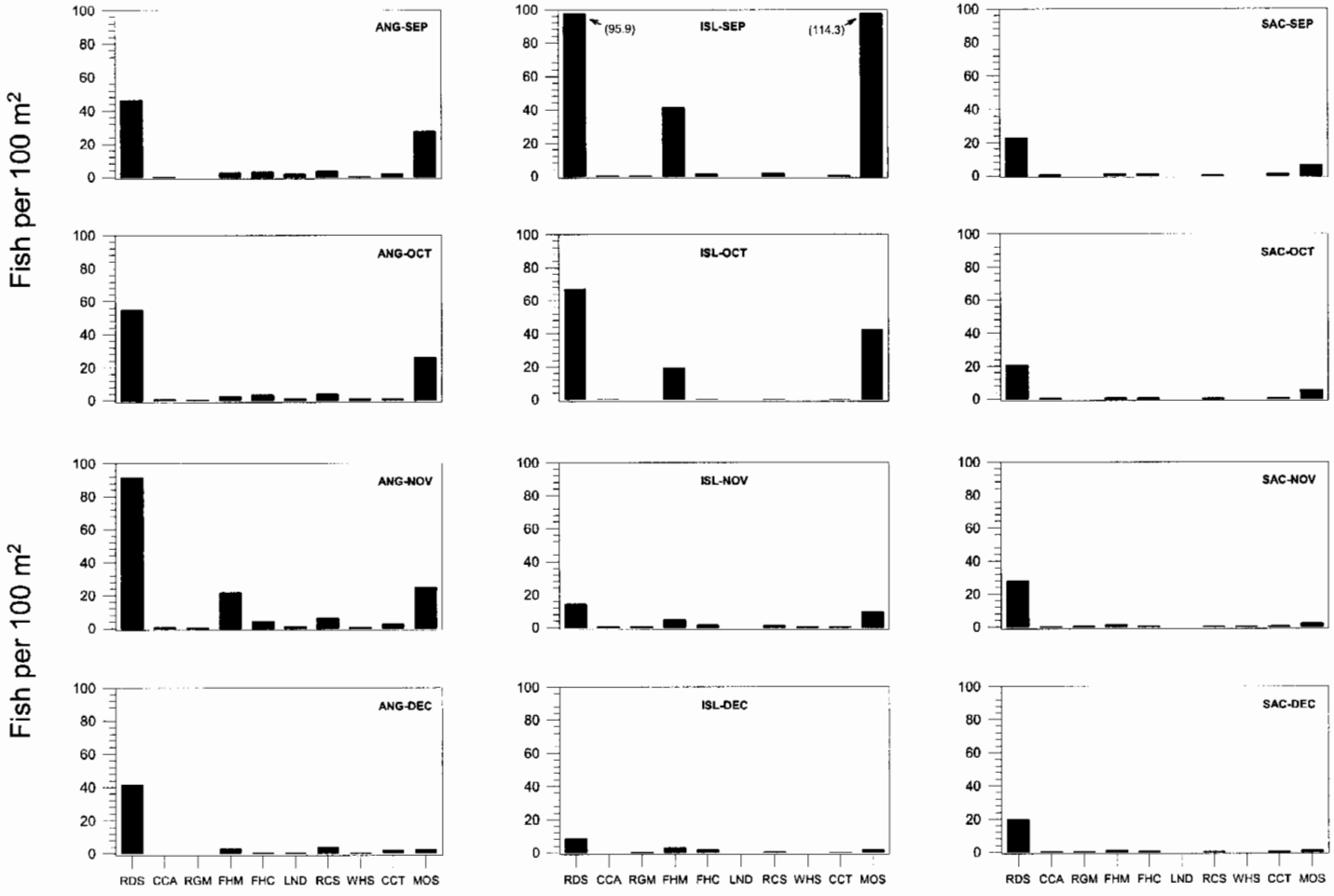

Figure 28. Fish catch rates (CPUE) by river reach from September-December 2003 for each focal species (see Table 1 for species codes) in the Middle Rio Grande (ANG=Angostura, ISL=Isleta, and SAC=San Acacia).

DISCUSSION

Long-term population monitoring data have been collected on the federally endangered Rio Grande silvery minnow since 1993. The unique value of this effort has been in providing consistent sampling of Middle Rio Grande ichthyofauna in a systematic fashion. Determining trends in short-lived fish populations is best accomplished by analyzing an extensive database of collections over time. A population monitoring sampling effort is, by default, designed so that an individual sample (or small number of samples) does not have a disproportionate effect on the results. It is not uncommon for a single sample to result in the collection of a relatively large number of Rio Grande silvery minnow. Selective samples taken for the purpose of collecting Rio Grande silvery minnow are not useful for identifying long-term population trends because methods are often inconsistent and sampling of specific habitats generates biased results. For these and other reasons, data generated from collecting efforts other than those of this comprehensive long-term population monitoring effort must be evaluated cautiously because few if any population comparisons would be valid.

Extended low-flow conditions throughout the Middle Rio Grande during 2003 were similar to conditions observed during 2002. However, a much larger portion of the Rio Grande between Isleta Diversion Dam and the southern terminus of the Bosque del Apache National Wildlife Refuge (NWR) was allowed to dry in 2003 compared with 2002. The waters of the Rio Grande were diverted from upstream portions of the Cochiti, Angostura, Isleta, and San Acacia reaches of the Middle Rio Grande. However, much of the flow had been diverted upstream of the Isleta Reach and the remainder was diverted at Isleta Diversion Dam. Extremely low flow conditions throughout the Isleta and San Acacia reaches resulted in extensive river drying and loss of aquatic life in this downstream section of the Middle Rio Grande. Low winter precipitation in combination with diversions of water during 2003 resulted in some of the lowest flows recorded in the Middle Rio Grande over the past decade. The lack of snowpack at high elevations in the Rio Grande Basin produced a spring runoff pattern that resembled hydrologic conditions more commonly observed during summer low flow periods. Extended periods of river drying over a broad geographic range occurred in the Middle Rio Grande from late spring through early autumn. The areas that most frequently dried during 2003 were sections of the river from Isleta Diversion Dam downstream to La Joya, NM and from near Escondida, NM downstream to the southern terminus of Bosque del Apache NWR. During periods of low flow, the lower section of the San Acacia Reach of the Rio Grande (downstream of Bosque del Apache NWR) was entirely supplemented by water pumped from the Low Flow Conveyance Channel into the Rio Grande. This strategy prevented river drying but flow in this section of the Rio Grande remained very low throughout the summer.

The annual reproductive effort of Rio Grande silvery minnow normally occurs during spring and is initiated, in part, by a large-scale increase in stream discharge associated with high-mountain snowmelt. The reproductive strategy of this species results in the production of relatively large numbers of eggs that released into the water column and dispersed downstream. Spring runoff, combined with increasing water temperatures, was likely the historical source of this reproductive stimulus. During years of sufficient snowpack, flow in the Middle Rio Grande peaked in late spring and resulted in several months of sustained flooded habitats. However, dams and reservoirs now moderate the magnitude, amplitude, and duration of spring discharge. Water diverted from the river for agricultural purposes can substantially reduce the total volume of water that would normally have flowed in the Rio Grande. This problem is further compounded in drought years when proportionally larger volumes of water are removed from the Rio Grande in early spring, often drying sections of the river or absorbing peak flows that stimulate silvery minnow spawning.

A relatively small amount of water was released from Cochiti Dam during 14-16 May 2003 (peak mean daily discharge=1,420 cfs) with the intent of stimulating a spawning response by Rio Grande silvery minnow. The vast majority of Rio Grande silvery minnow eggs collected during May

2003 were a direct result of this artificial flow spike (Platania and Dudley, 2004). There was a lower spawning response by this species to increases in flow that occurred naturally subsequent to the May flow spike. It appears that the artificial spike was strong enough to stimulate reproduction by a considerable portion of the Rio Grande silvery minnow population. The magnitude of spawning was, however, considerably less than which occurred during 2002.

Despite the collection of Rio Grande silvery minnow eggs collected during 2003 near the southern terminus of this species range, this production of propagules ultimately failed to result in the recruitment of very many individuals into the 2003 year-class. Catch rates of this species increased briefly following spring spawning but subsequently declined following persistent low flows and drying that occurred throughout much of the remainder of 2003. By autumn of 2003, the catch rate of Rio Grande silvery minnow had declined to some of the lowest levels ever recorded in the Middle Rio Grande. The rapid and reduced abundance of young-of-year individuals was evident by September 2003. The abundance of Rio Grande silvery minnow remained low throughout the rest of 2003 and was lower than autumnal collections made in 2002.

The timing of the May 2003 flow spike was similar to a flow increase that would normally be expected at the onset of the spring runoff period. During years of normal Rio Grande Basin snowpack, runoff would begin in May and last for an extended period (weeks) in contrast to the artificial spike which lasted for about four days. Flow in the river had returned to extremely low levels within a week of the brief period of elevated discharge induced by the artificial spike. In addition to multiple post-May river drying events that resulted in losses of all age-classes of Rio Grande silvery minnow, periods of extended low flow probably decreased the likelihood of successful recruitment of young-of-year individuals. The spawned eggs and subsequent larvae that were produced as a result of this flow event were subjected to biotic and physical conditions that may have precluded their successful growth and survivorship. Excessively elevated water temperatures (>30°C) in the Rio Grande, caused by warm ambient conditions and low flows, may have reduced the hatching success of newly spawned eggs and survival of larvae. In addition to high water temperatures and possibly poor water quality, the likelihood of intra- and inter-specific interactions (e.g., predator-prey or competition) would be expected to increase during low flows as available aquatic habitat decreases. The collection of eggs in 2003 documented the spawning effort by Rio Grande silvery minnow but the survival of these propagules in the Isleta and San Acacia reaches appears to have been very low. Larger numbers of young-of-year were collected in the Angostura Reach, than either Isleta or San Acacia reaches, but similar patterns of decline as noted in the other reaches were observed through the late summer and autumn.

