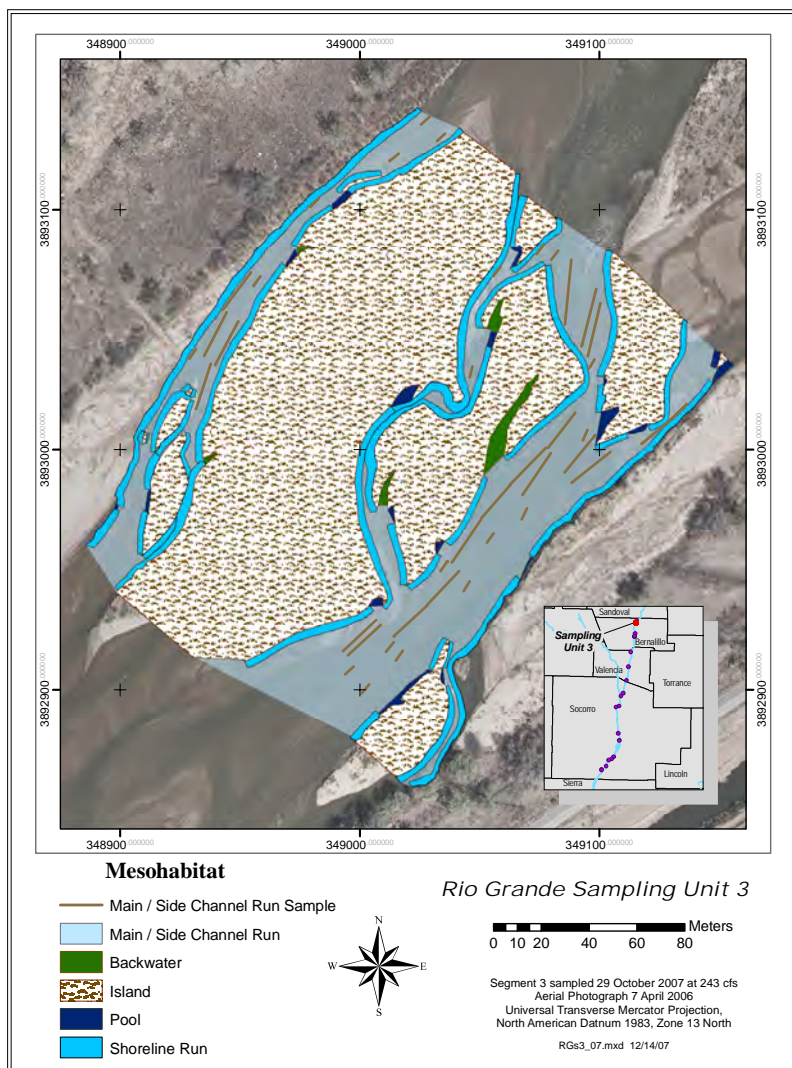


**RIO GRANDE SILVERY MINNOW POPULATION ESTIMATION
PROGRAM RESULTS FROM OCTOBER 2007**

FINAL

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



Robert K. Dudley¹, Gary C. White², Steven P. Platania¹, and Donald A. Helfrich¹

¹ American Southwest Ichthyological Researchers, L.L.C.
800 Encino Place NE; Albuquerque, NM 87102-2606

&

² Department of Fish, Wildlife, and Conservation Biology
136 Wagar, Colorado State University; Fort Collins, CO 80523-1474

8 August 2008

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Prepared by:

Robert K. Dudley¹, Gary C. White², Steven P. Platania¹, and Donald A. Helfrich¹

¹ American Southwest Ichthyological Researchers, L.L.C.
800 Encino Place NE; Albuquerque, NM 87102-2606
&

² Department of Fish, Wildlife, and Conservation Biology
136 Wagar, Colorado State University; Fort Collins, CO 80523-1474

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125 South State Street, Room 6107
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PREFACE

The Rio Grande silvery minnow Population Estimation Program was designed to develop, refine, test, and implement methods that could be used to generate statistically rigorous population estimates for that species in the Middle Rio Grande, New Mexico. The second of three years of fieldwork for this MRGESACP project was initiated in autumn 2007, with the third years' effort scheduled for autumn 2008. The sampling methods employed in 2007 were developed based on almost 15 years of Rio Grande silvery minnow population monitoring but modified based on what was learned from the first year of study (2006).

Given that the sampling and analytical aspects of this project were expected to evolve over time, the 2007 results presented in this report are preliminary and subject to revision as methodologies and analyses are refined. While the statistical methods employed to generate the 2007 Rio Grande silvery minnow population numbers contained herein are statistically defensible, determination of the relationship between the number of fish taken through sampling efforts versus the number of fish present at any given site is the most difficult aspect of this project. Thus, the population estimates presented in this report are preliminary and could be subject to notable revision in the future. The reader is cautioned that the numbers contained herein are of little importance in and of themselves and will be best evaluated in relation to all of the 2006-2008 results.

EXECUTIVE SUMMARY

Systematic monitoring of Rio Grande silvery minnow, *Hybognathus amarus*, and the associated Middle Rio Grande fish community has been conducted since 1993 and has provided relevant, quantifiable, and timely information regarding the status of this species both spatially and temporally. In contrast to the Population Monitoring Program, which continues to provide necessary year-round documentation of trends for the entire ichthyofaunal community, the Population Estimation Program provides a rigorous yearly estimate of the Rio Grande silvery minnow population during a single time-period (October). Estimating population size required employing statistical techniques that were subject to a series of assumptions. Estimates of the number of Rio Grande silvery minnow are presented within the context of those assumptions, especially given the inherent variation in the density and distribution of organisms within their environment.

Data collected during the 2007 Population Estimation Program indicated that the ichthyofaunal community in the Middle Rio Grande between Angostura Diversion Dam and Elephant Butte Reservoir was numerically dominated by cyprinids and included eight native fish species. Red shiner was the most abundant native species collected (N = 18,826), followed by Rio Grande silvery minnow (N = 3,122), flathead chub (N = 852), and river carpsucker (N = 429). The highest densities of Rio Grande silvery minnow were recorded in the Angostura and Isleta reaches.

While mean densities of Rio Grande silvery minnow were consistently higher in closed run habitats than in open run habitats (even after correcting for capture probability), there were no consistent patterns documented between open and closed samples in non-run mesohabitats. For all sampling units combined, the open run sampling method yielded a lower density of Rio Grande silvery minnow (N = 284, mean density = 1.60/100m², SD = 5.23) than did the closed run sampling method (N = 276, mean density = 6.80/100m², SD = 21.74). Of the 12 comparisons between mesohabitat patches that yielded estimates of >5 individuals total, five were non-significant, four had a significantly higher estimate for the closed habitats, and three had a significantly higher estimate for the open habitats.

Estimates of capture probability for hatchery Rio Grande silvery minnow were higher for all mesohabitats compared to wild Rio Grande silvery minnow. The largest significant difference in capture probability between hatchery and wild fish (0.7417 and 0.2412, respectively) was for backwater mesohabitat. The other significant difference was for pool mesohabitat (hatchery = 0.8585 and wild = 0.6878). While capture probabilities in both shoreline pools and runs were slightly higher for hatchery fish than for wild fish, neither of these comparisons was significantly different.

Problems were encountered with stocked fish schooling into the corners of the block nets that were set in areas with any water velocity (even after the acclimation period). This precluded making an accurate estimation of population size for habitats where there was flow. The only area where this did not occur was in a backwater where there was no perceptible water velocity. The population estimate for this habitat was 194.1469 (SE = 0.3921) with a 95% LCI of 194.0086 and UCI of 196.5067; the known number of individuals stocked was 200.

Probability of detection and probability of site occupancy estimates during 2007 were calculated for all Rio Grande silvery minnow and for the respective age-classes. The estimated probability of detection for all individuals was 0.4485 while the estimate for age-0 individuals was 0.4515. Estimates of probability of detection were much lower for age-1 and age-2 individuals (<0.01). The estimate of the probability of occupancy for all individuals was 0.5923 while the estimate for age-0 individuals was 0.5827. These results were similar to those recorded in 2006 and indicate a more patchy distribution of Rio Grande silvery minnow in 2007 as compared with 2005.

In addition to calculating the site occupancy estimates within sampling units, we also constructed a multi-year statistical model based on the patterns of occupancy observed within and among sampling units from 2005 to 2007. The site occupancy estimate was 1.0 for all age-classes combined and for age-0 individuals but was lower for age-1 (0.5697) and age-2 (0.1608) individuals.

Probability of site extinction estimates were relatively low for all age-classes (0.0256) and age-0 (0.1085) Rio Grande silvery minnow. Estimates of the probability of site colonization were relatively high for age-0 (0.7458) and age-1 (0.7581) individuals. Estimates of the probability of site occupancy varied among years but were most variable for groups with few data (i.e., age-1 and age-2 fish).

The 2007 population estimate was highest in the Isleta Reach (N = 417,099) and lowest in the San Acacia Reach (N = 5,800). The overall population estimate (N = 613,638) had a standard error [SE] of 259,983.21. The total population estimate for unmarked Rio Grande silvery minnow was 609,712. The overall population estimate for age-0 (N = 605,885) Rio Grande silvery minnow was significantly higher than for age-1 (N = 7,783) individuals. However, the overall proportion of each age-class exhibited a similar pattern among the three reaches (i.e., populations were highest in the Isleta Reach, moderate in the Angostura Reach, and lowest in the San Acacia Reach).

Population estimates were also generated using data from the Population Monitoring Program October 2007 sampling efforts. To facilitate a comparison between the Population Monitoring and Population Estimate data sets, we used a correction factor (4.26) to adjust observed densities of Rio Grande silvery minnow in runs for the Population Monitoring data. The population estimates for the study area varied among reaches with the highest numbers recorded in the Isleta Reach (303,936) and the lowest numbers in the San Acacia Reach (87,713). The reach-specific estimates were most divergent for the San Acacia Reach where the Population Monitoring value (N = 136,739) was significantly higher than the Population Estimate value (N = 5,800). The overall population estimate for Rio Grande silvery minnow using Population Monitoring Program data was 723,888 for age-0 individuals and 2,113 for age-1 individuals; neither estimate was significantly different from the values calculated based on Population Estimation Program data.

For comparative purposes, population estimates in 2006 were recalculated to reflect updated capture probability estimates for non-run mesohabitats and to include the correction (4.26) based on the statistical comparison of open vs. closed sampling in runs. The updated population estimate for 2006 was 56,690 (SE = 19,253.09) overall, 39,757 (SE = 11,144.46) for unmarked individuals, 31,010 (13,759.53) for age-0 individuals, and 25,361 (SE = 10,232.73) for age-1 individuals. The overall population increased by about an order of magnitude between 2006 and 2007. Based on a comparison of confidence intervals, the overall Rio Grande silvery minnow population estimate was significantly higher in 2007 than in 2006. Similar increases were noted for the other categories except age-1 individuals; their estimated numbers declined (but not significantly) from 2006 to 2007.

The site occupancy data should be used in combination with population estimate data to provide a more complete understanding of the conservation status of Rio Grande silvery minnow. It is well known that simply having large numbers of a particular species in an area doesn't ensure it long-term survival. This is particularly true for relatively short-lived species such as Rio Grande silvery minnow. The substantial changes in population size of this species within short time periods underscore the need to ensure the presence of individuals over a broad geographical range. Changing environmental conditions within a particular region (either natural or man-made) can have rapid and severe impacts to local populations. For these reasons, it is imperative that populations of Rio Grande silvery minnow are maintained at multiple locations within its current range and established at multiple locations within its historical range to ensure its long-term persistence.

The success of this project will be evaluated annually but true insight into the efficacy of estimating the population size of Rio Grande silvery minnow will require a multi-year commitment and consistency in sampling methodology. Data from future year's efforts will provide additional information that will supplement recent population estimation activities and furnish valuable information necessary to gauge recovery of Rio Grande silvery minnow in the three principal reaches of the Middle Rio Grande. Ultimately, these data will be used to evaluate progress towards meeting Rio Grande silvery minnow recovery goals, following both management actions and stochastic environmental events.

INTRODUCTION

Population information on Rio Grande silvery minnow and the associated Middle Rio Grande fish community has been gathered regularly since 1987. The first population monitoring studies were conducted from 1987-1992 (Platania, 1993a) with the goal of determining spatial and temporal changes in the ichthyofaunal community and providing resolution of species-specific mesohabitat use patterns. An additional purpose of those preliminary studies was to supply information on the conservation status of Rio Grande silvery minnow. The quarterly sampling efforts revealed that Rio Grande silvery minnow had declined markedly during the study period and was extremely rare in portions of its remaining range. The 90-95% reduction in the range of Rio Grande silvery minnow and threats to its continued existence 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).

Systematic monitoring of populations of Rio Grande silvery minnow, *Hybognathus amarus*, and the associated Middle Rio Grande fish community has been conducted since 1993. 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 those studies was long-term monitoring of the Middle Rio Grande fish community at numerous sites between Angostura Diversion Dam and Elephant Butte Reservoir. While Rio Grande silvery minnow was the primary focus of most efforts, research activities also provided information on the associated fish community.

The information generated during this decade-long effort has provided the foundation necessary to assess spatial and temporal changes in the Middle Rio Grande ichthyofaunal community. Catch-per-unit-effort (CPUE) is the primary metric used to monitor spatiotemporal trends in population levels of Rio Grande silvery minnow for each sampling effort at Middle Rio Grande sites. This metric provides a gauge by which to measure the relative increase or decrease in the population temporally (between months or years) or spatially (between sites or reaches). The current population monitoring protocol is not designed to provide an estimate of the total number of Rio Grande silvery minnow but rather an estimate of trends in abundance over time and space.

However, estimating the population size of Rio Grande silvery minnow on an annual basis may provide a useful gauge by which to assess the total increase or decrease in abundance of this federally endangered species. Analyzing population fluctuations of fishes and assessing the influence of environmental variability may lend insight to important mechanisms that regulate community structure (Starrett, 1951; Schlosser, 1985). Changes in the abundance of an organism, especially over long periods, can be strongly influenced by environmentally stochastic factors (Grossman et al., 1982). Short-lived fishes, such as Rio Grande silvery minnow and other Middle Rio Grande cyprinids, are well suited for the study of short-term ichthyofaunal dynamics (<5 years) as populations often fluctuate drastically within a few years. Quantitative and qualitative analyses of these changes using current and past Middle Rio Grande fish population monitoring data have provided insight to causal mechanisms that may control species abundance and community structure.

Techniques to estimate the presence and abundance of organisms, which do not require full site depletion or marking and recapture of individuals, have recently undergone notable advances (e.g., Royle and Nichols, 2003). New statistical methods have been developed that account for the inherent heterogeneity of population abundance among different sites. Data on the presence-absence of organisms provides useful information about the probabilities that underlie spatial patterns of abundance in the environment, and for detecting trends in population status (MacKenzie et al. 2003). Occupancy surveys provide a way to assess the likelihood of detecting the presence or absence of an organism by calculating the probability based on the detection history (i.e., previous information on presence/absence can be used to predict likelihood of non-detection versus

unoccupied). Failure to detect a species during sampling does not mean that the species is truly absent from the area (MacKenzie et al., 2002, Finley et al., 2005, White 2005).

An estimate of population size and historical patterns of site occupancy can be used to complement data collected during the long-term (1993-2007) Population Monitoring Program for the Middle Rio Grande ichthyofaunal community (Angostura, NM to Elephant Butte Reservoir). In contrast to population monitoring that documents patterns of recruitment and survival at a regular time interval (i.e., monthly or bimonthly sampling) for the entire ichthyofaunal community, population estimation supplements the current Population Monitoring Program by providing a rigorous yearly estimate of the Rio Grande silvery minnow population during a single time-period (October). The objectives of this study were to 1) Develop and implement methods that provide statistically robust population estimates of Rio Grande silvery minnow, 2) Provide a population estimate of Rio Grande silvery minnow based on fish densities stratified by mesohabitat for 20 sampling units, 3) Develop site occupancy rates for Rio Grande silvery minnow populations over time, and 4) Calculate a population estimate of Rio Grande silvery minnow using Population Monitoring Program data, controlling for mesohabitat, and compare this value to that generated in Objective #2.

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 km² (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 yields the majority of water for the Rio Grande, but transmontane diversions from the San Juan River (Colorado River Basin) supplement flow by providing water in route to agricultural users and municipalities. The highest flow in the Rio Grande generally occurs shortly after spring snowmelt, while the lowest flow usually occurs in late summer and early autumn prior to the cessation of irrigation season (October 31). 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).

Several large 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 is the primary flood control reservoir and regulates discharge in the mainstem Middle Rio Grande. The Middle Rio Grande has been greatly modified over the last 50 years; this has led to degradation, armoring, and narrowing of the river channel in addition to floodplain abandonment across various portions of the overall reach (Lagasse, 1980; Massong et al., 2006; Makar et al., 2006).

The Middle Rio Grande is defined as the reach between Velarde, New Mexico and Elephant Butte Reservoir. The study area (Figure 1) is a portion of the Middle Rio Grande, from Angostura Diversion Dam to the inflow of Elephant Butte Reservoir, that encompasses most of 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 Domingo Pueblo, and finally San Felipe Pueblo. Access is currently restricted or unreliable in the Cochiti Reach, precluding long-term fish monitoring in this area. 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 was not found within the boundaries of Cochiti Pueblo (Platania, 1993b).

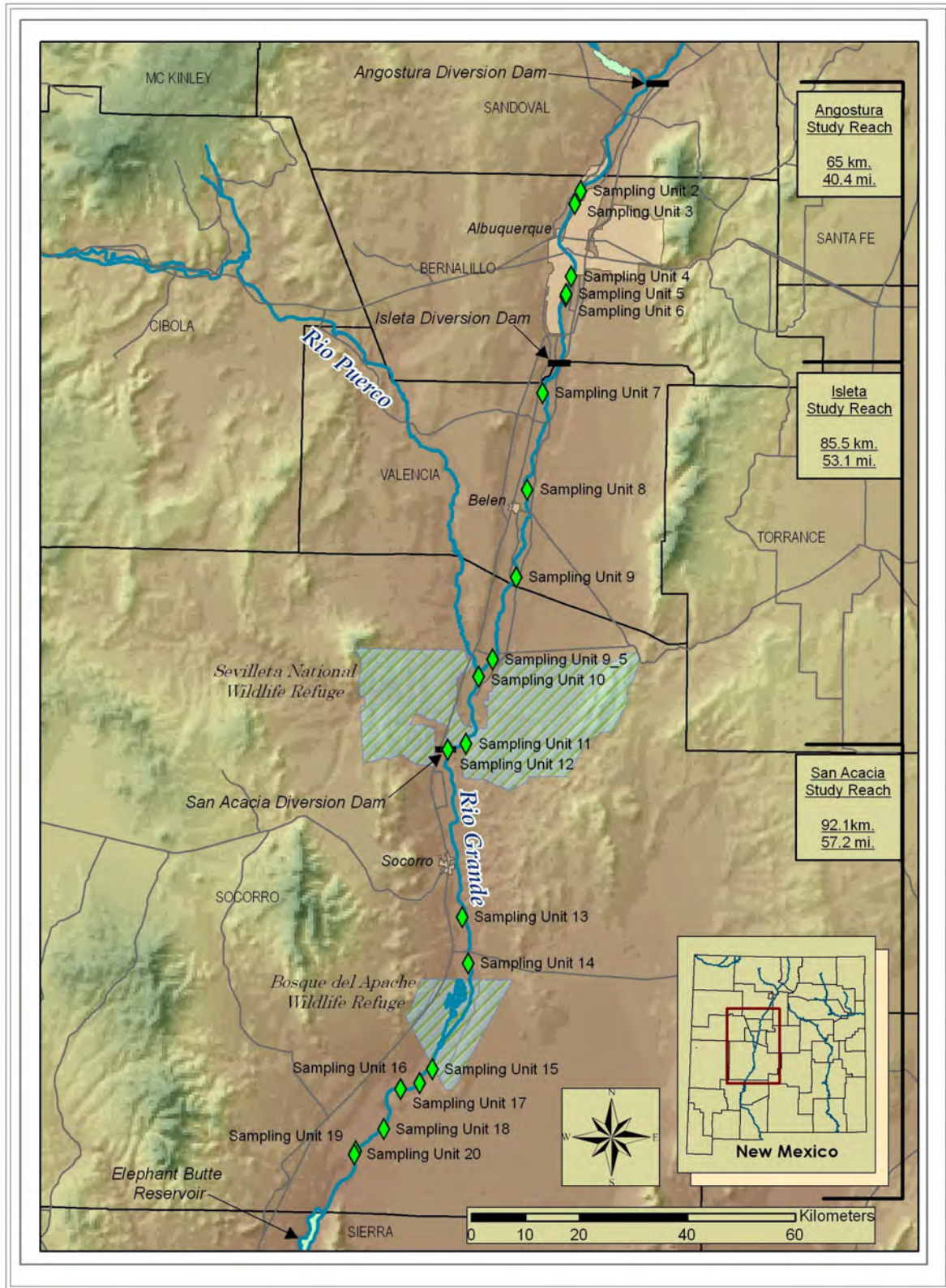


Figure 1. Map of the study area, reaches, and sampling units (numbered) for the Rio Grande silvery minnow Population Estimation Program. Sampling unit information is provided in Appendix A (Table A-1).

Reach names were derived from the diversion structure at the top of the reach. The Angostura Reach (Angostura Diversion Dam to Isleta Diversion Dam) had five sampling units and the Isleta Reach (Isleta Diversion Dam to San Acacia Diversion Dam) had six sampling units. There were nine sampling units in the San Acacia Reach (San Acacia Diversion Dam to inflow of Elephant Butte Reservoir). The 20 sampling units in the Middle Rio Grande overlap the current range of Rio Grande silvery minnow.

Diel and seasonal discharge varied greatly during 2006 and 2007, especially in southern reaches of the Middle Rio Grande (Figure 2). There was a general trend of lower flow at downstream locations (e.g., U. S. Geological Survey (USGS) San Acacia Gauge [#08354900] and USGS San Marcial Gauge [#08358400]) compared to upstream locations (e.g., USGS Albuquerque Gauge [#08330000]). Mean annual discharge was higher and included higher peaks in 2007 compared to 2006. From mid-March 2007 until late June 2007, flows were elevated and variable. Flow conditions in 2006 and 2007 included periodic intervals of very low discharge from July through October. Summer rains contributed little flow to the river in 2007 compared to 2006. Flows at the Albuquerque Gauge during October 2007 were very stable and slightly lower (mean = 304 cfs) than historical October flows (Mean of available data [1973-2006] = 473 cfs).

METHODS

Sampling and Mapping Methodology

Sampling unit location, selection, and timing

This study was structured to provide an estimation of the population of Rio Grande silvery minnow based on data collected from 20 sampling units in the study area. To maintain an unbiased probability of sampling at localities that support differing densities of Rio Grande silvery minnow, sampling units in this study were selected randomly using a spatially balanced statistical design. The use of generalized randomized tessellation stratified (GRTS) sampling, for long-term ecological studies, was discussed extensively by Stevens and Olsen (1999, 2003, 2004). The advantage this technique has over simple random sampling is that it ensures spatially balanced samples. This is important because the spatial distribution of an organism is necessary to understand abundance trends over both space and time. Additionally, the GRTS method is flexible in its ability to gain or lose units later while retaining spatial balance of the sampling design.

The computer program "S-Draw" (Western EcoSystems Technology, Inc. - Trent L. McDonald) was used to randomly select study units within the Middle Rio Grande. This program allows for efficient one-dimensional or two-dimensional drawing of GRTS samples. Additional features of S-Draw include allowing inputs such as population and sample size, or complex enumeration sampling frames containing UTM coordinates, ID's, and weights.

An initial step in generating the list of potential fish sampling units was to determine an appropriate length for each unit. The sampling unit had to be long enough to encompass the suite of mesohabitats present and to adequately represent the fish community in that area. Previous Middle Rio Grande fish-mesohabitat association studies demonstrated that multiple 200-m sampling units were of sufficient length to include a representative selection of the mesohabitats that occur in the Rio Grande between Angostura Diversion Dam and Elephant Butte reservoir (Platania 1993a, Dudley and Platania, 1997). The 234 river km (ca. 145.4 river miles) study area (Middle Rio Grande between Angostura Diversion Dam and Elephant Butte Reservoir) was partitioned (using aerial photographs, GIS data, and ArcView software) into 200-m sampling units (N = 1,170) starting immediately upstream of Bernalillo (just downstream of the southern boundary of Santa Ana Pueblo) and ending at Elephant Butte Reservoir. The Cochiti Reach (ca. 35 km) of the Middle Rio Grande was not

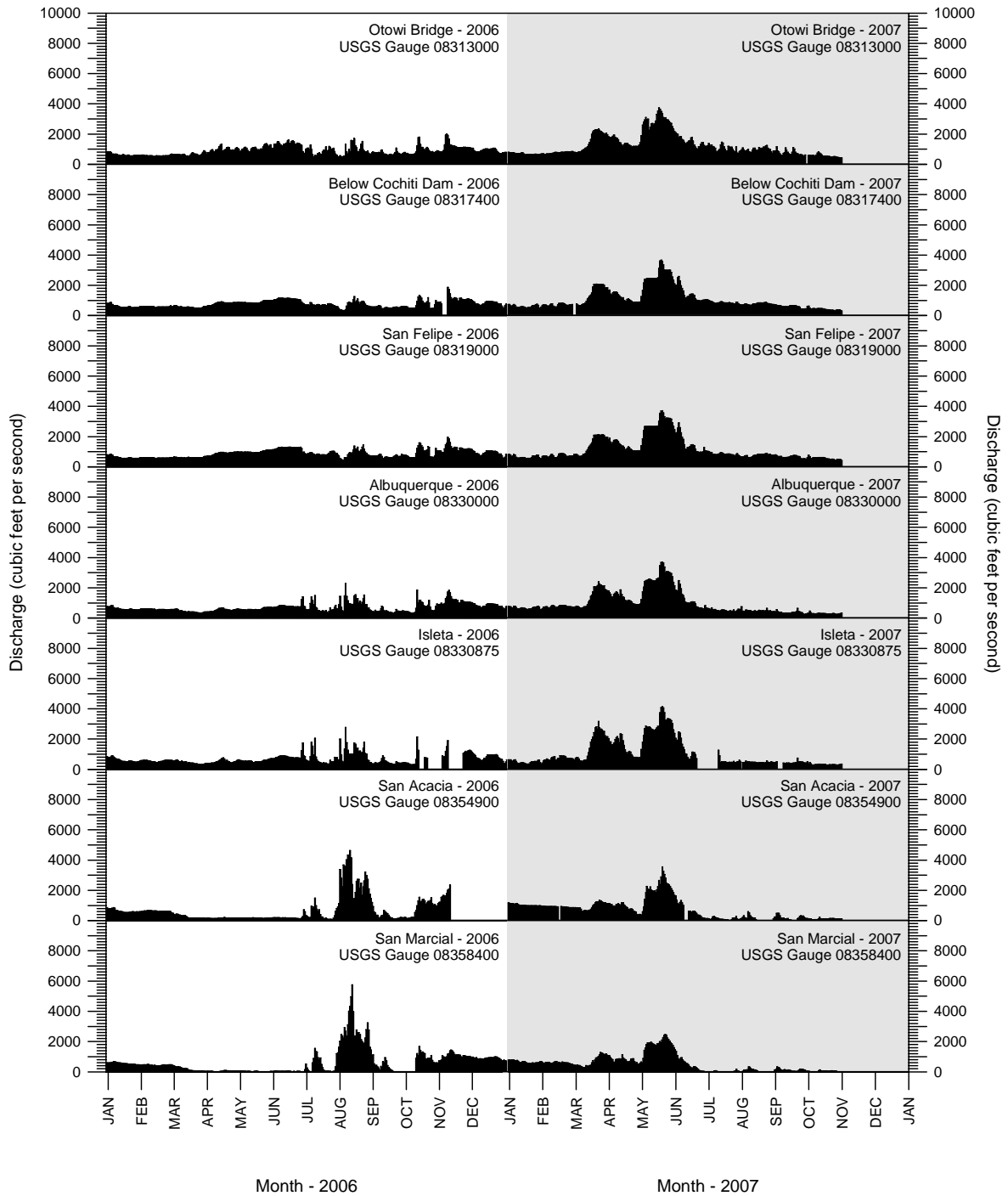


Figure 2. Discharge in the Rio Grande from January 2006 through October 2007 as recorded at seven U. S. Geological Survey (USGS) gauging stations. The Otowi Bridge gauge site is outside of the study area (ca. 25.5 river miles upstream of Cochiti Dam) but is provided for reference. USGS discharge data are provisional and subject to change.

included in this proposed study as all except a very small portion (< 5 km) drain sovereign Native American nations and are generally inaccessible.

The primary data that were used in S-Draw included UTM coordinates corresponding to the upper and lower boundaries of each 200-m sampling unit (N = 1,170) within the Middle Rio Grande study area. The first 20 sampling units (Appendix A, Table A-1) were used for this study in 2006 with the intention that the loss of a unit would require selecting the next sampling unit on the list (i.e., #21). This scenario (loss of a unit) happened in 2007 when the river at sampling unit #1 was diverted across the natural channel and turned into a channeled man-made ditch while heavy construction (possible levee reinforcement) proceeded along the original eastern shoreline. This site was dropped from sampling and the 21st sampling unit (Unit 9_5) was selected from the list. This procedure could be repeated as necessary in the future and has the added benefit of maintaining the randomized spatial balance of the sampling units.

The rationale for sampling at 20 units for the Population Estimation Program was also based on the statistical analyses and modeling techniques employed in this study. Power analysis of Rio Grande Population Monitoring Program data also supports using a sample size of about 20 to adequately detect trends over time (unpublished data). Rio Grande silvery minnow population estimates were generated from October 2007 samples obtained at each of the 20 units. Samples of Rio Grande silvery minnow from October provide a general assessment of results of the spring/summer spawn and subsequent recruitment. October collections also provide a reasonable estimate of the cohort available for spawning during the following year. However, the main factor in selecting October for population estimation sampling was because this was the time identified as the gauge by which recovery of Rio Grande silvery minnow would be measured (U.S. Department of Interior, 2007).

Mesohabitat mapping and analysis

The October 2007 sampling effort was structured to acquire data about the relative proportion of mesohabitats at each sampling locality. Aquatic mesohabitats were segregated into seven broad categories: backwater, debris, pool, run, riffle, shoreline pool, and shoreline run (Table 1). The seven mesohabitats have been designated, based on past autumnal Middle Rio Grande fish population monitoring and habitat use/availability studies (e.g., Dudley and Platania, 1997, 2008), as high (backwater, shoreline pool, debris), medium (pool, shoreline run), or low density (run, riffle) Rio Grande silvery minnow mesohabitats.

Ground measurements of mesohabitat spatial scale and location were acquired with Trimble GPS units and mapped in ArcInfo GIS to provide a detailed mesohabitat mosaic of the river for each sampling unit (Appendix B). Pathfinder Office was used for all post-processing of raw data. High quality natural color orthophotography images (15 cm resolution) were available (April 2006) and used for all sampling units in the Angostura and Isleta reaches; near infrared color orthophotography images (0.5 m resolution) were available (June 2005) and used for all units in the San Acacia Reach. There were noticeable shifts in the location of channel banks for some sampling units (e.g., #11) because of notable floods (summer 2006) that occurred after the original photography dates.

Sampling was originally to be conducted within each 200-m unit, using a random stratified subset of the available mesohabitats. However, we found that sampling efforts could be extended to all available non-run mesohabitats with only a modest increase in work time. This was because of the small percentage of non-run mesohabitats and because the time required analyzing and generating random sampling locations would greatly reduce sampling time. All coordinates of the wetted perimeter and individual perimeters within each non-run mesohabitat were recorded with a backpack-mounted Pathfinder GPS Receiver and a Ranger Handheld Data Collector for reliable submeter (RMS) 2-D data collection with a published accuracy of about 20 cm RMS. The precision

Table 1. Codes used for mesohabitat type classification in the Middle Rio Grande during this study.

MESOHABITAT TYPES

BW	Backwater- 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.
DE	Debris- any habitat that has associated organic cover (e.g., grasses, woody vegetation etc.).
PO	Pool- the portion of the river that is deep and with very low 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.
RI	Riffle- a shallow and high velocity habitat where the water surface is irregular and broken by waves; generally indicates gravel-cobble substrate.
SHPO	Shoreline pool- usually a shallower, very low velocity, area that is adjacent to shore of either the river channel margins or instream islands.
SHRU	Shoreline run- usually a shallower, relatively fast velocity, area that is adjacent to shore of either the river channel margins or instream islands.

of GPS mapping allowed for accurate calculation of the area even for small mesohabitats. Two crews worked simultaneously to collect the perimeter information (i.e., one for wetted perimeter and one for mesohabitat perimeters). Run mesohabitat was, by default, all the remaining area after the non-run mesohabitat area was subtracted. Surveyor flags and bamboo posts were used to delineate the perimeter of each mesohabitat, taking care not to enter or disturb the area that would later be sampled (It was determined that collecting fish prior to habitat mapping yielded less precise delineation of mesohabitats because the crew had to make immediate decisions as to the location of mesohabitat boundaries while actively sampling). Codes for spatial location (e.g., main channel left [ml], main channel right [mr], island #1 left [il-1] etc.) were used in addition to mesohabitat codes to facilitate later fish sampling of mapped locations. There were some minor changes in flow for some of the sampling units even during the same day. In these instances, a small fraction of the total fish sampling hauls were shifted <1 m to ensure collection of fish in the same habitat conditions as were mapped. It was determined that even modest changes in flow between days could cause notable shifts in the location and physical parameters (e.g., depth and velocity) of individual mapped mesohabitat localities. Thus, habitat mapping and sampling for fish occurred on the same day (several hours apart).