Comparison of Rio Grande silvery minnow mean October catch rates (1993-1997, 1999-2003) to hydraulic variables measured at two Middle Rio Grande gauges revealed some striking relationships. Peak discharge and duration of high flows during the spawning season (May-June) were significantly positively correlated with Rio Grande silvery minnow mean October catch rates. In contrast, extended low flow periods were negatively correlated with Rio Grande silvery minnow mean October catch rates. The physical conditions produced by prolonged and elevated flows may result in overbank flooding of vegetated areas, formation of inundated habitats within the river channel, and creation of shoreline and island backwaters. Low water velocities with variable depths frequently typify these habitat conditions. Overbank and other flooded habitats are well known to be essential for the successful recruitment of early life history stages of freshwater fishes throughout the world (for review see Welcomme, 1979). It is quite likely that similar processes are important for the successful survival and recruitment of the Middle Rio Grande ichthyofaunal community, including Rio Grande silvery minnow.

An ongoing factor in the decline of Rio Grande silvery minnow is the fragmentation of its range and longitudinal displacement of its propagules (drifting eggs and larvae) below instream barriers (i.e., Angostura, Isleta, and San Acacia diversion dams). These channel-wide structures do not preclude downstream passage of fish or their reproductive products but do prevent fish

movement upstream of the diversion dam structures. Considerable upstream movement of this species (>25 km) was recently verified in marked hatchery reared individuals (Platania, et al., 2002) providing further validation of the negative impact these structures have on Rio Grande silvery minnow populations.

Given the reproductive ecology of this species, reach lengths, and diversion dam placement, the sequential decline and loss of this species from upstream to downstream was predicted (Platania and Altenbach, 1998). Fragmentation of this species' range in the Middle Rio Grande due to Angostura, Isleta, and San Acacia diversion dams has been identified as an issue of paramount importance that requires resolution for recovery of Rio Grande silvery minnow (U. S. Fish and Wildlife Service, 1999).

The Isleta Reach is an intermediate reach, not only in geographic position but also in regards to flow. This reach does not maintain the volume or consistency of discharge as the Angostura Reach but, because of the numerous points of irrigation returns, has an increased likelihood of maintaining some continuous flow compared to the San Acacia Reach. Issues regarding range fragmentation and downstream transport of silvery minnow propagules in the Angostura Reach are equally as important in the Isleta Reach. Declines in the Rio Grande silvery minnow population in the Angostura Reach will result in fewer eggs and larvae being transported into the Isleta Reach and thereby negatively affect population levels in the latter reach. Likewise, fewer individuals in the Isleta and Angostura reaches will translate to a lower Rio Grande silvery minnow population level in the San Acacia Reach.

The barrier to upstream movement imposed by San Acacia Diversion Dam in combination with the downstream transport of silvery minnow eggs and larvae (especially those produced in the San Acacia Reach) into Elephant Butte Reservoir continue to adversely impact the San Acacia Reach population of this species. The effects of these problems are synergistic and become especially critical during periods when the population level of this species is extremely low, as in 2003. Efforts to maintain increased and variable flow throughout the Middle Rio Grande in 2003 is essential as substantial losses of Rio Grande silvery minnow from the San Acacia Reach could potentially lead to the extirpation of this species from the wild.

The cumulative effects of several consecutive years of river drying, downstream displacement, and habitat degradation continue to be manifested in the decline of Rio Grande silvery minnow. The marked and alarming declines in abundance of Rio Grande silvery minnow recorded in 2003 during this population monitoring study provide the strongest evidence that the problems that led to the precipitous decline of this species have not been remedied. A renewed focus on issues that directly affect the immediate survival of this species in the wild is essential. Removal of instream barriers that prevent Rio Grande silvery minnow from repopulating upstream reaches, the need to maintain increased and variable flow throughout downstream reaches, and restoration and reconnection of the historical floodplain are paramount issues that need to be resolved to assure the continued persistence of this species.

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Appendix A.
2003 Collection localities and
monthly fish catch rates by collection locality for each focal species

Table A-1. Collection localities for 2003 population monitoring of Rio Grande silvery minnow.

Site #	Site Locality
	ANGOSTURA REACH SITES
0	New Mexico, Sandoval County, Rio Grande, directly below Angostura Diversion Dam, Algodones. River Mile 209.7 SAN FELIPE PUEBLO QUADRANGLE UTM Easting: 363811 UTM Northing: 3916006 Zone: 13
1	New Mexico, Sandoval County, Rio Grande, at NM State Highway 44 bridge crossing, Bernalillo. River Mile 203.8 BERNALILLO QUADRANGLE UTM Easting: 358543 UTM Northing: 3909722 Zone: 13
2	New Mexico, Sandoval County, Rio Grande, ca. 4.0 miles downstream of NM State Highway 44 bridge crossing, at Rio Rancho Wastewater Treatment Plant, Rio Rancho. River Mile 200.0 BERNALILLO QUADRANGLE UTM Easting: 354772 UTM Northing: 3905355 Zone: 13
3	New Mexico, Bernalillo County, Rio Grande, at Central Avenue bridge crossing (US Highway 66), Albuquerque. River Mile 183.4 ALBUQUERQUE WEST QUADRANGLE UTM Easting: 346840 UTM Northing: 3884094 Zone: 13
4	New Mexico, Bernalillo County, Rio Grande, at Rio Bravo Boulevard bridge crossing, (NM State Highway 500), Albuquerque. River Mile 178.3 ALBUQUERQUE WEST QUADRANGLE UTM Easting: 347554 UTM Northing: 3877163 Zone: 13
	ISLETA REACH SITES
5	New Mexico, Valencia County, Rio Grande at Los Lunas bridge crossing (NM State Highway 49), Los Lunas. River Mile 161.4 LOS LUNAS QUADRANGLE UTM Easting: 342898 UTM Northing: 3852531 Zone: 13
6	New Mexico, Valencia County, Rio Grande, ca. 1.0 miles upstream of NM State Highway 309/6 bridge crossing, Belen. River Mile 151.5 TOME QUADRANGLE UTM Easting: 339972 UTM Northing: 3837061 Zone: 13
7	New Mexico, Valencia County, Rio Grande, ca. 2.2 miles upstream of NM State Highway 346 bridge crossing, Jarales. River Mile 143.2 VEGUITA QUADRANGLE UTM Easting: 338136 UTM Northing: 3827329 Zone: 13
8	New Mexico, Socorro County, Rio Grande, at US Highway 60 bridge crossing, Bernardo. River Mile 130.6 ABEYTAS QUADRANGLE UTM Easting: 334604 UTM Northing: 3809726 Zone: 13
9	New Mexico, Socorro County, Rio Grande, ca. 3.5 miles downstream of US Highway 60 bridge crossing, Bernardo. River Mile 127.0 ABEYTAS QUADRANGLE UTM Easting: 331094 UTM Northing: 3805229 Zone: 13

Table A-1. Collection localities for 2003 population monitoring of Rio Grande silvery minnow (continued).

Site #	Site Locality
	ISLETA REACH SITES (continued)
9.5	New Mexico, Socorro County, Rio Grande, ca. 0.6 miles upstream of San Acacia Diversion Dam, San Acacia River Mile 116.8LA JOYA QUADRANGLE UTM Easting: 327902 UTM Northing: 3792603 Zone: 13
	SAN ACACIA REACH SITES
10	New Mexico, Socorro County, Rio Grande, directly below San Acacia Diversion Dam, San Acacia. River Mile 116.2 SAN ACACIA QUADRANGLE UTM Easting: 326162 UTM Northing: 3791977 Zone: 13
11	New Mexico, Socorro County, Rio Grande, ca. 1.5 miles downstream of San Acacia Diversion Dam, San Acacia. River Mile 114.6 LEMITAR QUADRANGLE UTM Easting: 325263 UTM Northing: 3790442 Zone: 13
12	New Mexico, Socorro County, Rio Grande, east of Socorro, 0.5 miles upstream of the Socorro Low Flow Conveyance Channel bridge; east and upstream of Socorro Wastewater Treatment Plant, Socorro. River Mile 99.5 LOMA DE LAS CANAS QUADRANGLE UTM Easting: 327097 UTM Northing: 3771043 Zone: 13
13	New Mexico, Socorro County, Rio Grande, ca. 4.0 miles upstream of US Highway 380 bridge crossing. River Mile 91.7 SAN ANTONIO QUADRANGLE UTM Easting: 328140 UTM Northing: 3761283 Zone: 13
14	New Mexico, Socorro County, Rio Grande, at US Highway 380 bridge crossing, San Antonio. River Mile 87.1 SAN ANTONIO QUADRANGLE UTM Easting: 328914 UTM Northing: 3754471 Zone: 13
15	New Mexico, Socorro County, Rio Grande, directly east of Bosque del Apache National Wildlife Refuge Headquarters. River Mile 79.1 SAN ANTONIO, SE QUADRANGLE UTM Easting: 327055 UTM Northing: 3740839 Zone: 13
16	New Mexico, Socorro County, Rio Grande, at San Marcial Railroad bridge crossing, San Marcial. River Mile 68.6 SAN MARCIAL QUADRANGLE UTM Easting: 315284 UTM Northing: 3728347 Zone: 13
17	New Mexico, Socorro County, Rio Grande, at its former confluence with the Low Flow Conveyance Channel; 16 miles downstream of the southern end of the Bosque del Apache National Wildlife Refuge; ca. 8 miles downstream of San Marcial Railroad bridge crossing. River Mile 60.5 PARAJE WELL QUADRANGLE UTM Easting: 309487 UTM Northing: 3718178 Zone: 13

Table A-1. Collection localities for 2003 population monitoring of Rio Grande silvery minnow (continued).