Fish sampling and analysis

Surveyor flags were used to mark the start and stop points for each seine haul. Likewise, GPS coordinates were acquired for each seine haul. Fish were collected by rapidly drawing a two-person 3.1 m x 1.8 m small mesh (4.8 mm) seine through a discrete mesohabitat. Each seine haul represented a discrete sample and the results (species composition, Rio Grande silvery minnow age structure, and number of individuals per species) of those samples were maintained accordingly. Scientific and common names of fishes in this report follow Nelson et al. (2004; Table 2). Common names are arranged in phylogenetic order and appear throughout this report in tables, figures, and text.

Use of seines in the aquatic mesohabitats in the Middle Rio Grande has proven the most effective methodology to sample fish populations. This choice of sampling technique was based on having employed and reviewed the efficacy of numerous other sampling methodologies in the Middle Rio Grande during the past 15 years. Seining has constantly proved the most reliable sampling technique for providing consistent and inclusive information regarding the structure and composition of the ichthyofaunal community in the Middle Rio Grande. Additionally, seining is considered the most effective technique for collection and quantification of larval to adult stages of small-bodied cyprinids and other similar-sized species from a variety of shallow (<1 m deep) streams and rivers (see Hendricks et al., 1980; Matthews, 1986 [and citations within]; Matthews et al., 1988; Rutherford et al., 1987). Mean depths at sites sampled in the Rio Grande during October 1995 (mean monthly flow = 695.2 cfs at USGS gauge 08330000) were 37.7 cm with very few points (<1.5%) exceeding 100 cm and no points exceeding 120 cm; mean velocities were 39.0 cm/s and 98.5% of transect points were <100 cm/s (Dudley and Platania, 1997). The relatively shallow and low velocity Rio Grande, combined with a concentration of fish along the margins, makes this river quite suitable for seining small-bodied fishes.

Additional contributing factors that make seining appropriate for this study are the turbid conditions of the river and the cool water temperatures during sampling. Instream visibility in the Rio Grande during this study was frequently <10 cm. Unlike sampling in clear water streams, this allowed the seining crew to capture fish with little chance of being detected in advance. A seine will form a bag, which further traps fish, and helps prevent their escape. The cool water temperatures encountered during this study (<20° C) result in lower sustained (ca. 60 cm/s for a minute) and burst swimming speeds (ca. 100 cm/s for a few seconds) of Rio Grande silvery minnow (Bestgen et al.

Table 2. Scientific and common names and species codes of fish collected in the Middle Rio Grande from December 2006 to October 2007.

Scientific Name	Common Name	Code
Order Clupeiformes		
Family Clupeidae		
	herrings	
<i>Dorosoma cepedianum</i>	gizzard shad	(GZS)
<i>Dorosoma petenense</i>	threadfin shad	(TFS)
Order Cypriniformes		
Family Cyprinidae		
	carps and minnows	
<i>Cyprinella lutrensis</i>	red shiner ¹	(RDS)
<i>Cyprinus carpio</i>	common carp ¹	(CCA)
<i>Hybognathus amarus</i>	Rio Grande silvery minnow ¹	(RGM)
<i>Pimephales promelas</i>	fathead minnow ¹	(FHM)
<i>Pimephales vigilax</i>	bullhead minnow	(BHM)
<i>Platygobio gracilis</i>	flathead chub ¹	(FHC)
<i>Rhinichthys cataractae</i>	longnose dace ¹	(LND)
Family Catostomidae		
	suckers	
<i>Carpiodes carpio</i>	river carpsucker ¹	(RCS)
<i>Catostomus commersonii</i>	white sucker ¹	(WHS)
<i>Ictiobus bubalus</i>	smallmouth buffalo	(SMB)
Order Siluriformes		
Family Ictaluridae		
	North American catfishes	
<i>Ameiurus melas</i>	black bullhead	(BBH)
<i>Ameiurus natalis</i>	yellow bullhead	(YBH)
<i>Ictalurus punctatus</i>	channel catfish ¹	(CCT)
Order Salmoniformes		
Family Salmonidae		
	trouts and salmons	
<i>Oncorhynchus mykiss</i>	rainbow trout	(RBT)
<i>Salmo trutta</i>	brown trout	(BNT)
Order Cyprinodontiformes		
Family Poeciliidae		
	livebearers	
<i>Gambusia affinis</i>	western mosquitofish ¹	(MOS)

¹ focal taxa represent the 10 most abundant species present in recent Middle Rio Grande collections and are illustrated in summary plots of data.

Table 2. Scientific and common names and species codes of fish collected in the Middle Rio Grande from December 2006 to October 2007 (continued).

Scientific Name	Common Name	Code
Order Perciformes		
Family Percichthyidae		
	temperate basses	
<i>Morone chrysops</i>	white bass	(WHB)
Family Centrarchidae		
	sunfishes	
<i>Lepomis macrochirus</i>	bluegill	(BGL)
<i>Micropterus salmoides</i>	largemouth bass	(LMB)
<i>Pomoxis annularis</i>	white crappie	(WCR)
Family Percidae		
	perches	
<i>Perca flavescens</i>	yellow perch	(YWP)
<i>Sander vitreus</i>	walleye	(WLE)

2003). The speed that experienced seining crews are able to move through the water is about 1.5 m/s to 2 m/s (150 cm/s to 200 cm/s), which is faster than the swimming capabilities of Rio Grande silvery minnow.

Fish from individual seine hauls were handled briefly for identification and enumeration, placed in one of several fine mesh (nylon) holding cages (= live-well) present at the sampling unit (in the river), and released near their site of capture after sampling had concluded. Prior to release, all Rio Grande silvery minnow collected were examined for Visible Implant Elastomer (VIE) tags (= stocked fish), identified to age-class (based on standard length and past length-frequency histograms during the same time of year [unpubl. data, U. S. Fish and Wildlife Service 1999]), and measured (standard length range). Selected water quality parameters (temperature, conductivity, specific conductance, pH, salinity, and dissolved oxygen) were obtained at each sampling unit as well as digital photographs of physical river conditions.

While the number of seine hauls was originally going to be made in proportion to the abundance of each mesohabitat, it was determined that all non-run mesohabitats should be sampled to provide a comprehensive measurement of fish density at each sampling unit. This was based on a sampling allocation analysis based on density data by mesohabitat. The low density of fish in runs, combined with its abundant availability (often >75%), made it prudent to take a random sample in this mesohabitat. The same GRTS method that was used to generate spatially-balanced sampling localities in the Middle Rio Grande was also employed to determine fish sampling locations in run mesohabitats. For the purposes of this analysis, a series of ten transects (perpendicular to flow and spaced 20 m apart) were generated within ArcView. A unique identifying value was assigned to every available point along each transect, excluding non-run mesohabitats, at 2.5 m intervals. A total of 20 sampling start points in runs were generated based on the X, Y coordinates (e.g., X = 5.0 m from left shore, Y = 40 m from top of unit) of all possibilities. Sampling was conducted using a float rope (to maintain alignment with flow) that was 20 m long. In rare areas where seine hauls could not be completed effectively, alternate GRTS generated points were used.

During the first year of study (2006), capture probability estimates were generated for all of the mesohabitat types. Multiple seine hauls within the same mesohabitat were taken in areas where densities of Rio Grande silvery minnow were known or suspected to be relatively high (i.e., >10 individuals). Mesohabitats were blocked off (to prevent immigration or emigration) during depletion efforts by using small mesh seines (4.8 mm) staked to bamboo posts. We employed a depletion-sampling scheme where replicate seine hauls were made in a single mesohabitat until <5% of the original number of fish captured on the first haul was captured on a subsequent haul. In most instances, this only required a second or third pass but sometimes required as many as six passes. The collection of high numbers of Rio Grande silvery minnow in the first pass allowed for development of a more robust model; this also influenced the decision to not sample in areas with low densities of individuals. The exception to this protocol was in runs and riffles where densities of individuals were consistently very low; limited depletion sampling was conducted in these areas but with the realization that calculating robust capture probability estimates would be difficult. The Akaike Information Criterion (AIC; Akaike, 1973; Burnham and Anderson, 2002) using the Huggins removal estimator (Huggins, 1989, 1991) was used to generate the most parsimonious model based on the observed seine depletion data. The Huggins model, which is similar in approach to the Horvitz-Thompson sampling design, computes a population estimate for this type of removal study based on constant initial capture probabilities. Program MARK (White and Burnham, 1999) was used to compute all removal estimates. In seine haul locations where depletion sampling was not conducted, the appropriate mesohabitat-specific capture probability estimate was used to correct the first-pass calculation of fish density.

Additional depletion sampling within closed mesohabitats was conducted in 2007 to supplement information collected during 2006. Pool (PO) mesohabitats were not well represented in 2006 (i.e., few areas where Rio Grande silvery minnow were collected), which led to a high standard

error for the capture probability estimate. Supplemental data collected in 2007, from PO mesohabitats with adequate numbers of Rio Grande silvery minnow, were used to provide a more rigorous estimate of the capture probability (using the aforementioned statistical techniques) for this mesohabitat type. The other non-run mesohabitats were adequately represented during 2006 and so the capture probability estimates for those areas remained the same.

Capture probabilities in the RU mesohabitat type were estimated using the SHRU capture probabilities during 2006. However, it was determined that more intense closed sampling in run mesohabitats would provide additional rigor to the population estimates generated in 2007. The same GRTS method that was used to generate spatially-balanced sampling localities for seining run mesohabitats was used to determine closed sampling locations. For closed sampling of RU mesohabitats, a box (2 m wide, 10 m long, and 1.5 m high) was constructed out of PVC (open-ended to allow rapid sinking and draining) and screened using small mesh (4.8 mm) seine material. All sides of the box (except the top and bottom) were screened with mesh to prevent the entrance or exit of fish. Lead weights attached to the mesh prevented the movement of fish underneath the sampling box. A seine "bag" (ca. 1 m long) was added to the downstream panel of the box; this panel was modified so that it could be removed immediately after sampling was complete (i.e., trapping all fish inside the bag) while blocking the entrance or exit of fish during sampling. The sampling box was carried out over the water and then quickly dropped into place at the sampling location. Five personnel were required to operate the box under normal flow conditions (two to hold the box in place, two to operate the removable panel and collect the fish, and one to electrofish the inside of the box). The person with the electrofishing unit operated two wands (one on either side of the box) and moved slowly through the box until reaching the downstream end. The downstream panel of the box was removed immediately after electrofishing was complete. Fish from individual collecting efforts using the sampling box were handled briefly for identification and enumeration, placed in one of several fine nylon mesh holding cages (= live-well) present at the sampling unit (in the river), and released near their site of capture after sampling had concluded. A total of 20 box (closed samples) and 20 seining (open samples) in run mesohabitat were generally made for each sampling unit. For sampling units with a channel width that couldn't accommodate 40 run mesohabitat samples, half of the samples were conducted with the box and half were seined. Densities of Rio Grande silvery minnow were compared for the two classes (sampling unit and sampling technique {open vs. closed}) and analyzed by age-class (all ages, age-0, and age-1), using ANOVA to determine the significance of source variation for sampling unit, sampling technique, and the interaction between those two class variables.

Additional sampling was conducted in 2007 to determine differences in capture probabilities between open and closed mesohabitat sampling (i.e., to possibly modify existing first-pass capture efficiencies in open samples). It was noted that some percentage of fish were missed on each sampling pass during closed sampling of mesohabitats in 2006. This is common during any sampling for mobile organisms and forms the basis for calculating the mesohabitat-specific capture probability estimates. However, it is also possible that some unknown percentage of fish left the mesohabitat patch during open sampling (unlike closed sampling where escape is prevented with the block net). While it is expected that some fish will leave the mesohabitat during open sampling, densities were corrected by accounting for the difference in capture probabilities between open and closed samples. To test for these differences, mesohabitats were sampled at three locations in the Middle Rio Grande (Population Monitoring sampling units [#2 and #7] and Population Estimation sampling unit [#7]) over the course of six days. On day one (at each sampling unit), depletion sampling was conducted at 20-26 mesohabitat locations (half open samples and half closed samples). We employed the same depletion-sampling scheme where replicate samples were made in a single mesohabitat until less than 5% of the original number of fish captured on the first haul were captured on a subsequent haul. On day two, the same 20-26 mesohabitat locations were sampled but closed samples were taken

where open samples were taken on day one and vice versa. Capture probability estimates were made for both open and closed samples using the same statistical techniques employed for the other depletion efforts.

Another additional experiment conducted in 2007 involved the use of hatchery-raised Rio Grande silvery minnow (in closed depletion sampling efforts) to determine if there were differences between the capture probabilities of wild and stocked fish. The sampling protocol was based, in part, on the fact that power analyses indicated that large numbers of wild and hatchery individuals ($N = 100$ for each group) would be needed to detect differences ($\text{power} > 0.7$) between groups (unpublished data). The additional resolution of the differences in capture probabilities between wild and hatchery fish could be useful in further refining the population estimate. Also, sampling efforts with hatchery fish were used to determine the relative precision of capture probability estimates since the total number of individuals was known prior to sampling. A total of 200 hatchery individuals (marked with VIE tags) was released into 10 mesohabitats at Population Monitoring sampling unit #2. Stocked fish were given about six hours to acclimate to local river conditions before sampling commenced. Capture probability estimates for wild and hatchery fish were made for closed samples using the same statistical techniques employed for the other depletion efforts.

Determining Occupancy Rates from Past Population Monitoring Data

Intensive sampling data from population monitoring efforts (repeated sampling efforts in November [2005-2007]) were used to generate estimates of site occupancy rates based on methods developed by MacKenzie et al. (2002, 2003, 2006). Objective 3 (Develop site occupancy rates of Rio Grande silvery minnow) enabled assessment of the likelihood of detecting the presence or absence of Rio Grande silvery minnow by calculating the detection history probability. The encounter history was computed using data that were collected during intensive repeated monitoring of the same seine haul locations during November (2005-2007). For the intensive sampling effort, units were sampled once per day for four days. A variety of mesohabitats were sampled on the first day and samples were taken at the same locations on subsequent days; in some cases the location of the sample had to be shifted to a different area with similar mesohabitat conditions if there was a change in flow. This study was conducted using the same sampling protocols established for regular population monitoring efforts. These repeated samples were taken at our 20 Population Monitoring Program sampling units (Appendix C, Table C-1). The data were organized into categories based on the presence/absence of Rio Grande silvery minnow over the four day sampling effort. The encounter history was based on the presence of Rio Grande silvery minnow at individual mesohabitat locations. For example, an encounter history of 1101 meant that individuals were collected on days one, two, and four but not on day three. A higher proportion of presence encounters was interpreted as indicating that individuals were more consistently detected within the mesohabitat patch over time. The sampling unit was large enough (200 m) so that it was unlikely (and not observed during this study) that the area would change in status from occupied to unoccupied among days. Additional assumptions included that there could be no false detections, that there could be mesohabitats where the species was present but undetected, and that species detection within a specific mesohabitat was independent of species detection at other mesohabitats. Cumulative frequency and percent columns were included in output to allow simple comparison between encounter histories. The probability of detection was calculated for Rio Grande silvery minnow at individual seine haul locations along with the standard error and confidence intervals, following methods of MacKenzie et al. (2006). Estimates of the probability of detection were computed for all individuals and then separately for the different age-classes using Program MARK (White and Burnham 1999).

Site occupancy estimates for each of the sampling units were calculated using probability of detection estimates. Site occupancy was the proportion of mesohabitat locations occupied relative to

those surveyed. The October 2005-2007 Population Monitoring Program data sets were used for the purposes of calculating estimates of site occupancy. However, any sampling month could be calculated using the same techniques described below. The site occupancy estimate for each sampling unit was based on the probability of detection estimate (and its associated variance) and the actual site occupancy data calculated from raw data. In this way, the site occupancy was "corrected" using the detection estimate (MacKenzie et al., 2006). A higher degree of consistency between days (either 0000 or 1111) will result in a site occupancy model that yields results that more closely match those obtained from the original estimate of site occupancy based on a single survey. The specific pattern of presence/absence (i.e., 0010 vs. 0101) was incorporated into the model to determine the likelihood of detection over time for a particular mesohabitat patch. A measure of the variance associated with the resulting site occupancy estimate based on mesohabitat locations occupied was calculated, following methods of MacKenzie et al. (2006) for single sample locality surveys.

In addition to calculating the site occupancy estimates within sampling units, we also constructed a multi-year statistical model based on the patterns of occupancy observed within and among sampling units from 2005 to 2007. Encounter histories were constructed on the presence or absence of Rio Grande silvery minnow at the Population Monitoring Program sampling units based on repeated sampling efforts ($N = 4$). The encounter history data from the 20 sampling units over three years allowed for a robust-design model of occupancy (MacKenzie et al. 2003) to estimate the probability of occupancy each year (ψ_p , $i = 1,2,3$), the probability of extinction given a sampling unit is occupied (ϵ_p , $i = 2,3$), and the probability of colonization given a sampling unit is not occupied (γ_p , $i = 2,3$). Site occupancy models were constructed for age classes (All, Age-0, Age-1, Age-2; each age class was a separate attribute group), with covariates of year ($y = 2005, 2006, 2007$), and a discharge (d) covariate for measured flow (from the nearest USGS gauging station) during sampling. The Akaike Information Criterion corrected for small samples (AIC_c ; Akaike, 1973; Burnham and Anderson, 2002) was used to select the most parsimonious site occupancy model based on the encounter history data. In addition to the basic parameter estimates ordered by the age-class variable, detailed estimates of the probability of occupancy were also generated by group and year. All parameter estimates are presented with their associated measure of sampling variance (SE = standard error) and confidence intervals (LCI = 95% lower confidence interval, UCI = 95% upper confidence interval).

Population Estimation of Rio Grande Silvery Minnow

Generating population estimates from October 2007 data

Population estimates of Rio Grande silvery minnow from individual sampling units were based on densities within occupied mesohabitats and the total available area of mesohabitats. Fish densities were calculated as the number of individuals collected divided by the area sampled ($\#/m^2$). Densities were grouped by mesohabitat for the purposes of estimating population size for a particular sampling unit.

The final density calculation of individuals by mesohabitat was corrected using data generated from the depletion sampling model results (i.e., mesohabitat-specific capture probability estimate and the associated standard error). The number of sampled quadrats was determined for each mesohabitat category within a unit. The number of unsampled quadrats was calculated using the total unsampled area divided by the average area of the sampled quadrats. The total number of quadrats was the sum of the sampled and unsampled quadrats. Mesohabitat-specific calculations of density were made by multiplying the total number of quadrats by the average number of individuals collected per sampled quadrat and then dividing this product by the capture probability estimate. The associated standard errors for mesohabitat-specific calculations of density were made using

detailed formulae outlined in Thompson (1992) and Skalski (1994). The total population estimate for each sampling unit was calculated as the sum of the population estimates for each mesohabitat. The standard error of the population estimate for each sampling unit was calculated by taking the sum of squares for all of the mesohabitat-specific standard errors (i.e., sampling variances) and then taking the square root of the resulting value. The upper and lower 95% confidence intervals were calculated around log-normal(N) and then converted back to linear scale; variance estimates were equivalent between scales (i.e., $\text{Var}(\log\text{-normal}(\hat{N})) = \text{Var}(\hat{N})/\hat{N}^2$). The coefficient of variation (CV = ratio of the standard deviation to the mean) was calculated for the reach-specific average population estimates for all categories (i.e., marked vs. unmarked and age-classes).

The GRTS locality selection methodology allowed Rio Grande silvery minnow population estimates to be calculated for each of the three study reaches as well as the entire Middle Rio Grande study area. However, the resulting values do not necessarily sum to the same value (e.g., estimates of the three reaches won't sum to the total study area) because the number of units per reach is not strictly proportional to the length of the reach. Estimates of Rio Grande silvery minnow (for different reaches, the total study area, different age-classes, and marked versus unmarked) were generated, assuming random sampling across all units.

Comparing RGSM estimates from Population Monitoring and Population Estimation data

In addition to population estimates of Rio Grande silvery minnow generated from data collected during this study, population size was also estimated using Population Monitoring Program data from October 2007. Estimates were generated for each of the three study reaches (Angostura, Isleta, and San Acacia). Fish densities were calculated as the number of individuals collected divided by the area sampled ($\#/m^2$). Densities were grouped by mesohabitat for the purposes of estimating population size in a particular sampling reach. Density data from the Population Monitoring Program were corrected using the appropriate mesohabitat-specific value (from capture probability estimates) based on the observed seine depletion data obtained from the Population Estimation Program.

An estimate of mesohabitat availability was necessary to complete the calculation of density using Population Monitoring Program data. While mesohabitat availability data from a previous study of Rio Grande silvery minnow habitat use and availability (Dudley and Platania, 1997) were originally going to be used for this analysis, it was determined that these data might not be applicable to slightly different flow conditions and channel morphology observed in 2006-2007. Also, mesohabitat availability measures from the aforementioned study were limited to a few sampling units and did not reflect the variation among reaches.

Mesohabitat availability was calculated from the October 2007 Population Monitoring Program data whenever possible. However, as the perimeter of each sampling unit was not mapped during population monitoring efforts, the area of the wetted channel was estimated by multiplying the width of the river channel by the length of the study unit. All non-run mesohabitats were measured and sampled in their entirety, with the exception of shoreline runs. The remaining shoreline run mesohabitat (unsampled) was calculated as the area of all shoreline mesohabitat minus the area of shoreline mesohabitat that was sampled. Similarly, run mesohabitat area was calculated as the area of all wetted mesohabitat minus the sum of the non-run mesohabitat and sampled run mesohabitat areas. Population estimates of Rio Grande silvery minnow (for different reaches, the total study area, different age-classes, and marked versus unmarked) were made using the same methods that were used for determining population size in the Population Estimation Program.

The undertaking of this computational exercise was recommended by MRGESACP peer-review statisticians and biologists. Those individuals, as well as the authors of this study, clearly recognize that the Population Monitoring Program generated population estimate is based on general estimates of mesohabitat area, relies on non-randomly selected sampling units, will violate numerous

statistical assumptions, and thus must be viewed cautiously. The estimate generated from the population monitoring data was not designed to provide the same high level of rigor inherent in the statistical methodology used to address Objectives 1, 2, and 3 as presented in the Introduction. The primary reason for performing this exercise was to determine if additional investigation should be pursued regarding a potential statistical relationship between Rio Grande silvery minnow Population Monitoring Program data and the Rio Grande silvery minnow Population Estimation Program data.

RESULTS

Fish Community

Population status

The ichthyofaunal community in the Middle Rio Grande between Angostura Diversion Dam and Elephant Butte Reservoir was numerically dominated by cyprinids (Table 3; Appendix D, Report D-1). The native ichthyofauna consisted of eight species (red shiner, Rio Grande silvery minnow, fathead minnow, flathead chub, longnose dace, river carpsucker, smallmouth buffalo, and bluegill). Smallmouth buffalo and bluegill (both $N = 1$) were the least abundant native fishes while longnose dace ($N = 39$) was the second least abundant taxon. Red shiner was the most abundant native species collected ($N = 18,826$), followed by Rio Grande silvery minnow ($N = 3,122$), flathead chub ($N = 852$), and river carpsucker ($N = 429$). The most abundant introduced species were western mosquitofish ($N = 3,397$), channel catfish ($N = 1,351$), common carp ($N = 37$), and white sucker ($N = 24$). The three remaining nonnative fish species were present at much lower numbers (i.e., $N = 1$ or $N = 2$) than were the aforementioned nonnative species.

Abundance and distribution

The largest numbers of fish were collected in the Isleta Reach ($N = 18,681$; Table 4). Fish were distributed relatively evenly within this reach, with the exception of sampling unit #9 where a large number of individuals were collected and sampling unit #11 where few individuals were collected. The Angostura Reach produced the second highest overall catch rate of fish ($N = 5,778$ in $18,159.9 \text{ m}^2$ sampled). The distribution of fish within the Angostura Reach was uneven with higher densities in the upper portion of the reach (Sampling unit #2). The heavily channelized sampling unit #4 yielded the fewest number of fish ($N = 919$) of any sampling unit in the Angostura Reach. Fish abundance in the San Acacia Reach was uneven. Sampling unit #13 yielded the fewest number of fish ($N = 155$) while unit #18 yielded the most fish ($N = 1,161$). Rio Grande silvery minnow were most common in the Isleta Reach ($N = 2,531$) and least common in the San Acacia Reach ($N = 36$). The distribution of this species was uneven and the highest densities were generally recorded in the upper portions of each of the three fragmented river reaches.

The fish composition and species-specific relative abundance of the three sampling reaches varied considerably (Figure 3). The relative abundance of species (other than red shiner) in the Angostura and San Acacia reaches was relatively low. This was in contrast to the Isleta Reach where Rio Grande silvery minnow and western mosquitofish were abundant. Western mosquitofish was most numerous in the Isleta Reach and about equally abundant in the Angostura and San Acacia reaches. While flathead chub was most concentrated in the Angostura Reach, fathead minnow densities were highest in the Isleta Reach. For all reaches combined, red shiner and western mosquitofish were the most common species. Rio Grande silvery minnow was found in moderate densities throughout the study area (Figure 4). The highest densities of Rio Grande

Table 3. Summary of the Rio Grande silvery minnow Population Estimation Program fish collections from October 2007.

SPECIES	RESIDENCE STATUS ¹	TOTAL NUMBER OF SPECIMENS	PERCENT (%) OF TOTAL	FREQUENCY OF OCCURRENCE ²	% FREQUENCY OF OCCURRENCE ²
HERRINGS					
gizzard shad	I	--	0.00	--	--
CARPS AND MINNOWS					
red shiner	N	18,826	66.39	20	100
common carp	I	37	0.13	12	60
Rio Grande chub	N	--	0.00	--	--
Rio Grande silvery minnow	N	3,122	11.01	19	95
fathead minnow	N	273	0.96	14	70
bullhead minnow	I	--	0.00	--	--
flathead chub	N	852	3.00	16	80
longnose dace	N	39	0.14	6	30
SUCKERS					
river carpsucker	N	429	1.51	14	70
white sucker	I	24	0.08	6	30
smallmouth buffalo	N	1	0.00	1	5
BULLHEAD CATFISHES					
black bullhead	I	--	0.00	--	--
yellow bullhead	I	2	0.01	1	5
channel catfish	I	1,351	4.76	20	100
flathead catfish	I	--	0.00	--	--
TROUTS					
rainbow trout	I	--	0.00	--	--
brown trout	I	--	0.00	--	--
LIVEBEARERS					
western mosquitofish	I	3,397	11.98	18	90
TEMPERATE BASSES					
white bass	I	--	0.00	--	--
SUNFISHES					
bluegill	N	1	0.00	1	5
largemouth bass	I	2	0.01	1	5
white crappie	I	1	0.00	1	5
PERCHES					
yellow perch	I	--	0.00	--	--
bigscale logperch	I	--	0.00	--	--
walleye	I	--	0.00	--	--
TOTAL		28,357			

¹ N = native; I = introduced

² Frequency and % frequency of occurrence are based on n=20 sampling units

Table 4. Summary of Rio Grande silvery minnow (including marked individuals) and total fish abundance and sampling effort, by sampling unit and reach, during the 2007 Rio Grande silvery minnow Population Estimation Program.

REACH Sampling Unit and Name	TOTAL NUMBER OF RGSM	TOTAL NUMBER OF MARKED RGSM	TOTAL NUMBER OF ALL FISH	SAMPLING EFFORT (m ²)
ANGOSTURA REACH				
2 Paseo del Norte upper	150	-	822	2,584.964
3 Paseo del Norte lower	254	-	1,309	6,319.197
4 Rio Bravo upper	23	-	919	3,078.569
5 Rio Bravo middle	51	-	1,194	3,545.019
6 Rio Bravo lower	77	-	1,534	2,632.178
Angostura Reach Total	555	0	5,778	18,159.927
ISLETA REACH				
7 Los Lunas	1,925	-	3,652	3,633.836
8 Belen	112	-	2,961	1,205.926
9 Jarales	158	-	5,137	3,910.236
9_5 Bernardo	101	11	4,272	2,274.752
10 S of Bernardo	231	1	2,418	2,813.585
11 Sevilleta	4	-	241	3,084.615
Isleta Reach Total	2,531	12	18,681	16,922.950
SAN ACACIA REACH				
12 S of San Acacia	7	-	418	2,506.894
13 Socorro	12	2	155	3,187.863
14 San Antonio	4	-	157	1,685.933
15 Bosque del Apache	1	-	476	1,900.724
16 S of Bosque del Apache	3	-	551	2,917.638
17 San Marcial	3	-	498	2,485.861
18 S of San Marcial	1	-	1,161	3,668.971
19 S of LFCC Return	5	-	304	2,620.499
20 S of Site 19	0	-	178	2,354.438
San Acacia Reach Total	36	2	3,898	23,328.821
MONTHLY TOTALS	3,122	14	28,357	58,411.7

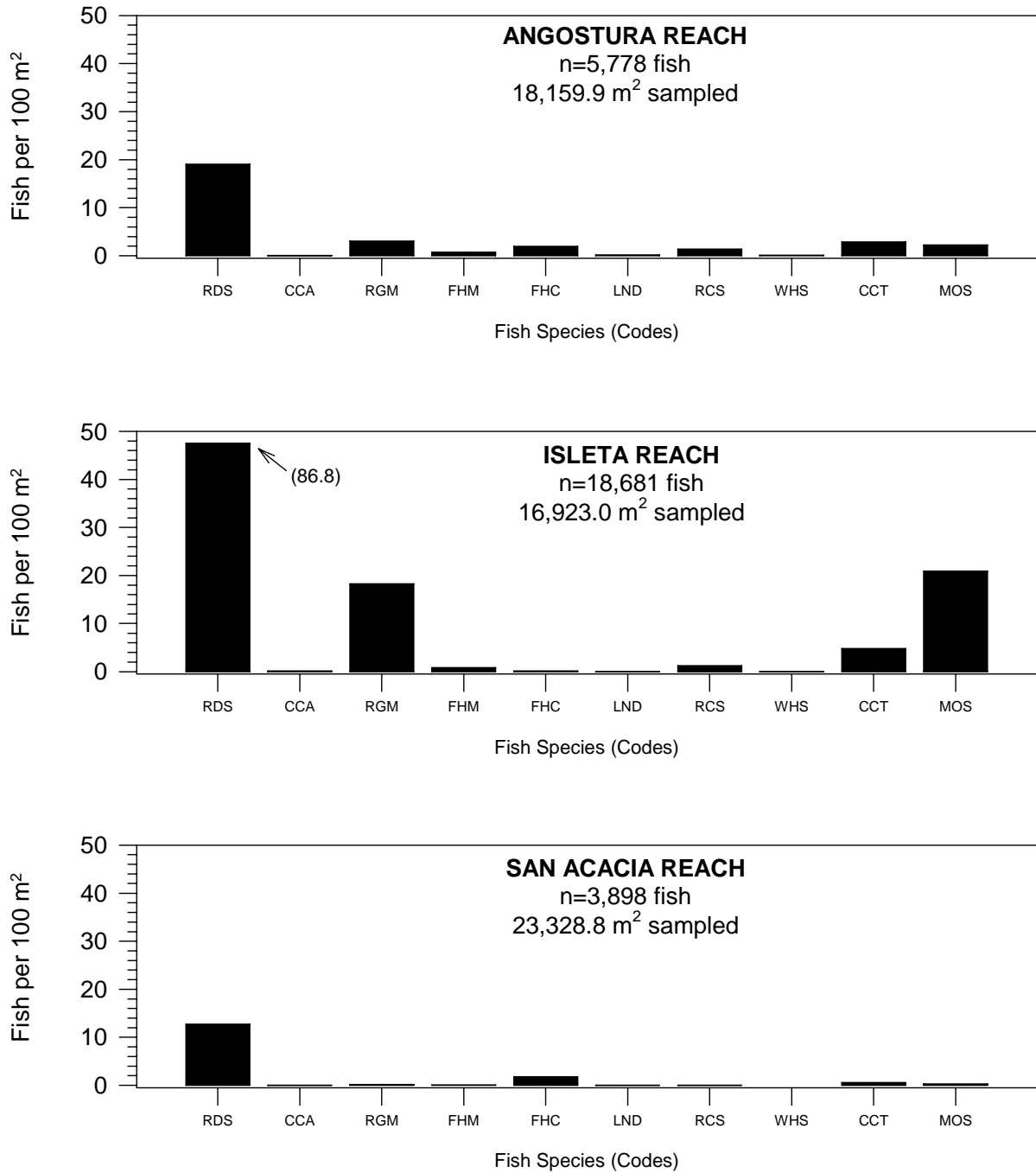


Figure 3. Catch rates, for the 10 focal species, by river reach during October 2007 at Rio Grande silvery minnow Population Estimation Program sampling units (see Table 2 for fish species codes).