Site #	Site Locality
	SAN ACACIA REACH SITES
18	New Mexico, Socorro County, Rio Grande, ca. 19 miles downstream of the southern end of the Bosque del Apache National Wildlife Refuge. River Mile 57.7 PARAJE WELL QUADRANGLE UTM Easting: 307380 UTM Northing: 3714740 Zone: 13

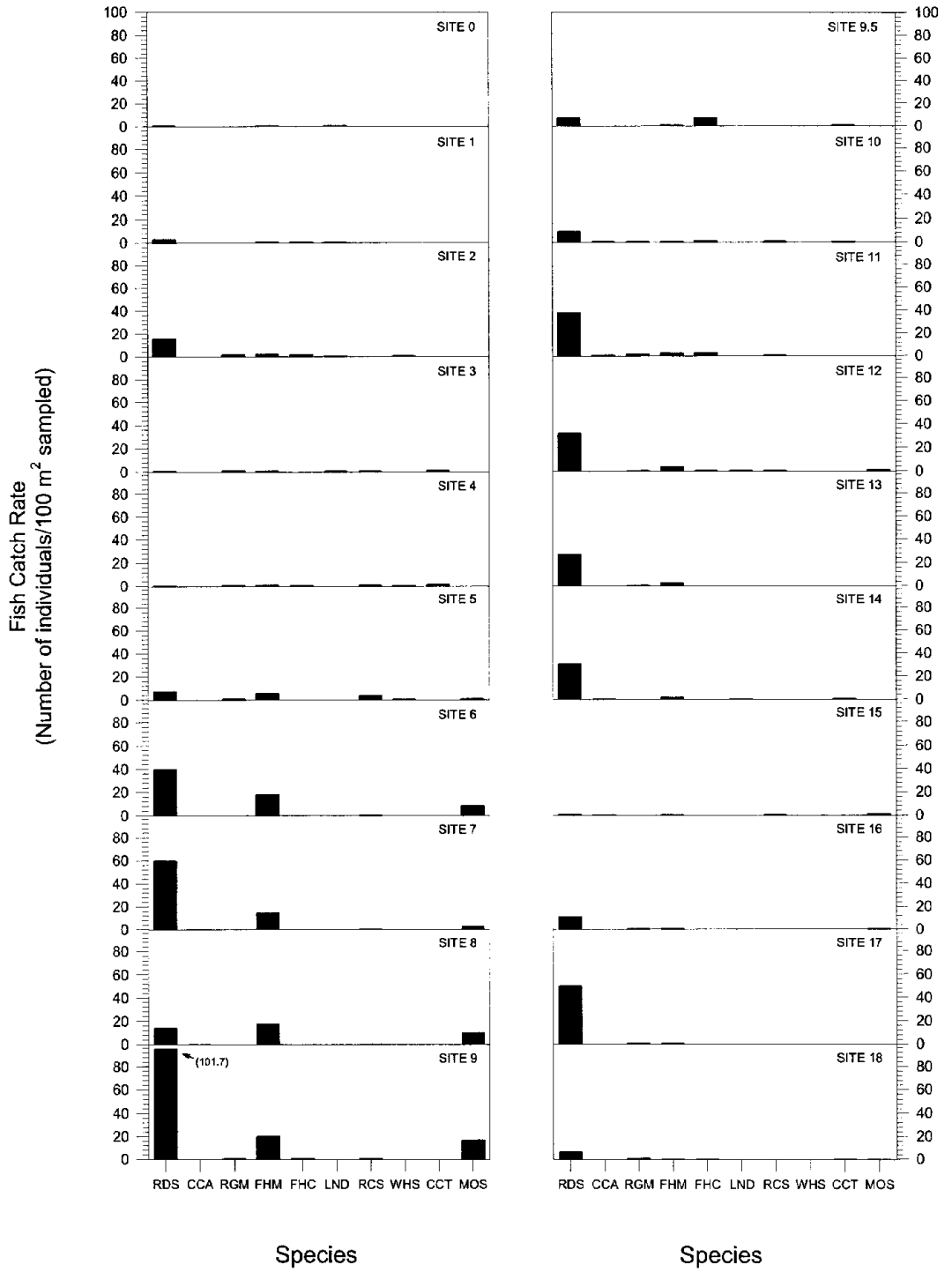


Figure A-1. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for January 2003.

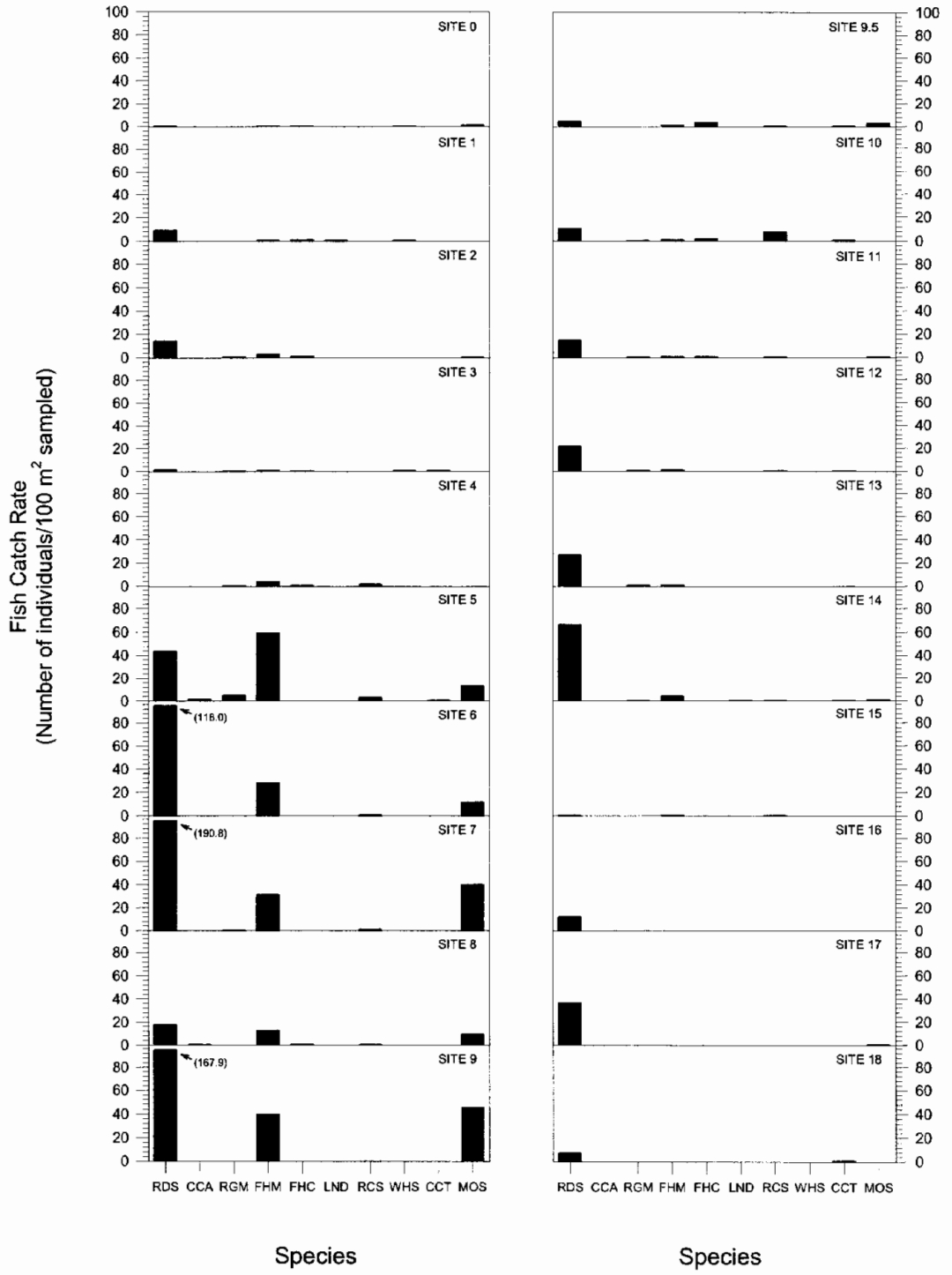


Figure A-2. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for February 2003.

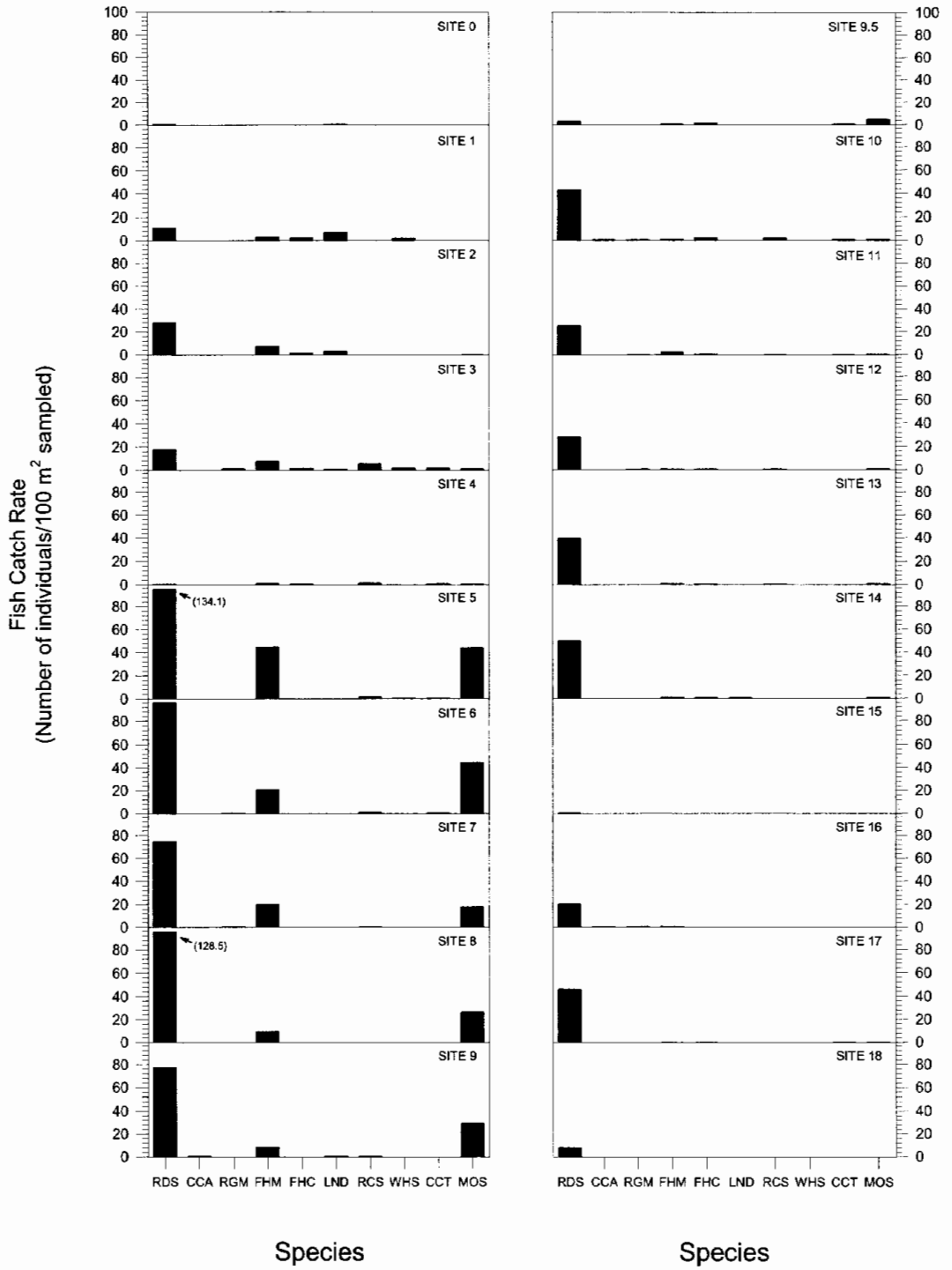


Figure A-3. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for March 2003.

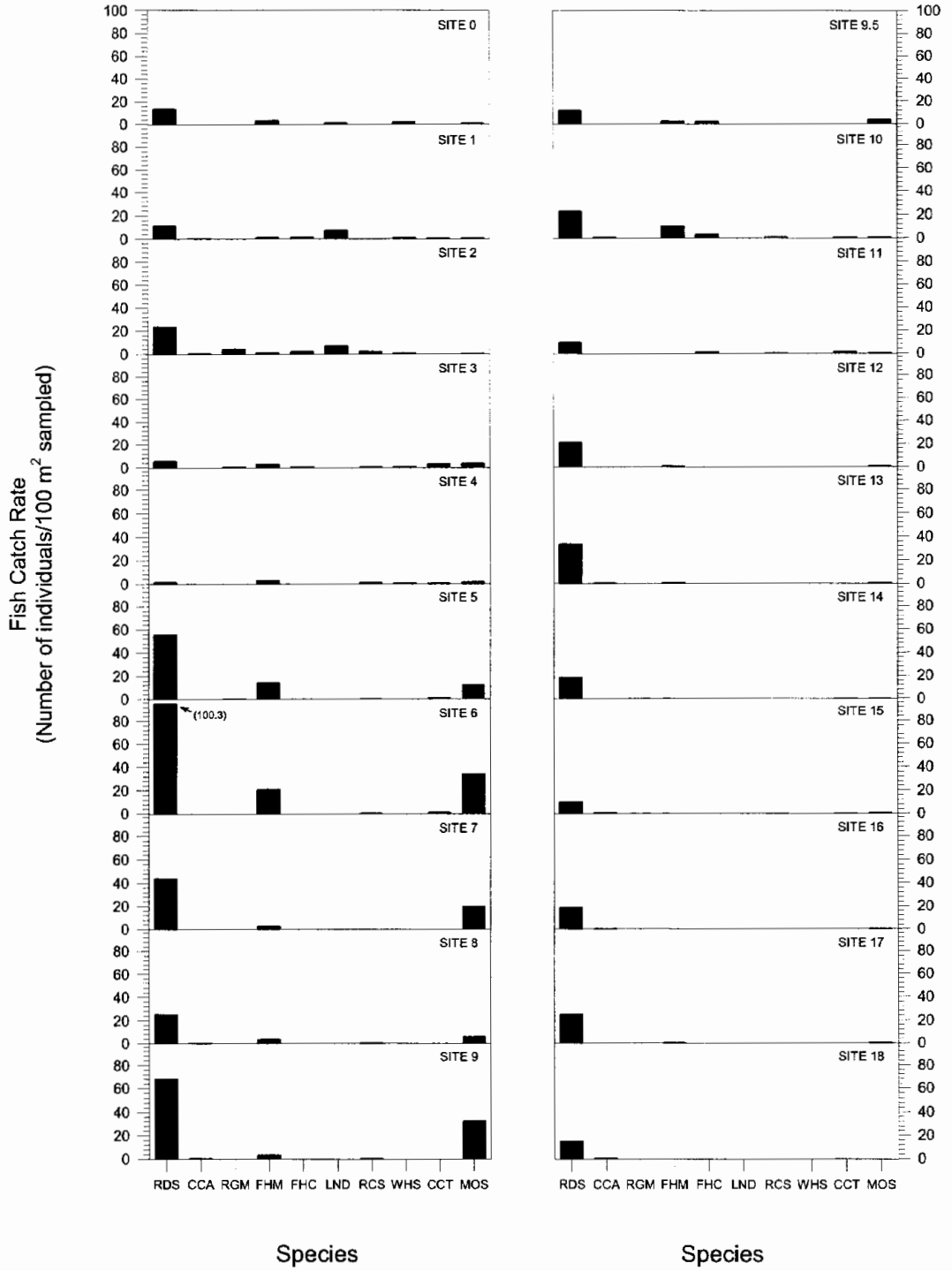


Figure A-4. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for April 2003.