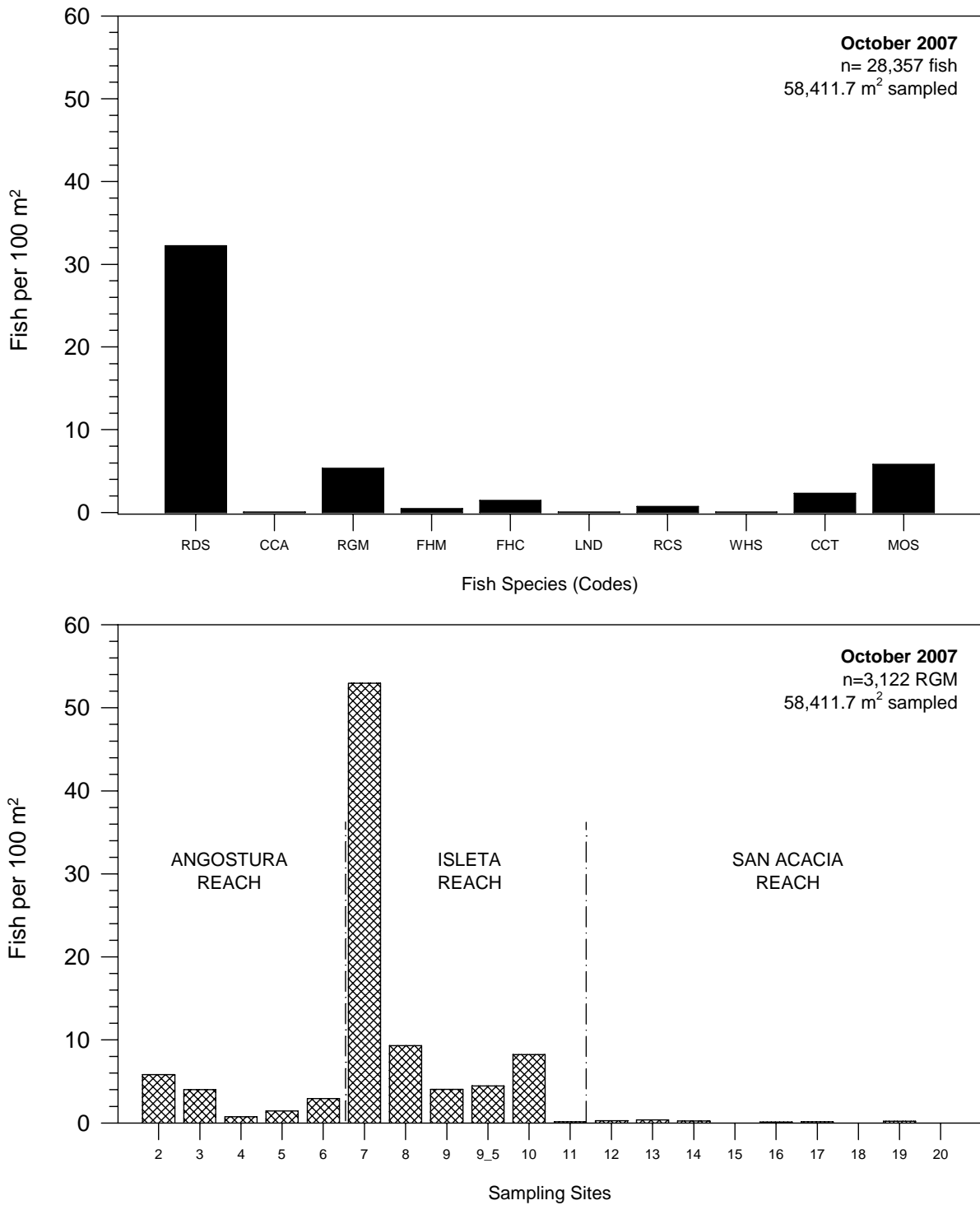


Figure 4. Catch rates for ten focal species (upper graph), including Rio Grande silvery minnow, (RGM; lower graph) during October 2007 at Rio Grande silvery minnow Population Estimation Program sampling units (see Table 2 for fish species codes).

silvery minnow were recorded in the upper portion of the Isleta Reach. The upper portion of the Angostura Reach yielded the most Rio Grande silvery minnow while very few individuals were collected from any of the sampling units in the San Acacia Reach.

Depletion Sampling

Multiple seine haul samples within discrete mesohabitats were used to generate depletion model estimates using data collected in 2006 and 2007 (Table 5). The best model for the seine haul data (based on the lowest AIC_c value) was by mesohabitat only and was supported by a high model weight. Riffles (RI) did not yield Rio Grande silvery minnow and so capture probability could not be estimated. Debris piles (DE) almost invariably formed pools along the shoreline of the main bank or islands and so the capture probability estimate for SHPO was used for this mesohabitat; low densities in DE mesohabitat precluded a separate calculation. The second best model was by mesohabitat and location combined, but the model weight was substantially lower (0.018) than that for the mesohabitat-only model. The capture probability estimates (i.e., proportion of fish removed per seine haul) for the different mesohabitats varied from 0.241 (backwaters) to 0.823 (shoreline pools). Low numbers of Rio Grande silvery minnow in offshore pools (PO) precluded the calculation of a rigorous capture probability estimate for this mesohabitat during 2006. However, additional data were collected during 2007 in pool mesohabitat, which greatly reduced the variability and provided a more precise capture probability. The associated standard errors for estimates were consistent between mesohabitats and ranged between 0.044 and 0.076.

There were differences in mean densities of Rio Grande silvery minnow between open and closed samples made in run habitats for individual sampling units and for all sampling units combined. However, there were also differences in the densities of Rio Grande silvery minnow among sampling units. The most appropriate comparison, given the above observation, was between open and closed samples made at an individual sampling unit. This comparison (interaction of sampling unit and sampling technique) yielded a significant difference ($F = 6.61$; $p < 0.0001$); the mean density of Rio Grande silvery minnow was higher in the closed samples than in the open samples. However, there were exceptions to this trend when comparing individual sampling units (i.e., sometimes the open sampling method yielded more fish than did the closed sampling method). For all sampling units combined, the open sampling method yielded a lower density of Rio Grande silvery minnow ($N = 284$, mean density = $1.60/100m^2$, $SD = 5.23$) than did the closed sampling method ($N = 276$, mean density = $6.80/100m^2$, $SD = 21.74$). When examining the difference between open and closed samples for the different age-classes, a similar pattern emerged. Age-0 individuals had lower ($F = 6.37$; $p < 0.0001$) densities in open samples ($N = 284$, mean density = $1.55/100m^2$, $SD = 5.13$) than in closed samples ($N = 276$, mean density = $6.69/100m^2$, $SD = 21.63$). Age-1 individuals also had lower ($F = 4.08$; $p < 0.0001$) densities in open samples ($N = 284$, mean density = $0.06/100m^2$, $SD = 0.37$) than in closed samples ($N = 276$, mean density = $0.11/100m^2$, $SD = 1.08$). Based on differences between the open and closed samples, we used only the closed sample data to estimate the densities of Rio Grande silvery minnow in runs.

Additional experiments were conducted in 2007 to further refine the capture probability estimates in the non-run (BW, PO, SHPO, SHRU) mesohabitats. However, comparisons between open and closed sampling efforts produced inconclusive results from the three sampling units. Two of the three localities (Population Monitoring sampling units [#2 and #7]) did not yield adequate numbers of Rio Grande silvery minnow (in either open or closed habitats) to conduct a rigorous comparison of population estimates using the open or closed sampling methods. The other locality (Population Estimation sampling unit [#7]) yielded modest numbers of Rio Grande silvery minnow. The AIC_c model results suggest that the sampling method (open vs. closed) was having an effect on the estimate of p (Table 6). The most parsimonious model with method as an effect (Model B)

Table 5. Rio Grande silvery minnow depletion removal analysis and modeling results for seining data collected from multiple mesohabitat types and locations in the Middle Rio Grande (2006-2007).

RGSM depletion data

Models	AICc	Delta AICc	AICc Weights	Model Likelihood	Number of Parameters	Deviance
A-{Mesohabitat}	312.6662	0	0.9822	1	4	697.2313
B-{Mesohabitat+Location}	320.6828	8.0166	0.0178	0.0182	20	672.5193
C-{Groups}	360.5569	47.8907	0	0	1	751.1543

A-{Mesohabitat}	Capture Probability Estimate	Standard Error of Estimate	Lower 95% CI of Estimate	Upper 95% CI of Estimate
BW	0.2412	0.0715	0.1288	0.4061
PO	0.6878	0.0509	0.5806	0.7780
SHPO	0.8231	0.0438	0.7207	0.8936
SHRU	0.7192	0.0760	0.5506	0.8427

Table 6. Rio Grande silvery minnow depletion removal analysis and modeling results for open and closed sampling data collected from multiple mesohabitat types and locations at Population Estimation sampling unit #7.

RGSM open vs. closed depletion data

Models	AICc	Delta AICc	AICc Weights	Model Likelihood	Number of Parameters	Deviance
A-{Groups}	1136.3690	0	0.9170	1	33	2734.3322
B-{Location+Method}	1141.1730	4.8040	0.0830	0.0905	14	2777.7410
C-{Habitat*Method}	1165.7341	29.3651	0	0	5	2820.4205
D-{Habitat+Method}	1166.6194	30.2504	0	0	4	2823.3125
E-{Method}	1172.8402	36.4712	0	0	2	2833.5424

Models with a Method Effect	Beta Estimate	Standard Error of Estimate	Lower 95% CI of Estimate	Upper 95% CI of Estimate
B-{Location+Method}	1.7135	0.3313	1.0642	2.3628
C-{Habitat*Method}	4.7626	221.7005	-429.7704	439.2955
D-{Habitat+Method}	1.4639	0.2768	0.9215	2.0063
E-{Method}	1.3611	0.2765	0.8192	1.9030

yielded a beta parameter estimate that did not overlap with zero (indicating a significant effect). While Model C exhibited a high but non-significant estimate because of the confounding effect of captures within the various habitats, the other two models (Models D and E) demonstrated a significant effect of sampling method on the estimate of p . The large differences between locations resulted in a far lower AIC_c model (Model B = 1,141.71) with a method effect than the other possible models with a method effect (Models C = 1,165.73, D = 1,166.62, and E = 1,172.84). Despite a sampling method effect on the estimate of p , individual comparison of population estimates based on sampling method did not demonstrate a consistent pattern. Of the 12 comparisons between mesohabitat patches that yielded estimates of >5 individuals total, five were non-significant, four had a significantly higher estimate for the closed habitats, and three had a significantly higher estimate for the open habitats.

The capture probability estimates for hatchery Rio Grande silvery minnow were higher for all mesohabitats as compared to wild Rio Grande silvery minnow (Table 7). The AIC_c model suggested strong differences between sample location and between the interaction of type (hatchery and wild) and mesohabitat. The largest significant difference (based on a comparison of the upper and lower confidence intervals) in capture probability between hatchery and wild fish (0.7417 and 0.2412, respectively) was for backwater mesohabitat. The other significant difference was for pool mesohabitat (hatchery = 0.8585 and wild = 0.6878). While capture probabilities in both shoreline pools and runs were slightly higher for hatchery fish than for wild fish, neither of these comparisons was significantly different. A total of 200 marked Rio Grande silvery minnow were released into each of the 10 mesohabitats used in this experiment. However, problems were encountered with stocked fish schooling into the corners of the block nets that were set in areas with any water velocity (even after the acclimation period). This precluded making an accurate estimation of population size for habitats where there was flow. The only area where this did not occur was in a backwater where there was no perceptible water velocity. The population estimate for this habitat was 194.1469 (SE = 0.3921) with a 95% LCI of 194.0086 and UCI of 196.5067.

Occupancy Rates from Past Population Monitoring Data

The encounter history for Rio Grande silvery minnow (Table 8) during November 2007 was dominated by a single sampling category (0000 [46.25%]). This represented sampling visits to the same mesohabitat location where Rio Grande silvery minnow were not collected on any of the days (0000). The other sampling encounter categories had a relatively even probability distribution and there were not strong patterns in the combinations of encounters. The rarest combination (0110 [0.25%]) was where individuals were collected on days two and three but not on days one or four.

Probability of detection and probability of occupancy estimates during 2007 were calculated for all Rio Grande silvery minnow and for the respective age-classes. Age-0 Rio Grande silvery minnow dominated the relative abundance of age-classes and so there were only very minor differences between the calculations for this age-class and for all age-classes combined. The probability of detection estimate for all Rio Grande silvery minnow was 0.4485 while the estimate for age-0 individuals was 0.4515; probability of detection estimates were much lower for age-1 and age-2 individuals (<0.01). The probability of occupancy estimate for all Rio Grande silvery minnow was 0.5923 while the estimate for age-0 individuals was 0.5827. The occupancy estimate for age-2 individuals was very low as expected. However, analysis of age-1 individuals led to a spurious result (i.e., occupancy approaching 1.0) because the encounter history was static for the only data series where individuals were encountered.

The availability of additional data from 2006 and 2007 allowed for a preliminary calculation of the probability of occupancy for all sampling units combined based on collections within each sampling unit (Table 9). This was different than the preceding analysis (i.e., Table 8) in that the

Table 7. Wild vs. hatchery Rio Grande silvery minnow depletion removal analysis and modeling results for seining data collected from multiple mesohabitat types and locations in the Middle Rio Grande.

RGSM depletion data (Wild vs. Hatchery)

Models	AICc	Delta AICc	AICc Weights	Model Likelihood	Number of Parameters	Deviance
A-{Location}	1121.2497	0	1	1	31	5370.6024
B-{Type*Mesohabitat}	1159.8802	38.6305	0	0	8	5455.4859
C-{Type+Mesohabitat}	1167.9860	46.7363	0	0	5	5469.6033
D-{Type}	1218.3405	97.0908	0	0	2	5525.9643
E-{Mesohabitat}	1225.3781	104.1284	0	0	4	5528.9980

B-{Type*Mesohabitat}	Capture Probability Estimate	Standard Error of Estimate	Lower 95% CI of Estimate	Upper 95% CI of Estimate
Type=Wild RGSM				
BW	0.2412	0.0715	0.1288	0.4061
PO	0.6878	0.0509	0.5806	0.7780
SHPO	0.8231	0.0438	0.7207	0.8936
SHRU	0.7192	0.0760	0.5506	0.8427
Type=Hatchery RGSM				
BW	0.7417	0.0236	0.6928	0.7851
PO	0.8585	0.0307	0.7872	0.9087
SHPO	0.9059	0.0373	0.8033	0.9578
SHRU	0.7766	0.0353	0.6998	0.8382

Table 8. Rio Grande silvery minnow encounter history summaries, probability of detection estimates, and probability of occupancy estimates based on repeated sampling efforts in November 2007.

RGSM encounter history (all age-classes)

Encounters*	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0000	185	46.25	185	46.25
0001	17	4.25	202	50.5
0010	29	7.25	231	57.75
0011	8	2	239	59.75
0100	19	4.75	258	64.5
0101	5	1.25	263	65.75
0110	1	0.25	264	66
0111	10	2.5	274	68.5
1000	30	7.5	304	76
1001	16	4	320	80
1010	14	3.5	334	83.5
1011	5	1.25	339	84.75
1100	15	3.75	354	88.5
1101	10	2.5	364	91
1110	7	1.75	371	92.75
1111	29	7.25	400	100

*1=present and 0=absent over four repeated sampling efforts (e.g., 1011 = present on days 1, 3, and 4 but absent on day 2).

RGSM probability of detection and probability of occupancy estimates

Parameter	Estimate	Standard Error of Estimate	Lower 95% CI of Estimate	Upper 95% CI of Estimate
<i>p</i>: All RGSM	0.4485	0.01976	0.4101	0.4874
<i>p</i>: Age-0 RGSM	0.4515	0.01988	0.4130	0.4907
<i>p</i>: Age-1 RGSM	0.0050	0.00183	0.0025	0.0100
<i>p</i>: Age-2 RGSM	0.3067E-04	0.2189E-04	0.7578E-05	0.1242E-03
ψ: All RGSM	0.5923	0.0288	0.5349	0.6473
ψ: Age-0 RGSM	0.5827	0.0287	0.5257	0.6377
ψ: Age-1 RGSM	0.9999	0.0000	0.9999	0.9999
ψ: Age-2 RGSM	0.1482E-05	0.0000	0.1482E-05	0.1482E-05

*Where *p*=detection probability and ψ (psi)=probability of occupancy.

Table 9. Rio Grande silvery minnow site occupancy analysis among years for all sampling units combined (from Population Monitoring Program) in the Middle Rio Grande based on repeated sampling efforts in November (2005-2007).