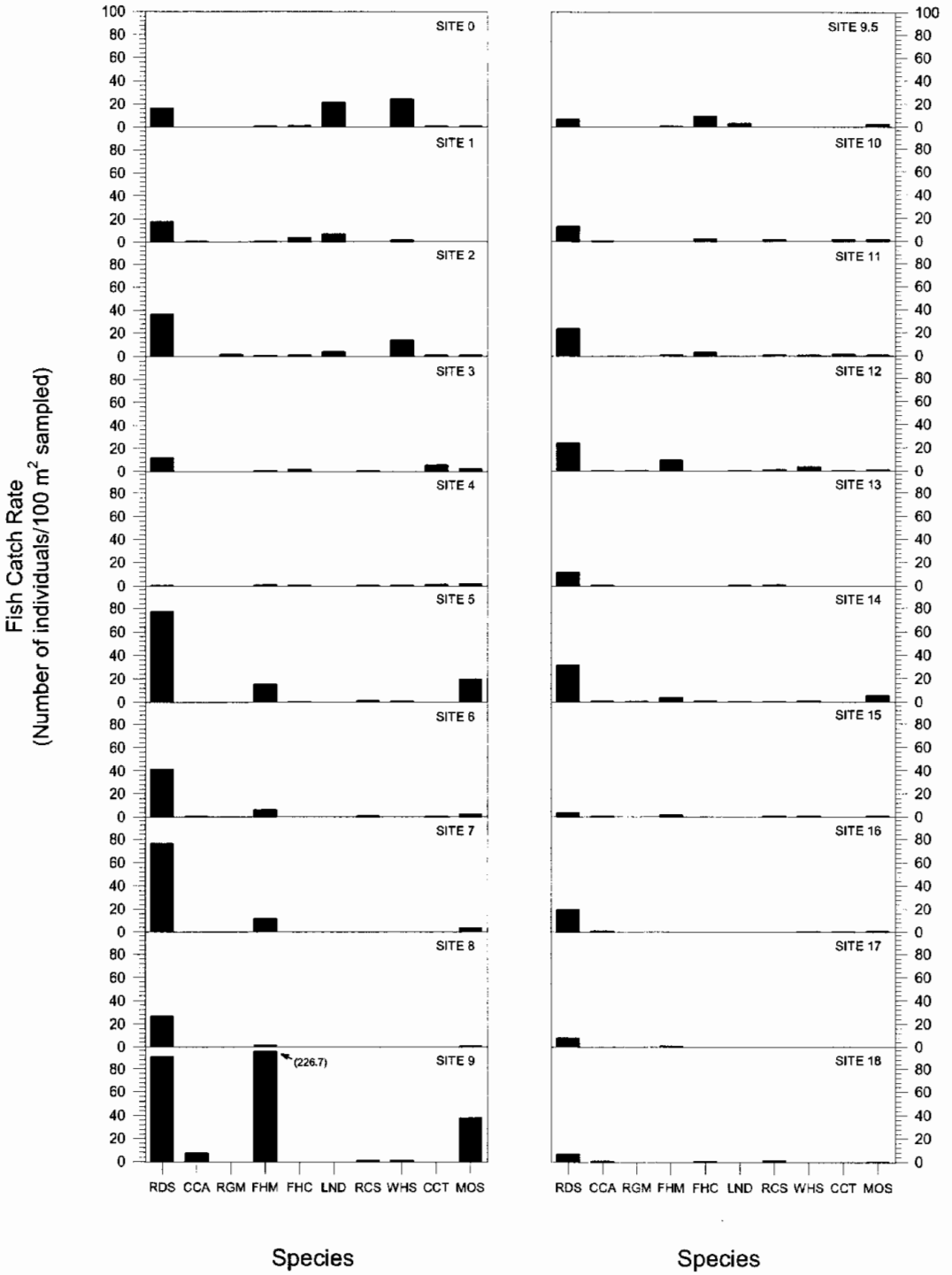


Figure A-5. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for May 2003.

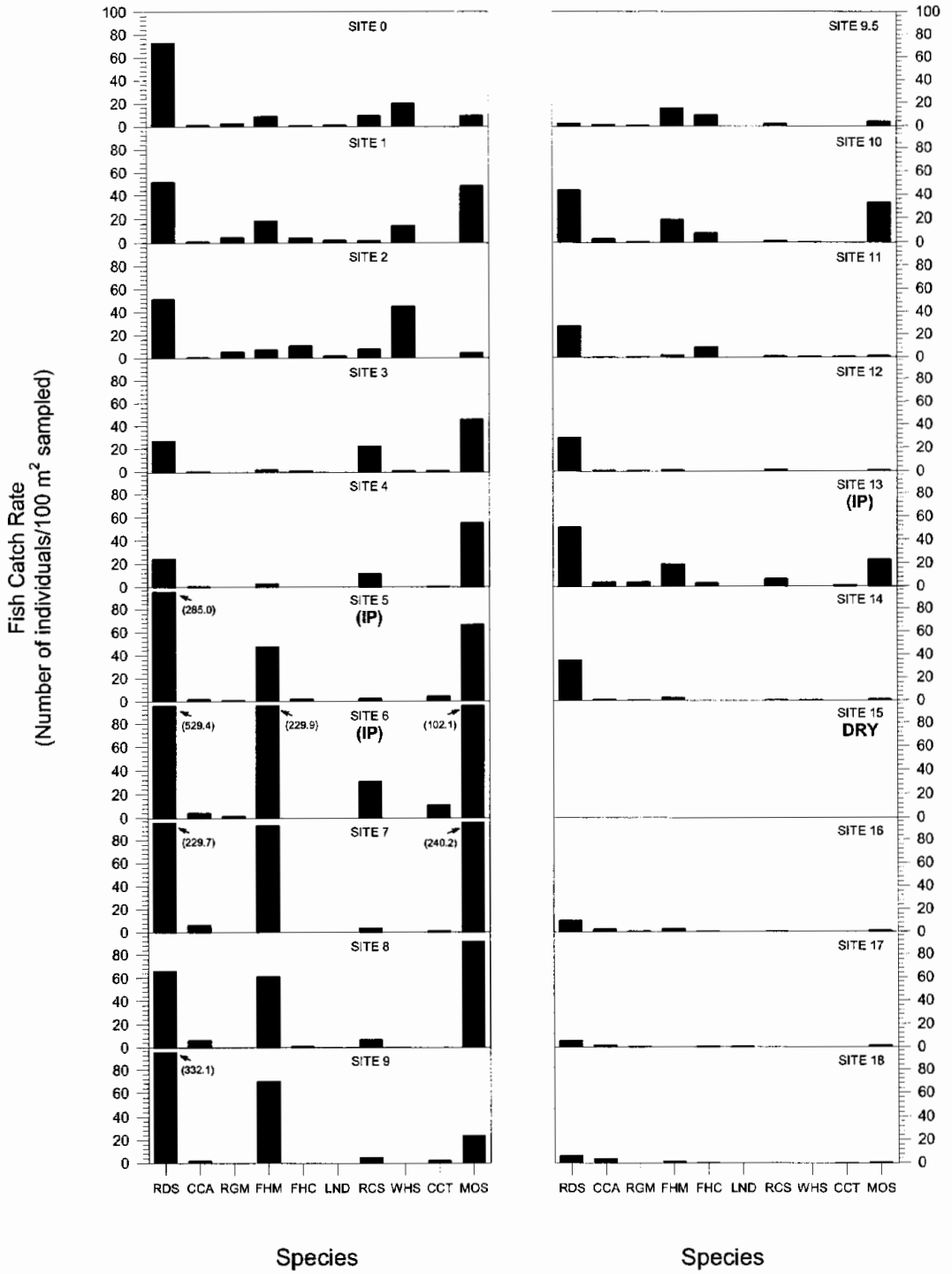


Figure A-6. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for June 2003. Sites where the river had dried (DRY) or where only isolated pools (IP) remained are indicated.

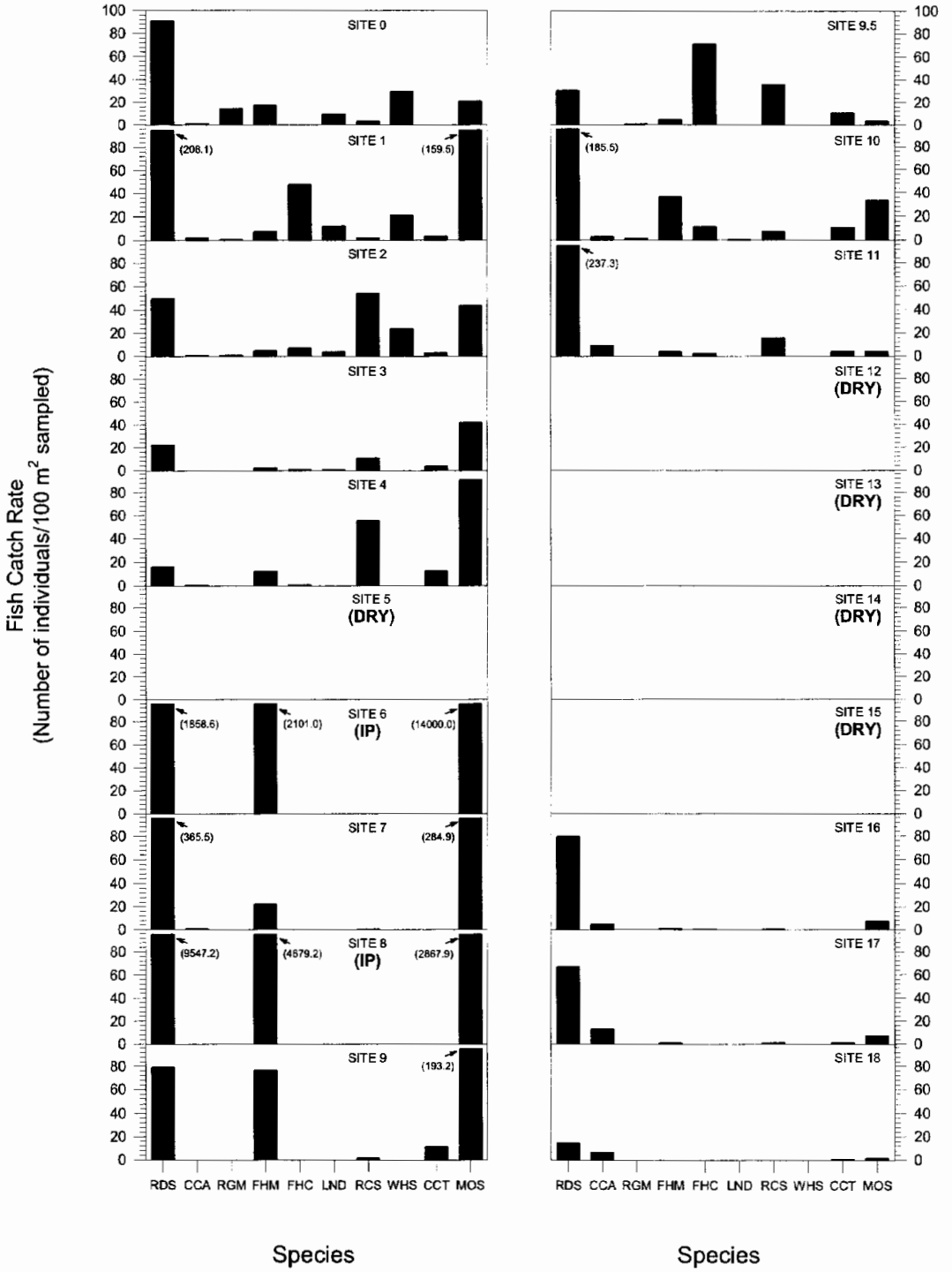


Figure A-7. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for July 2003. Sites where the river had dried (DRY) or where only isolated pools (IP) remained are indicated.

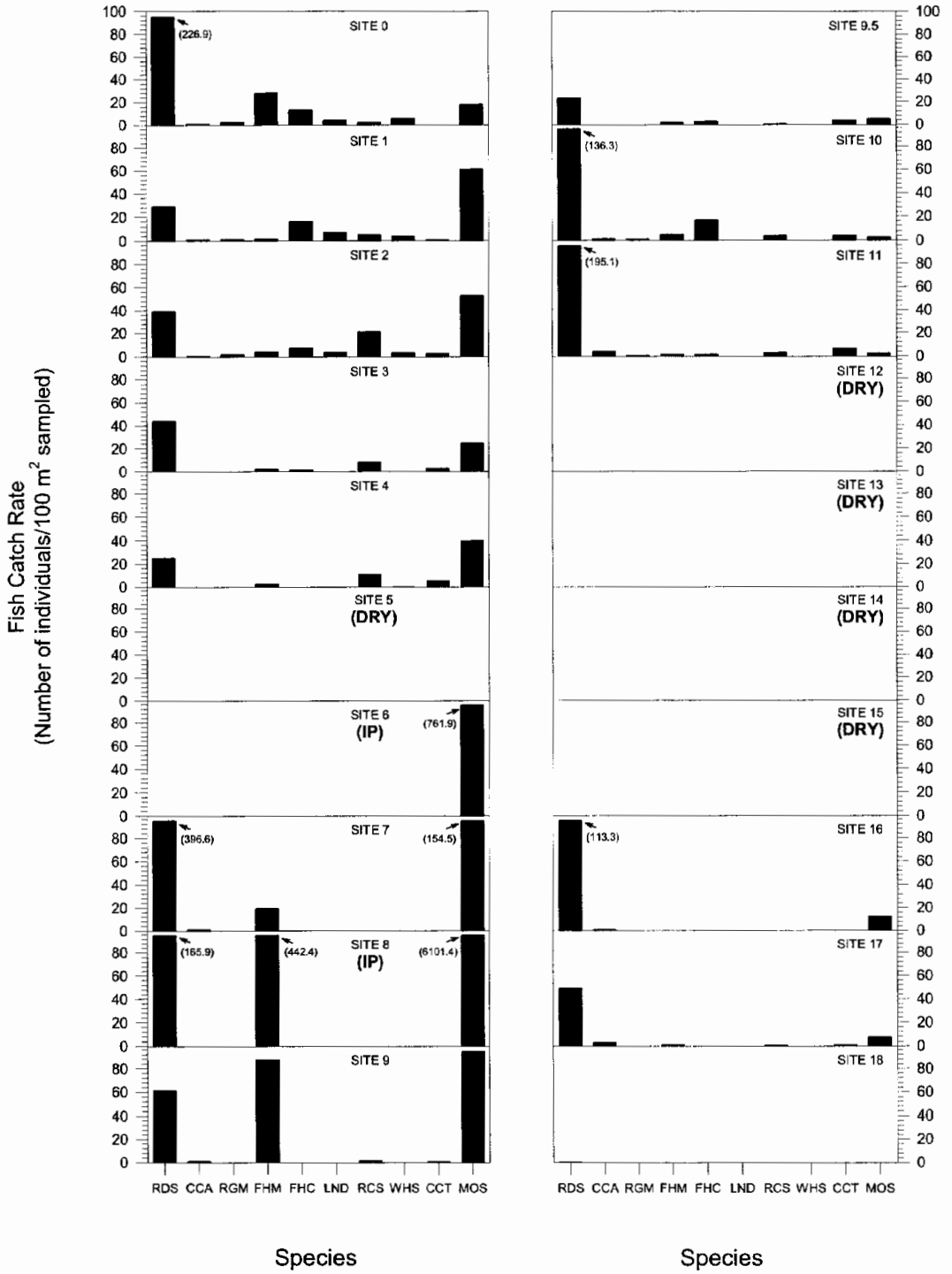


Figure A-8. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for August 2003. Sites where the river had dried (DRY) or where only isolated pools (IP) remained are indicated.

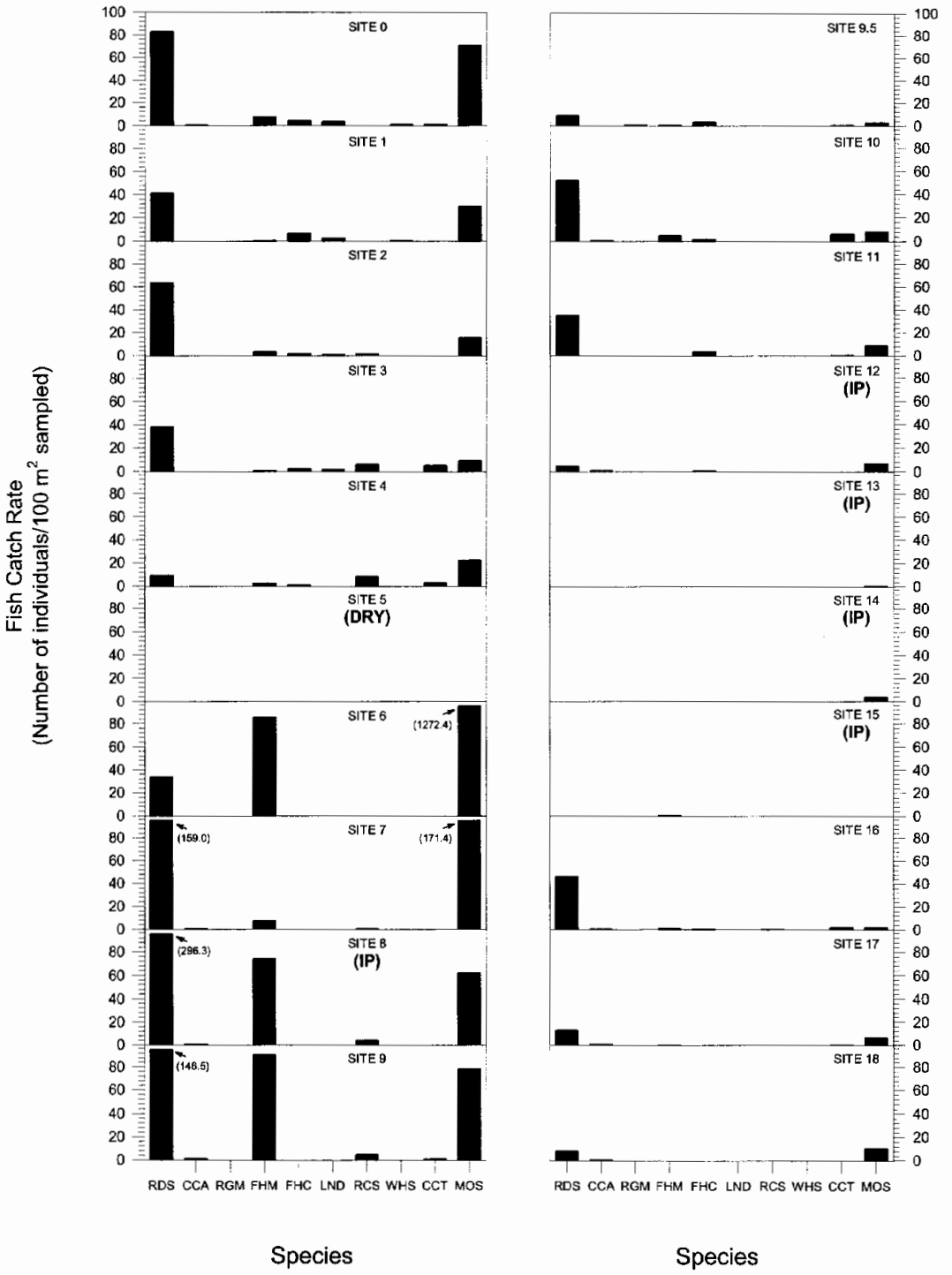


Figure A-9. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for September 2003. Sites where the river had dried (DRY) or where only isolated pools (IP) remained are indicated.