RGSM Site Occupancy Models

Models*	AIC _c	Delta AIC _c	AIC _c Weights	Model Likelihood	Number of Parameters	Deviance
A: $\{\Psi(g) \epsilon(g) \gamma(g) p(g^*y^*d)\}$	522.8055	0.0000	0.8815	1.0000	25	540.5062
B: $\{\Psi(g) \epsilon(g) \gamma(g) p(g^*y)\}$	527.1342	4.3287	0.1012	0.1148	24	473.5529
C: $\{\Psi(g) \epsilon(g^*y) \gamma(g) p(g^*y)\}$	530.8182	8.0127	0.0160	0.0182	28	467.1215
D: $\{\Psi(g) \epsilon(g) \gamma(g^*y) p(g^*y)\}$	536.1332	13.3277	0.0011	0.0013	28	472.4366
E: $\{\Psi(g) \epsilon(g^*y) \gamma(g^*y) p(g^*y)\}$	540.2045	17.3990	0.0002	0.0002	32	466.0016

Parameter Estimates from Minimum AIC_c Model (A)**

Label*	Estimate	SE	LCI	UCI
ψ All Fish	1	0	1	1
ψ Age-0	1	0	1	1
ψ Age-1	0.5698	0.1670	0.2585	0.8341
ψ Age-2	0.1608	0.2488	0.0051	0.8768
ϵ All Fish	0.0257	0.0253	0.0036	0.1608
ϵ Age-0	0.1085	0.0526	0.0402	0.2611
ϵ Age-1	0	4.36E-05	0	0.9990
ϵ Age-2	1	0.0029	1.04E-05	1
γ All Fish	0	0	0	0
γ Age-0	0.7458	0.2216	0.2289	0.9667
γ Age-1	0.7581	0.1693	0.3392	0.9503
γ Age-2	1	1	0	1

Estimates of ψ by Year from Minimum AIC_c Model (A)

Group	Year	Estimate	SE	LCI	UCI
All Fish	2005	1	0	1	1
All Fish	2006	0.9744	0.0253	0.9248	1.0240
All Fish	2007	0.9494	0.0493	0.8527	1.0460
Age-0	2005	1	0	1	1
Age-0	2006	0.8915	0.0526	0.7884	0.9946
Age-0	2007	0.8757	0.0593	0.7595	0.9919
Age-1	2005	0.5697	0.1669	0.2426	0.8969
Age-1	2006	0.8959	0.0709	0.7570	1.0348
Age-1	2007	0.9748	0.0334	0.9094	1.0402
Age-2	2005	0.1608	0.2488	-0.3270	0.6485
Age-2	2006	0.8392	0.2488	0.3515	1.3270
Age-2	2007	0.1608	0.2488	-0.3270	0.6485

*Where ψ (psi)=probability of occupancy, ϵ (epsilon)=probability of extinction, γ (gamma)=probability of colonization, p =detection probability, y =year, d =discharge, and g (group)=age-class; group 1 = All Fish, group 2 = Age-0, group 3 = Age-1, and group 4 = Age-2.

**Detailed estimates of p by year and sampling occasion are provided in Appendix E.

variable of interest was the sampling unit vs. individual mesohabitats within a sampling unit. The minimum AIC_c model had constant occupancy (ψ , ψ), extinction (ϵ , ϵ), and colonization (γ , γ) parameters across the two intervals, but detection probabilities (p) varying by year (y) and discharge (d). Note that the “group” variable (g) is the age-class category ($N = 4$, for 0, 1, 2, and all age classes combined). The site occupancy estimate was 1.0 for all age-classes combined and for age-0 individuals but was lower for age-1 (0.5697) and age-2 (0.1608) individuals. Estimates of the probability of extinction were relatively low for all age-classes (0.0256) and age-0 (0.1085) individuals. The extinction rate for age-2 fish was 1.0 because no sampling unit occupied by age-2 fish was also occupied by age-2 fish the following year. Estimates of the probability of colonization were relatively high for age-0 (0.7458) and age-1 (0.7581) individuals. However, because a site for all age-classes never went from unoccupied to occupied, the colonization estimate for this group was zero. Estimates of the probability of occupancy varied among years and age-classes but were most variable for groups with fewer data (i.e., age-1 and age-2 individuals). Detailed Rio Grande silvery minnow detection probability estimates among years and for individual sampling occasions (for all sampling units combined) are provided in Appendix E.

Population Estimation of Rio Grande Silvery Minnow

Population estimates from October 2007 data

Average population estimates of Rio Grande silvery minnow were calculated for each of the 20 units and varied among reaches (Table 10). The lowest average population estimate for sampling units was recorded in the San Acacia Reach (12.24) while the highest was recorded in the Isleta Reach (990.74). The average population estimate for all reaches was 524.48. The lowest coefficient of variation (CV) was recorded in the San Acacia Reach (0.97) while the highest CV was in the Isleta Reach (1.52). The number of sampling units used to calculate total population size was similar between the Isleta ($N = 421$) and San Acacia ($N = 474$) reaches; the shortest reach was Angostura ($N = 275$). The total population estimate was highest in the Isleta Reach ($N = 417,099$) and lowest in the San Acacia Reach ($N = 5,800$). The standard errors associated with population estimates for the three reaches were proportionally comparable for the Angostura and Isleta reaches; standard error was notably lower in the San Acacia Reach. The overall population estimate ($N = 613,638$) had a standard error [SE] of 259,983.21. The upper 95% confidence intervals (CI), particularly in the Isleta Reach, reflected the high densities of Rio Grande silvery minnow in several of the sampling units.

Analysis was also conducted for unmarked Rio Grande silvery minnow. The average population size estimates and associated measures of CV were relatively unchanged for any of the sampling reaches. The total population estimate for unmarked Rio Grande silvery minnow was 609,712. There was no change in the population estimate in the Angostura Reach (between the marked-unmarked vs. unmarked-only) because there were no marked individuals collected in that reach during this study. The bounds of the confidence intervals were similar in all of the sampling reaches.

Population estimates were also generated for the different age-classes of Rio Grande silvery minnow (Table 11). The average population estimates for the different reaches largely reflected the overall estimates (i.e., both age-0 and age-1 individuals included). This was primarily caused by the large numbers of age-0 Rio Grande silvery minnow in all reaches. The coefficient of variation for age-0 individuals was highest in the Isleta Reach and lowest in the San Acacia Reach. Values of CV for age-1 individuals were similar between the Angostura and Isleta reaches; no age-1 individuals were collected in the San Acacia Reach. The overall population estimate for age-0 ($N = 605,885$) Rio Grande silvery minnow was significantly higher than for age-1 ($N = 7,783$) individuals.

Table 10. Rio Grande silvery minnow population estimation results for all sampling reaches and the overall study area in the Middle Rio Grande (all individuals and for only unmarked individuals).

Rio Grande silvery minnow (both marked and unmarked)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	682.11	803.55	275	187,579.25	98,086.57	71,562.81	491,679.66
Isleta	990.74	1,497.65	421	417,099.24	255,618.37	137,899.82	1,261,580.87
San Acacia	12.24	11.85	474	5,799.78	1,865.89	3,135.26	10,728.74
All Reaches	524.48	1,001.87	1,170	613,638.34	259,983.21	276,726.69	1,360,736.12

Rio Grande silvery minnow (unmarked only)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	682.11	803.55	275	187,579.25	98,086.57	71,562.81	491,679.66
Isleta	981.36	1,499.30	421	413,151.56	255,898.43	135,224.47	1,262,302.73
San Acacia	11.64	10.77	474	5,519.06	1,697.22	3,061.89	9,948.11
All Reaches	521.12	1,001.19	1,170	609,711.88	259,804.52	273,798.97	1,357,742.79

Table 11. Rio Grande silvery minnow population estimation results for all sampling reaches and the overall study area in the Middle Rio Grande (age-0 and age-1 individuals).

Rio Grande silvery minnow (age-0)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	678.79	805.24	275	186,667.39	98,292.34	70,790.36	492,223.96
Isleta	973.54	1,502.20	421	409,860.95	256,393.69	132,879.37	1,264,199.23
San Acacia	12.24	11.85	474	5,799.78	1,865.89	3,135.26	10,728.74
All Reaches	517.83	1,001.25	1,170	605,855.37	259,820.43	270,781.80	1,355,559.11

Rio Grande silvery minnow (age-1)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	3.32	2.92	275	911.87	356.25	435.63	1,908.75
Isleta	17.19	17.85	421	7,238.29	3,062.55	3,267.41	16,034.95
San Acacia	0	0	474	0	0	-	-
All Reaches	6.65	12.51	1,170	7,782.96	3,258.53	3,540.39	17,109.55

However, the overall proportion of each age-class exhibited a similar pattern among the three reaches (i.e., populations were highest in the Isleta Reach, moderate in the Angostura Reach, and lowest in the San Acacia Reach).

Comparison of RGSM estimates from Population Monitoring and Population Estimation data

Population estimates were also generated using data from the Population Monitoring Program October 2007 sampling efforts. To facilitate a comparison between the Population Monitoring and Population Estimate data sets, we used a correction factor to adjust observed densities of Rio Grande silvery minnow in runs for the Population Monitoring data. This correction was based on the statistical comparison of open vs. closed sampling in runs during the Population Estimation Program and was calculated as the ratio (4.26) of Rio Grande silvery minnow density in closed runs to their density in open runs. When applied to the Population Estimation data, this ratio results in an estimate of 535,541 (SE = 234,447.36) as compared to the estimate of 613,638 (SE = 259,983.21) when using the actual closed sample data.

For all Rio Grande silvery minnow and only unmarked individuals, the average population estimates per sampling unit were slightly higher than those generated using the Population Estimation Program data (Table 12). The highest average population estimate per sampling unit was recorded in the Angostura Reach (1,096.47) while the lowest was in the San Acacia Reach (288.48). Values of CV ranged from 0.75 in the Angostura Reach to 1.94 in the San Acacia Reach.

The population estimates for the study area varied among reaches with the highest numbers recorded in the Isleta Reach (303,936) and the lowest numbers in the San Acacia Reach (87,713). Reach-specific calculated population estimate values were slightly higher using the Population Monitoring Program data compared to the Population Estimation Program data. The overall population estimate ratio between the two data sets was 1.18. The reach-specific estimates were most divergent for the San Acacia Reach where the Population Monitoring value (N = 136,739) was significantly higher than the Population Estimate value (N = 5,800).

When analyzing only unmarked Rio Grande silvery minnow from the Population Monitoring Program data set, the population estimate dropped very little from what it was when including marked individuals. The ratio of the estimate of unmarked Rio Grande silvery minnow (N = 702,639) relative to the Population Estimation Program data set (1.15) was quite similar to that calculated for the marked/unmarked data set (1.18). The standard errors and confidence intervals of population estimates were similar for the Population Monitoring Program and Population Estimation Program data sets.

While the estimated number of age-0 Rio Grande silvery minnow was higher when calculated using the Population Monitoring than with the Population Estimate data, the reverse was true for age-1 individuals (Table 13). The overall population estimate for Rio Grande silvery minnow using Population Monitoring Program data was 723,888 for age-0 individuals and 2,113 for age-1 individuals while 605,855 (age-0) and 7,783 (age-1) individuals were estimated using Population Estimation Program data. However, neither comparison yielded a statistically significant difference. No age-1 Rio Grande silvery minnow were collected in the San Acacia Reach during either the Population Monitoring efforts or the Population Estimation efforts.

Comparison of RGSM estimates from Population Estimation data (2006 and 2007)

For comparative purposes, population estimates in 2006 were recalculated to reflect updated capture probability estimates for non-run mesohabitats and to include the correction (4.26) based on the statistical comparison of open vs. closed sampling in runs. The updated 2006 population estimate was 56,690 (SE = 19,253.09) overall, 39,757 (SE = 11,144.46) for unmarked

Table 12. Rio Grande silvery minnow population estimation results (using Population Monitoring Program data) for all sampling reaches and the overall study area in the Middle Rio Grande (all individuals and for only unmarked individuals).

Rio Grande silvery minnow (both marked and unmarked)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	1,096.47	825.78	275	301,528.39	100,665.71	159,448.92	570,210.01
Isleta	721.94	550.21	421	303,935.86	93,912.17	168,166.54	549,318.59
San Acacia	288.48	560.49	474	136,738.97	87,713.49	43,269.06	432,122.77
All Reaches	620.51	685.99	1,170	726,000.87	177,960.26	452,188.57	1,165,613.87

Rio Grande silvery minnow (unmarked only)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	1,096.47	825.78	275	301,528.39	100,665.71	159,488.92	570,210.01
Isleta	676.88	601.22	421	284,966.05	102,613.80	143,737.82	564,956.75
San Acacia	274.15	562.96	474	129,945.22	88,099.46	38,929.79	433,749.07
All Reaches	600.55	699.39	1,170	702,638.97	181,434.89	427,040.28	1,156,100.60

Table 13. Rio Grande silvery minnow population estimation results (using Population Monitoring Program data) for all sampling reaches and the overall study area in the Middle Rio Grande (age-0 and age-1 individuals).

Rio Grande silvery minnow (age-0)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	1,096.18	825.46	275	301,448.42	100,627.03	159,418.11	570,017.73
Isleta	716.16	553.37	421	301,503.30	94,450.71	165,520.02	549,203.91
San Acacia	288.48	560.49	474	136,738.97	87,713.49	43,269.06	432,122.77
All Reaches	618.71	686.26	1,170	723,887.73	178,030.26	450,185.90	1,163,993.44

Rio Grande silvery minnow (age-1)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	0.29	0.65	275	79.97	79.47	15.76	405.90
Isleta	5.78	8.50	421	2,432.55	1,453.76	823.49	7,185.63
San Acacia	0	0	474	0	0	-	-
All Reaches	1.81	5.12	1,170	2,113.15	1,331.32	680.44	6,562.52

individuals, 31,010 (SE = 13,759.53) for age-0 individuals, and 25,361 (SE = 10,232.73) for age-1 individuals. Based on a comparison of confidence intervals, the overall Rio Grande silvery minnow population estimate was significantly higher in 2007 than in 2006; the overall population increased by about an order of magnitude between 2006 and 2007. Similar increases were noted for the other categories except age-1 individuals; their estimated numbers declined (but not significantly) from 2006 to 2007.

DISCUSSION

In contrast to population monitoring that provides year-round documentation of trends (i.e., monthly or bimonthly sampling) for the entire ichthyofaunal community, the Population Estimation Program supplements the current Population Monitoring Program by providing a robust yearly estimate of the Rio Grande silvery minnow population during a single time-period (e.g., October). Systematic population monitoring activities provide an assessment of recruitment success over short time periods, a basis for comparing the changes in monthly recruitment success among years, insight to seasonal mortality rates, timely information about the status of the species during periods of reduced abundance, and a valuable tool to assess the real-time effectiveness of adaptive management activities. This study complements the ongoing population monitoring activities and furnishes valuable information necessary to gauge recovery of Rio Grande silvery minnow in the three principal downstream reaches of the Middle Rio Grande (i.e., Angostura, Isleta, and San Acacia). However, a long-term commitment to monitoring populations of Rio Grande silvery minnow will be necessary to ensure that insight gained from this study will have lasting value.

Estimating population size is conducted with statistical techniques that require a series of assumptions. Hence, any estimate of the number of Rio Grande silvery minnow must be presented within the context of those assumptions, especially given inherent variation in densities of organisms in the environment. A series of units, selected at random, was sampled to develop population estimates based on densities of Rio Grande silvery minnow in different mesohabitats. The relative proportional availability of mesohabitat types, combined with actual density estimates in mesohabitats, was used to generate the population estimate at each unit. Density estimates were calculated for each sampling unit and were used to estimate population size for each reach and for the entire Rio Grande study area. A relatively large number of units were sampled intensively in an effort to maintain a high degree of statistical confidence.

Estimation of the abundance of organisms has received considerable theoretical and applied study (for review, see Seber 1992; Schwarz and Seber, 1999). Estimating the number of organisms in the environment is of great interest to biologists studying spatiotemporal population changes. The abundance of different species is of interest to government agencies charged with managing populations of rare organisms (i.e., federally threatened or endangered). Monitoring changes in populations requires estimating species-specific abundance over time, usually from multiple sites.

The use of catch-per-unit-effort (CPUE) to monitor the status of fish populations is well established in fisheries science. Some of the first important theoretical contributions were provided by the mid-1900s (Ricker 1940, 1944; Zippin 1956, 1958). Constant effort on each pass simplifies the CPUE estimator to the standard removal estimator (Otis et al. 1978). The relationship between CPUE and abundance has received considerable attention in the literature (see reviews by Otis et al. 1978, Bannerot and Austin 1983). Experimental and statistical treatment of the issue has demonstrated that CPUE is a valid estimator of abundance and that the relationship is one of strict proportionality for single species (Richards and Schnute, 1986). The work of Richards and Schnute (1986, 1992) and other researchers using CPUE in fisheries applications has appeared in international reviews on the general topic of estimating animal abundance (Seber 1992). Extensive

reviews of the various methods for estimating animal abundance identify CPUE as one of the most widely used and well-researched techniques in fisheries science (e.g., Seber 1992, Schwarz and Seber 1999). CPUE provides a metric by which to gauge the relative increases or decreases (trends) in populations over time and space.