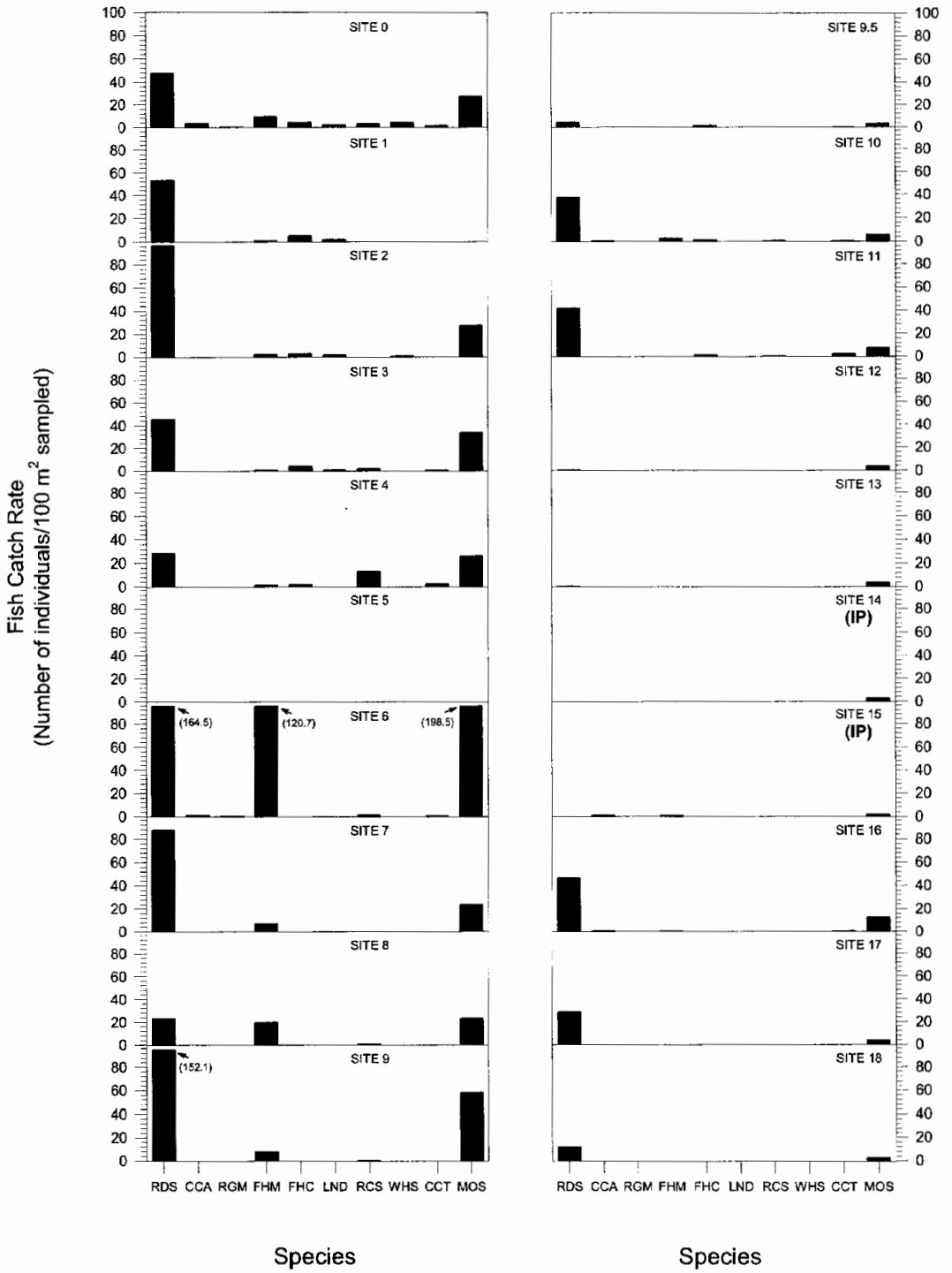


Figure A-10. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for October 2003. Sites where the river had been reduced to only isolated pools (IP) are indicated.

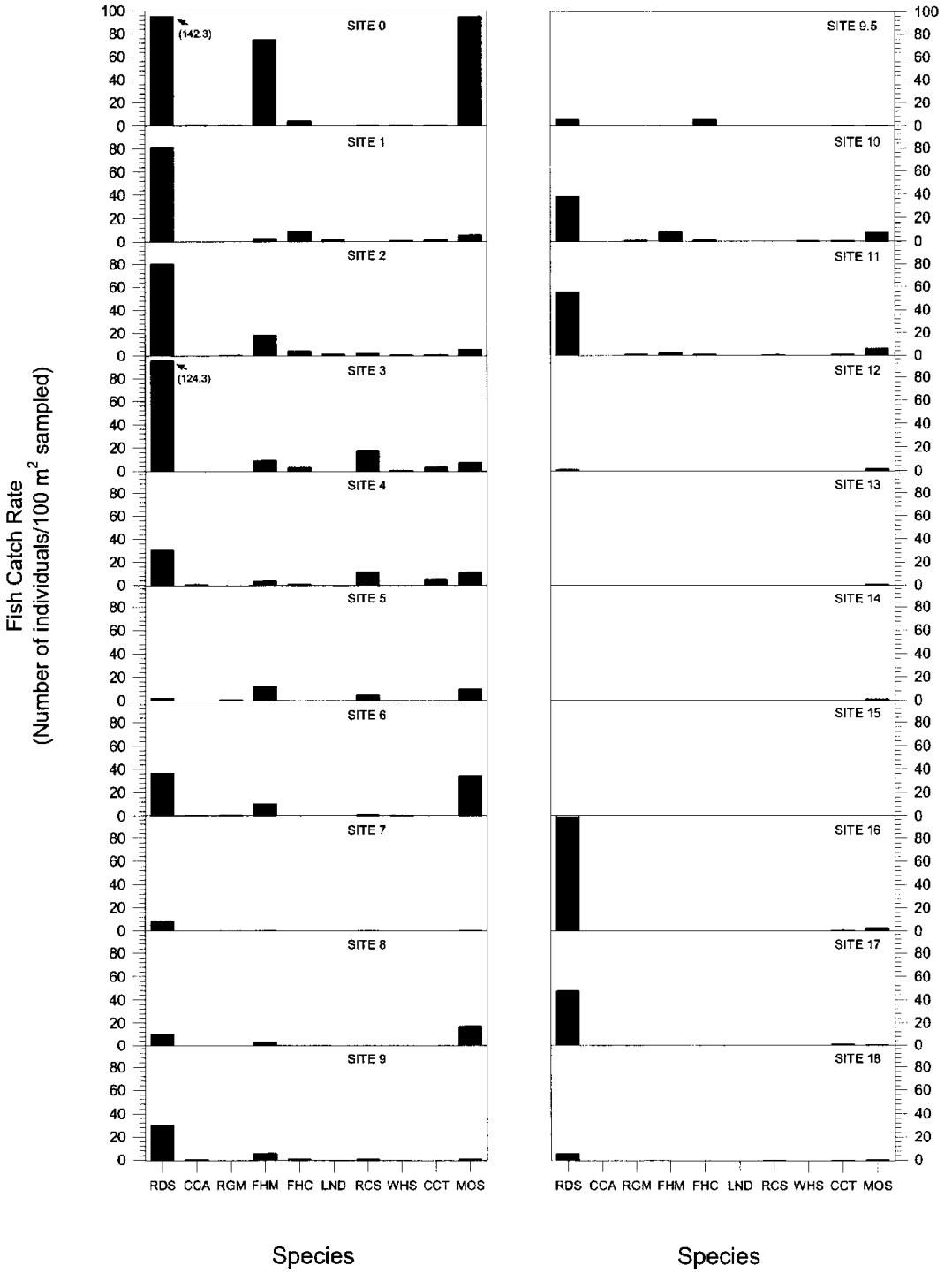


Figure A-11. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for November 2003. Histogram bar for Rio Grande silvery minnow (RGM) is black to highlight this species.