However, there are some instances where knowledge of the actual population size is desirable. Management of federally protected species may require the use of some benchmark by which to gauge the potential success or failure of various management actions (e.g., a target number of individuals may be required to ensure the genetic viability of a population). Managers can determine if the goal has been met or exceeded in any year by referring to a population estimate and its associated confidence interval.

Techniques utilized in this study demonstrated that statistically robust population estimates of Rio Grande silvery minnow, even during a period of relatively low abundance, can be obtained when sampling over a large geographical area. The sampling of 20 randomly selected units yielded Rio Grande silvery minnow population estimates that had modest associated measures of standard error. The large number of samples taken from each sampling unit reduced the sampling variation in density among mesohabitats while the large number of sampling units reduced sampling variation of density across study reaches and over the entire study area.

Depletion (removal) sampling techniques were used to obtain an estimate of density within each mesohabitat. Seine sampling techniques appeared to be appropriate for all mesohabitats. In certain high-density mesohabitats (e.g., backwaters), electrofishing was shown to be comparable to seining but was sometimes ineffective or not possible (because of safety reasons) in deeper portions of these discrete mesohabitats (Dudley et al., 2007). Capture probability estimates from closed mesohabitats were used to correct density estimates in the open mesohabitats that had single seine pass data in 2006. This method was applied because it was reasoned that fish in non-run mesohabitats were more likely to be missed during first-pass sampling than to flee from the area just prior to sampling (Dudley et al., 2007). Since capture probability estimates are inversely proportional to population size, there would have to be a substantial bias (e.g., >50%) to have a large impact on final estimates.

The lack of Rio Grande silvery minnow collected in runs precluded development of a robust capture probability estimate in this mesohabitat in 2006. It was reasoned that shoreline runs would be the most similar mesohabitat to runs. If one were to assume that fish were fleeing in great numbers just prior to being sampled, then the estimate of population for this rather large mesohabitat category could be too low. Intensive closed mesohabitat sampling was conducted in runs during October 2007 to provide additional and more precise data on capture probabilities and estimated densities. The overall density estimates in closed runs were higher than in open runs. While a capture probability estimate is applied to open runs prior to calculating population size, the corrected values were still lower than those documented in the closed runs. Low densities of Rio Grande silvery minnow in run habitats meant that the population size estimates for sampled areas were not very different (i.e., non-run habitats account for the majority of the total number of individuals collected). However, the extensive availability of run habitat at most of the sampling units meant that any resulting population estimate could be too low. While a correction factor could be developed for open vs. closed sampling in run habitat, it is likely that any correction would be subject to change based on other factors (e.g., spatial and temporal differences in flow conditions of runs). Possible issues with using a uniform correction factor and the observed difference between sampling methods in the run habitat suggests that closed samples should be used to estimate densities of Rio Grande silvery minnow in runs for future sampling years.

Additional depletion sampling (including random [open or closed] sampling at the same mesohabitat location between days) was implemented in 2007 to further address this question by quantifying the relative importance of this bias. While intensive open and closed sampling in non-run mesohabitats (e.g., shoreline pools, backwaters etc.) was conducted at three sampling localities, there were no consistent patterns in the estimates of Rio Grande silvery minnow population using

either open or closed sampling. This indicates that the current capture probability estimates for non-run mesohabitats are probably adequate to use in combination with first pass capture densities for the purpose of calculating population size. However, the low densities of Rio Grande silvery minnow (documented by both techniques) at two of the three sampling localities reduced the statistical power of the comparisons. It was also documented that the time required to conduct closed sampling at a mesohabitat location was about five times longer than with open sampling because of the additional effort needed to set up the block nets. Future study should be conducted to address this question and to determine the relative benefits of increased sampling across a diversity of mesohabitats and conditions vs. the potential advantages of closing off a smaller number of mesohabitat sampling locations.

Discrete sampling of hatchery and wild Rio Grande silvery minnow in closed mesohabitats was conducted to determine how estimates of capture probability might differ between the two groups. Several significant differences were documented between hatchery and wild fish for specific mesohabitat types. In all cases, hatchery fish were more easily captured than were wild fish. This is not surprising considering that wild fish have the advantage of long-term acclimation to the local environment. In contrast, the hatchery fish used were only exposed to river conditions for less than a day before being subjected to capture experiments. It is possible that hatchery fish that are stocked and allowed to acclimate to river conditions over a several week or month period would not show a similar effect. It was determined that changing capture probability estimates for marked fish would not be prudent based on the possible effects of acclimation period, age, and flow. Further study would be required to investigate the relative impact of these factors on capture probability estimates. However, it was noted that population estimates in closed mesohabitats closely matched the known number of Rio Grande silvery minnow placed into those habitats. While this comparison was based on limited data, it indicates that current methods to calculate mesohabitat-specific capture probability estimates are relatively accurate.

Probability of detection values were used to estimate both the proportion of mesohabitat locations occupied and the proportion of sampling units occupied by Rio Grande silvery minnow during population monitoring efforts from 2005 to 2007 (based on November sampling efforts). There are numerous benefits in being able to document the estimated site occupancy rate of species over time. Probability of detection estimates can provide insight to patterns of site occupancy of Rio Grande silvery minnow both within and among sampling units. Site occupancy models can be developed over time to incorporate changes in the probability of detection and the presence/absence patterns at a particular site.

Site occupancy rates at the mesohabitat level were generated using techniques developed by MacKenzie et al. (2002, 2003, and 2006). The large decline in the abundance of Rio Grande silvery minnow from 2005 to 2006 was reflected in changes in the site occupancy rates at the established Population Monitoring Program sampling units. There was a noticeable decline in the percentage of sites occupied by age-0 Rio Grande silvery minnow between 2005 and 2006 (Dudley et al. 2007). Probability of detection estimates were lower than those recorded in 2005 but similar to those recorded in 2006. Site occupancy estimates for 2007 reflected the modest amount of variation in the encounter histories and were higher than those recorded in 2006 but lower than those recorded in 2005.

More detailed site occupancy models at the sampling unit level were generated this year based on the availability of extensive data spanning three years (2005-2007). The most parsimonious model suggested that the occupancy, extinction, and colonization estimates were constant but that detection probabilities varied by year and with discharge. Additional data from future years will likely result in some changes to the structure of the model since it is based on a relatively short-term data set. For example, the influence of discharge on the detection probabilities was likely included as an important parameter in the model because of the lower estimate of p in 2006 compared with either 2005 or 2007. It is unknown if this pattern will remain consistent over

time. Parameter estimates from the model suggest that site occupancy is highest for age-0 fish and lowest for age-2 fish. However, the low number of age-1 and age-2 individuals adds notable variation to the estimates for these age-classes. The overall site extinction probability of Rio Grande silvery minnow is relatively low (0.0257) based on data collected over the past three years. Estimates of site occupancy suggest a minor decline from 2005 to 2007 but this was not supported with any statistically significant differences among years. Based on data collected over the past decade, it is likely that parameter estimates could change dramatically over a short time period when drought conditions return to the Middle Rio Grande. Thus, the long-term site extinction probability should not be based on recently collected data during a relatively stable discharge period (i.e., modest spring runoff and the avoidance of massive river drying).

The population estimate of Rio Grande silvery minnow for 2007 was based on an intensive sampling regime. A high degree of precision was obtained in mapping mesohabitats and determining the areas and densities of silvery minnow in specific mesohabitats. Data were collected from a relatively large number of sampling units over a one-month period. Subsequent powerful statistical and modeling analytical techniques were used to examine the data and calculate population estimates. The methodology employed allowed for calculations of population size of Rio Grande silvery minnow among reaches, for marked and unmarked fish, and between age-classes. The sampling variances associated with population estimates were reasonable, especially given the widely variable observed densities of Rio Grande silvery minnow among sampling units.

There were differences in the sampling variance of population estimates among reaches and between all-fish and unmarked-only categories (the patchy distribution of marked Rio Grande silvery minnow appears, in part, to be affecting these values). It is likely that recently stocked Rio Grande silvery minnow have not had adequate time to redistribute within or among sampling reaches. It is also possible that these fish are more likely to school together than with wild individuals, which could further contribute to their relatively clumped distribution.

While large numbers of Rio Grande silvery minnow have been annually stocked into the river for at least the past five years (including 2006), there was little correlation between these stocking numbers and this population estimate. However, this is not surprising considering that while populations of Rio Grande silvery minnow have increased or decreased over several orders of magnitude in the past few years, this variation could be explained almost entirely from critical aspects of the annually dynamic hydraulic regime (Dudley and Platania, 2008) as opposed to the steady input of hatchery fish. In addition, the Rio Grande silvery minnow stocked in 2007 appear not to have dispersed widely throughout the system and/or had relatively high mortality rates. Only a few of the sampling units yielded marked individuals and the distribution limits, based on tag color and stocking date, indicate a highly clumped pattern of abundance. Mortality rate of Rio Grande silvery minnow stocked in the spring would be expected to be high, especially if those individuals had spawned. However, the young of those marked fish would be included in our population estimate as wild fish. Also, marked individuals stocked in the fall would not have had an adequate time to disperse throughout the system, and would likely be proportionally underrepresented in the population estimate. Increased sampling in the areas where stocked fish were spot released would result in higher population estimates of marked fish. However, the purpose of this study was to estimate the population of wild Rio Grande silvery minnow (i.e., marked fish were noted so that they could be removed from the estimate of population size). Further, only wild individuals (unmarked) are counted toward recovery of the Rio Grande silvery minnow (U. S. Department of the Interior, 2007).

A large number of Rio Grande silvery minnow are salvaged from drying portions of the river each year but the number of individuals released into upstream reaches appears to have had little effect on inter- or intra-annual population fluctuations, based on results from population monitoring (Dudley and Platania, 2008). It is possible that the stresses inflicted on fish during the capture, handling, and transport activities could result in high rates of initial mortality (C. Caldwell, NMSU,

pers. comm.). In addition, many of the salvaged individuals are collected earlier in the year than this study was conducted. These smaller life stages are expected to have higher rates of mortality and it is likely many of these fish perished before recruiting into the population. Additionally, the point stocking of fish does not allow adequate time to ensure full mixing within the population. This will result in a similar effect as that described for hatchery Rio Grande silvery minnow.

There were inadequate numbers of age-2 or age-2+ Rio Grande silvery minnow to conduct separate analyses for either population estimates or for the site occupancy models. The age-class structure of these larger Rio Grande silvery minnow is not well understood. While some data suggest that the largest Rio Grande silvery minnow collected over a century ago may survive up to five years (Cowley et al. 2006), it is unclear how well those data relate to current conditions. Despite these uncertainties, sampling efforts completed during this project resulted in the capture of the full range of sizes (or ages) of Rio Grande silvery minnow presumed to be present in the wild at this time of year (range = 30 to 80 mm SL).

The population estimates from October 2007 data were generated following a period of improved (as compared with 2006) Rio Grande silvery minnow spawning and recruitment (Dudley and Platania, 2008). There have been multiple massive changes in the abundance of Rio Grande silvery minnow within a relatively short period (1999-2007). Recent changes (i.e., within the past four years) have been some of the most dramatic during the period of record; populations have changed by about an order of magnitude (10X) every year since 2003 (Dudley and Platania, 2008). October population monitoring samples illustrate that there was a substantial decline from 2005 to 2006 following by a substantial increase from 2006 to 2007. The mean CPUE (catch per unit effort) of Rio Grande silvery minnow dropped from 36.99 in 2005 to 1.38 in 2006 but rebounded to 10.85 in 2007. Short-term increases and decreases in abundance are indicative of a population dominated by the youngest age-classes (i.e., age-0 and age-1 individuals).

Elevated and extended spring runoff in the Rio Grande during 2004, 2005, and 2007 contrasted with the low-flow conditions observed throughout the Middle Rio Grande during spring of 2002, 2003, and 2006. Portions of the Rio Grande between Isleta Diversion Dam and the southern terminus of the Bosque del Apache National Wildlife Refuge (NWR) were dried sporadically over the period of record. Low flow conditions during the summer of 2007, in portions of the Isleta and San Acacia reaches, resulted in river drying and loss of aquatic life. During periods of low flow, the lower section of the San Acacia Reach of the Rio Grande (downstream of Bosque del Apache NWR) was supplemented by water pumped from the Low Flow Conveyance Channel into the Rio Grande. This strategy prevented river drying but flow in this area of the Rio Grande remained low during summer.

There was a modest difference between the population size estimates when using Population Estimation Program data vs. Population Monitoring Program data. It is likely that the larger estimate obtained using the Population Monitoring Program data was caused by the non-random selection of sampling units. The original Population Monitoring Program units were chosen more than a decade ago to provide localities where Rio Grande silvery minnow could be monitored during periods of both high and low abundance. Of the more than 100 units originally sampled, a total of 20 were selected because of their increased likelihood of remaining wetted through periods of drought and also because they consistently yielded higher numbers of Rio Grande silvery minnow. Units that failed to consistently yield Rio Grande silvery minnow were eliminated. This original strategy for sampling unit selection has proven very successful over time in allowing trends to be detected even during periods of low abundance. However, for the purposes of generating a population estimate, the Population Monitoring Program data appear to be overestimating the number of Rio Grande silvery minnow. Further, since the Population Monitoring Program data were not collected randomly, they violate the assumptions of the statistical methodology applied to them. In contrast, the sampling units for the Population Estimation Program were chosen at random and thus meet the statistical assumptions of the population estimation formulae. These units were

occasionally in areas with complex mesohabitats but were frequently in the dominant channelized regions of the Middle Rio Grande and often in areas that dry during periods of river dewatering.

Also, there were a number of differences in how the data were gathered and compiled during the Population Estimation Program vs. Population Monitoring Program studies. While the Population Estimation Program relied on actual mapping and precise calculation of the areas of mesohabitats for each unit, the Population Monitoring Program simply utilized stream width approximations and much less refined estimates of mesohabitat area. These areas were used to generate density estimates of fish in both studies but a much higher degree of confidence should be ascribed to data collected as part of the Population Estimation Program. Also, there was a nonrandom selection of mesohabitats for sampling during the Population Monitoring Program. This selection process could have led to higher density estimates of Rio Grande silvery minnow since less sampling effort is allocated to typically low density mesohabitats and lower quality or smaller mesohabitat patches. Thus, the population size estimates generated as part of the Population Estimation Program are more statistically valid and realistic compared to the estimates generated using Population Monitoring Program data.

For comparative purposes, population estimates in 2006 were recalculated to reflect updated capture probability estimates and a correction for open vs. closed sampling in runs. The updated population estimate calculations for 2006 resulted in an estimate of 39,757 (SE = 11,144.46) wild fish as compared with the original estimate of 24,469.75 (SE = 7,596.43); this increase was not significant based on a comparison of confidence intervals (Dudley et al., 2007). The overall population increased by about an order of magnitude between 2006 and 2007 based on Population Estimation Program data, which was very similar to the relative increase obtained by a simple comparison of CPUE values between 2006 and 2007 (Dudley and Platania, 2008). This was in contrast to a comparison of population estimates derived from Population Monitoring Program data, which indicated a more modest increase in population over those two years (Dudley et al., 2007). Known violations of statistical assumptions used for generating a population estimate based on Population Monitoring Program data appear to be producing spurious results. While it is recommended that estimates be derived from Population Monitoring Program data for several more years, this exercise may be superseded by a more rigorous effort to relate CPUE values to population estimates. However, the limited amount of data at this time preclude the development of a robust statistical relationship between the trends in Rio Grande silvery minnow abundance as documented by the Population Monitoring Program and Population Estimation Program.

Further, the 2006 and 2007 estimates of Rio Grande silvery minnow population size should be viewed cautiously as they are only two data points and are preceded by the rigorous long-term Population Monitoring Program that was initiated in 1993. There have been numerous periods of rapidly expanding and contracting population size that have occurred over the past 15 years. While estimates from a few years provide a useful starting point for long-term monitoring, its importance (both statistically and from a resource management standpoint) will only be realized after multiple years of population estimation data are collected and analyzed.

The site occupancy data should be used in combination with population estimate data to provide a more complete understanding of the conservation status of Rio Grande silvery minnow. It is well known that simply having large numbers of a particular species in an area doesn't ensure its long-term survival. This is particularly true for short-lived species such as Rio Grande silvery minnow. The vast changes in populations of this species within short time periods underscore the need to ensure the presence of individuals over a broad geographical range. Changing environmental conditions within a particular region (either natural or manmade) can have rapid and severe impacts to local populations of Rio Grande silvery minnow. Large populations within these affected regions can be decimated within days because of river dewatering. Alternatively, the lack of spring runoff can inhibit spawning and limit recruitment to such a degree that populations decline

several orders of magnitude within a year. The short life span of this species means that, following periods of low recruitment, total population size is not well buffered by surviving age-classes. For these reasons, it is imperative that populations of Rio Grande silvery minnow are established at multiple locations within its current range and at multiple locations within its historical range to ensure its long-term persistence in the wild.