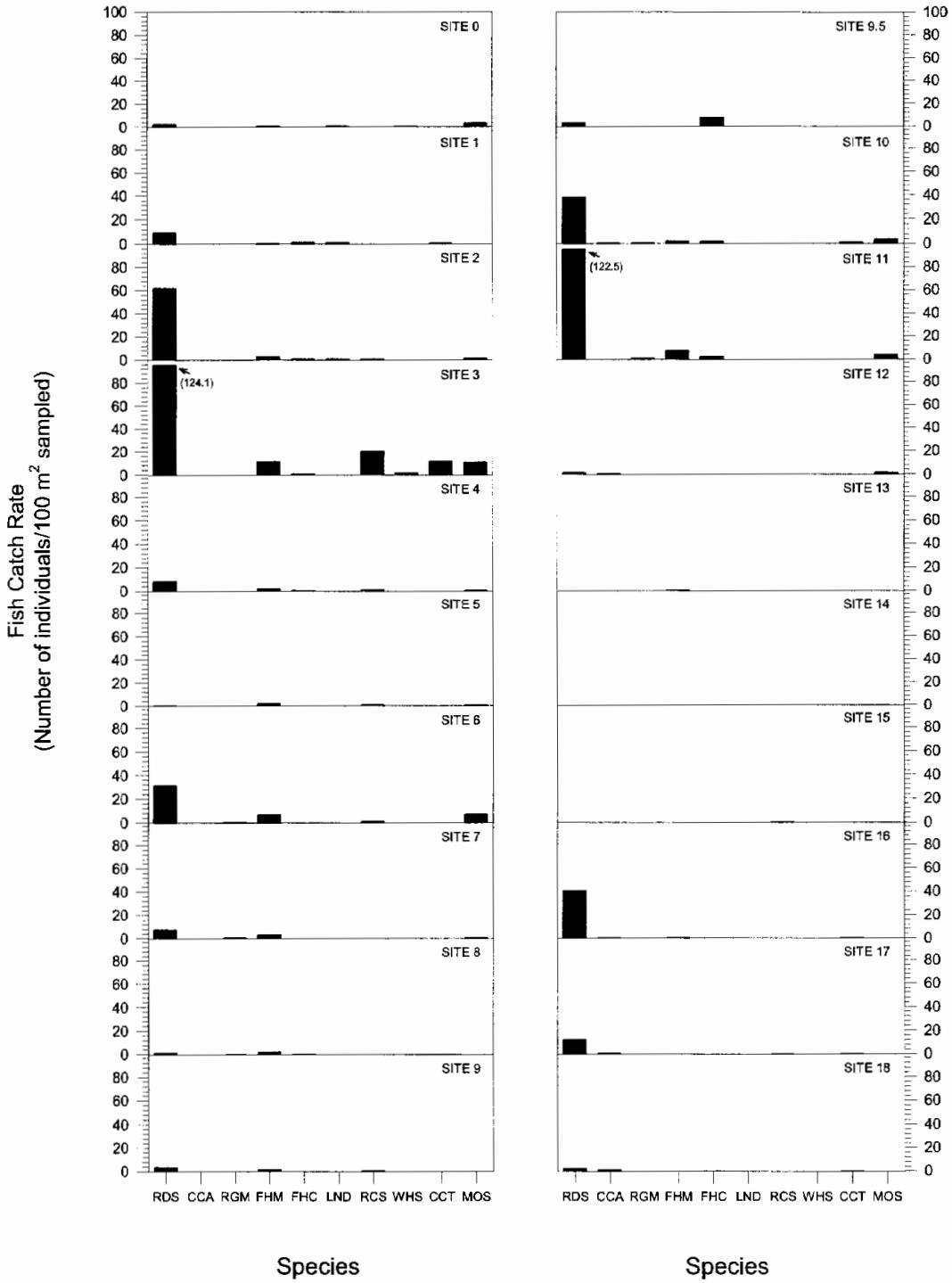


Figure A-12. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for December 2003. Histogram bar for Rio Grande silvery minnow (RGM) is black to highlight this species.

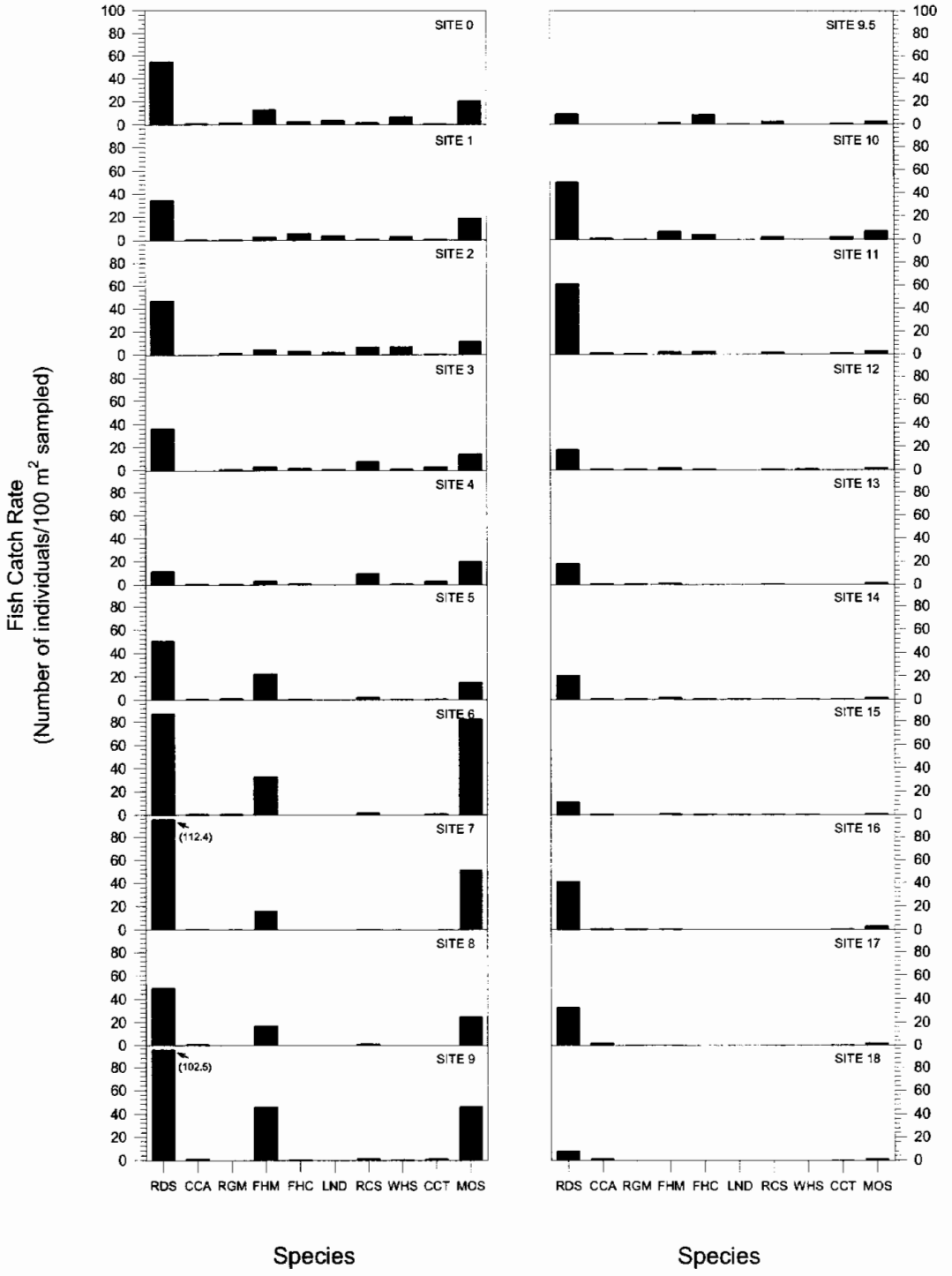


Figure A-13. Fish catch rates (CPUE) by collection locality for each focal species (see Table 1 for species codes) in the Middle Rio Grande for 2003. Histogram bar for Rio Grande silvery minnow (RGM) is black to highlight this species.

Appendix B.
Rio Grande silvery minnow population monitoring 2003

World-Wide-Web Cover Page

URL: http://www.usbr.gov/uc/albuq/envprog/rg/rgsm2003/index.html

Rio Grande Silvery Minnow Population Monitoring 2003

Monthly Fish Monitoring Data Reports:

- Most recent report: December

Spawning Periodicity Study (ended 30 June)

General Information about the Monitoring Sites

Site-Specific Information:

Angostura Reach

Angostura Dam
Bernalillo
Rio Rancho
Central Ave. Bridge
Rio Bravo Blvd.

Isleta Reach

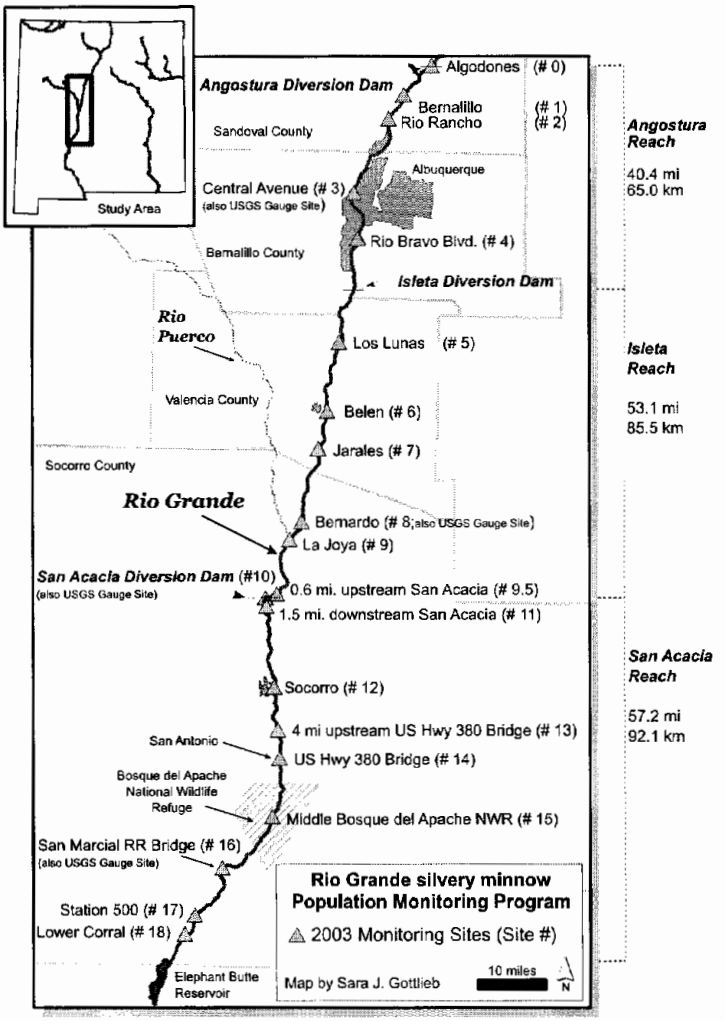
Los Lunas
Belen
Jarales
Bernardo
La Joya
0.6 mi upstream San Acacia

San Acacia Reach

San Acacia Dam
1.5 mi. downstream San Acacia
Socorro
4 mi. upstream 380 Bridge
380 Bridge
Middle Bosque del Apache
San Marcial
Station 500
Lower Corral

Data from previous project years:

2000 | 2001 | 2002



Appendix C.
Ichthyofaunal composition of the 2003
Rio Grande silvery minnow population monitoring collections [1]

Data are available at:
http://www.usbr.gov/uc/albuq/envprog/rg/rgsm2003

[1] The monthly 2003 fish collection data comprises about 100 pages and is not included in this hardcopy of the 2003 Rio Grande silvery minnow population monitoring report. It is, however, included in the electronic version of the report available at the above world-wide-web address.