The success of this project will be evaluated annually but insight into the efficacy of estimating the population size of Rio Grande silvery minnow will require a multi-year commitment. Data from future year's efforts will provide additional information that will supplement recent population estimation activities and furnish valuable information necessary to gauge recovery of Rio Grande silvery minnow in the three principal reaches of the Middle Rio Grande. Ultimately, these data will be used to evaluate progress towards meeting Rio Grande silvery minnow recovery goals, following both management actions and stochastic environmental events.

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LITERATURE CITED

- Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. *In*: B. N. Petrov and F. Csaki (eds.). Second International Symposium on Information Theory. Akademiai, Budapest.
- Bannerot, S. P., and C. B. Austin. 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. *Transactions of the American Fisheries Society* 112: 608-617.
- Bestgen, K. R., B. Mefford, J. Bundy, C. Walford, B. Compton, S. Seal, and T. Sorensen. 2003. Swimming performance of Rio Grande silvery minnow. Final Report to U. S. Bureau of Reclamation, Albuquerque Area Office, New Mexico. Colorado State University, Larval Fish Laboratory Contribution 132, 70 p.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd Edition. Springer-Verlag, New York, New York, USA. 488 pp.
- Cowley, D. E., P. D. Shirey, and M. D. Hatch. 2006. Ecology of the Rio Grande silvery minnow (Cyprinidae: *Hybognathus amarus*) inferred from specimens collected in 1874. *Reviews in Fisheries Science* 14:111-125.

- Dudley, R. K. and S. P. Platania. 1997. Habitat use of Rio Grande silvery minnow. Report to the N.M. Department of Game and Fish, Santa Fe, and U. S. Bureau of Reclamation, Albuquerque, New Mexico. 88 pp.
- Dudley, R. K. and S. P. Platania. 2008. Rio Grande silvery minnow population monitoring program results from 2007. Report to the Middle Rio Grande Endangered Species Act Collaborative Program and the U.S. Bureau of Reclamation, Albuquerque, New Mexico. 159 pp.
- Dudley, R. K., G. C. White, S. P. Platania, and D. A. Helfrich. 2007. Rio Grande silvery minnow population estimation program results from 2006. Report to the Middle Rio Grande Endangered Species Act Collaborative Program and the U.S. Bureau of Reclamation, Albuquerque, New Mexico. 84 pp.
- Finley, D. J., G. C. White and J. P. Fitzgerald. 2005. Estimation of swift fox population size and occupancy rates in eastern Colorado. *Journal of Wildlife Management* 69:861-873.
- Gold, R. L., and L. P. Denis. 1985. National water summary-New Mexico surface-water resources. U. S. Geological Survey water-supply paper 2300:341-346.
- Grossman, G. D., P. B. Moyle, and J. O. Whitaker. 1982. Stochasticity in structural and functional characteristics of an Indiana stream fish assemblage: a test of community theory. *American Naturalist* 120:423-454.
- Hendricks, M. L., C. H. Hocutt, and J. R. Stauffer, Jr. 1980. Monitoring of fish in lotic habitats, p. 205-231. *In*: C. H. Hocutt and J. R. Stauffer, Jr. (eds.). *Biological Monitoring of Fish*. D. C. Heath, Lexington, Massachusetts.
- Huggins, R. M. 1989. On the statistical analysis of capture-recapture experiments. *Biometrika* 76:133-140.
- Huggins, R. M. 1991. Some practical aspects of a conditional likelihood approach to capture experiments. *Biometrics* 47:725-732.
- Lagasse, P. F. 1980. An assessment of the response of the Rio Grande to dam construction-Cochiti to Isleta reach. A technical report for the U.S. Army Engineer District, Albuquerque, Corps of Engineers, Albuquerque, New Mexico. 133 pp.
- MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83:2248-2255.
- MacKenzie, D. I., J. D. Nichols, J. E. Hines, M. G. Knutson, and A. B. Franklin. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology* 84:2200-2207.
- MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. *Occupancy Estimation and Modeling : Inferring Patterns and Dynamics of Species Occurrence*. Elsevier, Burlington, MA.

- Makar, P., Massong, T., Bauer, T., Tashjian, P., and Oliver, K J. 2006. Channel Width and Flow Regime Changes along the Middle Rio Grande NM. Joint 8th Federal Interagency Sedimentation Conf. and 3rd Federal Interagency Hydrologic Modeling Conf., Reno, NV.
- Massong, T., P. Tashjian, and P. Makar. 2006. Recent Channel Incision and Floodplain Evolution within the Middle Rio Grande, NM. Joint 8th Federal Interagency Sedimentation Conf. and 3rd Federal Interagency Hydrologic Modeling Conf., Reno, NV.
- Matthews, W. J. 1986. Fish faunal structure in an Ozark stream: stability, persistence and a catastrophic flood. *Copeia* 1986:388-397.
- Matthews, W. J., R. C. Cashner, and F. P. Gelwick. 1988. Stability and persistence of fish faunas and assemblages in three Midwestern streams. *Copeia* 1988:945-955.
- Nelson, J. S., E. J. Crossman, H. Espinosa-Peréz, L. T. Findley, C. R. Gilbert, R. N. Lea, and J. D. Williams. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. American Fisheries Society, Special Publication 29, Bethesda, Maryland. 386 pp.
- Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monograph* 62. 135pp.
- Platania, S. P. 1993a. The fishes of the Rio Grande between Velarde and Elephant Butte Reservoir and their habitat associations. Report to the New Mexico Department of Game and Fish, Santa Fe, and U. S. Bureau of Reclamation (Albuquerque Projects Office), Albuquerque, NM. 188 pp.
- Platania, S. P. 1993b. Ichthyofaunal survey of the Rio Grande and Santa Fe River, Cochiti Pueblo, NM, July 1993. Report to U. S. Army Corps of Engineers, Albuquerque, NM. 28pp.
- Platania, S. P. 1995. Ichthyofaunal survey of the Rio Grande, Santo Domingo and San Felipe pueblos, NM, July 1994. Report to U. S. Army Corps of Engineers, Albuquerque, NM. 56 pp.
- Richards, L. J., and J. T. Schnute. 1986. An experimental and statistical approach to the question: is CPUE an index of abundance? *Can. J. Fish. Aquat. Sci.* 43:1214-1227.
- Richards, L. J., and J. T. Schnute. 1992. Statistical models for estimating CPUE from catch and effort data. *Can. J. Fish. Aquat. Sci.* 49:1315-1327.
- Ricker, W. E. 1940. Relation of "catch per unit effort" to abundance and rate of exploitation. *J. Fish. Res. Board Can.* 5:43-70.
- Ricker, W. E. 1944. Further notes on fishing mortality and effort. *Copeia* 1944: 23-44.
- Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. *Ecology* 84:777-790.
- Rutherford, D. A., A. A. Echelle, and O. E. Maughan. 1987. Changes in the fauna of the Little River drainage, southeastern Oklahoma, 1948-1955 to 1981-1982: a test of the hypothesis of environmental degradation, p. 178-183. *In*: W. J. Matthews and D. C. Heins (eds.). *Community and Evolutionary Ecology of North American Stream Fishes*. University of Oklahoma Press, Norman, Oklahoma.

- Schlosser, I. J. 1985. Flow regime, juvenile abundance, and the assemblage structure of stream fishes. *Ecology* 66:1484-1490.
- Schwarz, C. J., and G. A. F. Seber. 1999. Estimating animal abundance: review III. *Statistical Science* 14:427-456.
- Seber, G. A. F. 1992. A review of estimating animal abundance II. *International Statistical Review* 60:129-166.
- Skalski, J. R. 1994. Estimating Wildlife Populations Based on Incomplete Area Surveys. *Wildlife Society Bulletin* 22:192-203.
- Starrett, W. C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. *Ecology* 32:13-27.
- Stevens, Don L. and Olsen, Anthony R. 1999. Spatially restricted surveys over time for aquatic resources. *Journal of Agricultural, Biological, and Environmental Statistics* 4:415-428.
- Stevens, Don L. and Olsen, Anthony R. 2003. Variance estimation for spatially balanced samples of environmental resources. *EnvironMetrics* 14:593-610.
- Stevens, Don L. and Olsen, Anthony R. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99:262-278.
- Thompson, S. K. 1992. *Sampling*. Wiley, New York, New York, USA.
- U. S. Department of the Interior. 1994. Endangered and threatened wildlife and plants: final rule to list the Rio Grande silvery minnow as an endangered species. *Federal Register* 59: 36988-36995.
- U. S. Fish and Wildlife Service. 1999. Rio Grande silvery minnow recovery plan. Albuquerque, NM. 141 pp.
- U. S. Fish and Wildlife Service. 2007. Draft revised Rio Grande silvery minnow (*Hybognathus amarus*) Recovery Plan.
- White, G. C. 2005. Correcting wildlife counts using detection probabilities. *Wildlife Research* 32: 211-216.
- White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study* 46 Supplement:120-138.
- Zippin, C. 1956. An evaluation of the removal method of estimating animal populations. *Biometrics* 12:169-183.
- Zippin, C. 1958. The removal method of population estimation. *Journal of Wildlife Management* 22:82-90.
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Appendix A.

Middle Rio Grande sampling units for the Population Estimation Program

Table A-1. Sampling unit localities for the October 2007 Rio Grande silvery minnow Population Estimation Program.

Sampling Unit #	Sampling Unit Locality
ANGOSTURA REACH SITES	
2	New Mexico, Bernalillo County, Rio Grande, ca. 0.4 miles upstream of Paseo del Norte Bridge crossing, Albuquerque. River Mile 191.6 (upper), 191.5 (lower) LOS GRIEGOS QUADRANGLE UTM Easting (upper): 349942 UTM Northing (upper): 3895288 Zone: 13 UTM Easting (lower): 349847 UTM Northing (lower): 3895111 Zone: 13
3	New Mexico, Bernalillo County, Rio Grande, ca. 1.2 miles downstream of Paseo del Norte Bridge crossing, Albuquerque. River Mile 189.9 (upper), 189.8 (lower) LOS GRIEGOS QUADRANGLE UTM Easting (upper): 348954 UTM Northing (upper): 3892935 Zone: 13 UTM Easting (lower): 348801 UTM Northing (lower): 3892807 Zone: 13
4	New Mexico, Bernalillo County, Rio Grande, ca. 1.6 miles upstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. River Mile 179.9 (upper), 179.8 (lower) ALBUQUERQUE WEST QUADRANGLE UTM Easting (upper): 348261 UTM Northing (upper): 3879455 Zone: 13 UTM Easting (lower): 348133 UTM Northing (lower): 3879297 Zone: 13
5	New Mexico, Bernalillo County, Rio Grande, ca. 0.6 miles downstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. River Mile 177.6 (upper), 177.5 (lower) ALBUQUERQUE WEST QUADRANGLE UTM Easting (upper): 347381 UTM Northing (upper): 3876106 Zone: 13 UTM Easting (lower): 347291 UTM Northing (lower): 3875933 Zone: 13
6	New Mexico, Bernalillo County, Rio Grande, ca. 1.0 miles downstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. River Mile 177.3 (upper), 177.2 (lower) ALBUQUERQUE WEST QUADRANGLE UTM Easting (upper): 347155 UTM Northing (upper): 3875786 Zone: 13 UTM Easting (lower): 346986 UTM Northing (lower): 3875681 Zone: 13
ISLETA REACH SITES	
7	New Mexico, Valencia County, Rio Grande, ca. 4.0 miles upstream of Los Lunas Bridge crossing (NM State Highway 49), Los Lunas. River Mile 164.8 (upper), 164.7 (lower) LOS LUNAS QUADRANGLE UTM Easting (upper): 342969 UTM Northing (upper): 3857901 Zone: 13 UTM Easting (lower): 343003 UTM Northing (lower): 3857710 Zone: 13
8	New Mexico, Valencia County, Rio Grande, ca. 2.9 miles upstream of NM 6 bridge crossing, Belen. River Mile 152.4 (upper), 152.3 (lower) TOME QUADRANGLE UTM Easting (upper): 340193 UTM Northing (upper): 3840028 Zone: 13 UTM Easting (lower): 340242 UTM Northing (lower): 3839829 Zone: 13

Table A-1. Sampling unit localities for the October 2007 Rio Grande silvery minnow Population Estimation Program (continued).

Sampling Unit #	Sampling Unit Locality
ISLETA REACH SITES (continued)	
9	New Mexico, Valencia County, Rio Grande, ca. 0.2 miles downstream of NM State Highway 346 Bridge crossing, Jarales. River Mile 140.6 (upper), 140.5 (lower) VEGUITA QUADRANGLE UTM Easting (upper): 338117 UTM Northing (upper): 3823765 Zone: 13 UTM Easting (lower): 338057 UTM Northing (lower): 3823577 Zone: 13
9_5	New Mexico, Socorro County, Rio Grande, ca. 1.0 miles downstream of US Highway 60 bridge crossing, Bernardo. River Mile 130.0 (upper), 129.9 (lower) ABEYTAS QUADRANGLE UTM Easting (upper): 333822 UTM Northing (upper): 3808522 Zone: 13 UTM Easting (lower): 333704 UTM Northing (lower): 3808335 Zone: 13
10	New Mexico, Socorro County, Rio Grande, ca. 3.7 miles downstream of US Highway 60 Bridge crossing, Bernardo. River Mile 126.9 (upper), 126.8 (lower) ABEYTAS QUADRANGLE UTM Easting (upper): 330997 UTM Northing (upper): 3805306 Zone: 13 UTM Easting (lower): 330850 UTM Northing (lower): 3805171 Zone: 13
11	New Mexico, Socorro County, Rio Grande, ca. 1.7 miles upstream of San Acacia Diversion Dam, San Acacia. River Mile 117.9 (upper), 117.8 (lower) LA JOYA QUADRANGLE UTM Easting (upper): 328767 UTM Northing (upper): 3792883 Zone: 13 UTM Easting (lower): 328699 UTM Northing (lower): 3792691 Zone: 13
SAN ACACIA REACH SITES	
12	New Mexico, Socorro County, Rio Grande, ca. 0.8 miles downstream of San Acacia Diversion Dam, San Acacia. River Mile 115.4 (upper), 115.3 (lower) SAN ACACIA QUADRANGLE UTM Easting (upper): 325363 UTM Northing (upper): 3791796 Zone: 13 UTM Easting (lower): 325288 UTM Northing (lower): 3791608 Zone: 13
13	New Mexico, Socorro County, Rio Grande, ca. 4.5 miles upstream of US Highway 380 Bridge crossing, San Antonio. River Mile 91.6 (upper), 91.5 (lower) SAN ANTONIO QUADRANGLE UTM Easting (upper): 328199 UTM Northing (upper): 3760830 Zone: 13 UTM Easting (lower): 328206 UTM Northing (lower): 3760627 Zone: 13
14	New Mexico, Socorro County, Rio Grande, ca. 1.5 miles downstream of US Highway 380 Bridge crossing, San Antonio. River Mile 85.7 (upper), 85.6 (lower) SAN ANTONIO QUADRANGLE UTM Easting (upper): 329256 UTM Northing (upper): 3752209 Zone: 13 UTM Easting (lower): 329312 UTM Northing (lower): 3752018 Zone: 13

Table A-1. Sampling unit localities for the October 2007 Rio Grande silvery minnow Population Estimation Program (continued).

Sampling Unit #	Sampling Unit Locality
SAN ACACIA REACH SITES (continued)	
15	New Mexico, Socorro County, Rio Grande, ca. 0.2 miles downstream of the south boundary of the Bosque del Apache National Wildlife Refuge. River Mile 73.6 (upper), 73.5 (lower) SAN MARCIAL QUADRANGLE UTM Easting (upper): 322489 UTM Northing (upper): 3732572 Zone: 13 UTM Easting (lower): 322331 UTM Northing (lower): 3732455 Zone: 13
16	New Mexico, Socorro County, Rio Grande, ca. 2.2 miles downstream of the south boundary of the Bosque del Apache National Wildlife Refuge. River Mile 71.6 (upper), 71.5 (lower) SAN MARCIAL QUADRANGLE UTM Easting (upper): 320044 UTM Northing (upper): 3730043 Zone: 13 UTM Easting (lower): 319924 UTM Northing (lower): 3729881 Zone: 13
17	New Mexico, Socorro County, Rio Grande, ca. 0.9 miles upstream of San Marcial Railroad Bridge crossing, San Marcial. River Mile 69.5 (upper), 69.4 (lower) SAN MARCIAL QUADRANGLE UTM Easting (upper): 316840 UTM Northing (upper): 3728978 Zone: 13 UTM Easting (lower): 316652 UTM Northing (lower): 3729038 Zone: 13
18	New Mexico, Socorro County, Rio Grande, ca. 5.0 miles downstream of San Marcial Railroad Bridge crossing, San Marcial. River Mile 63.6 (upper), 63.5 (lower) PARAJE WELL QUADRANGLE UTM Easting (upper): 313417 UTM Northing (upper): 3721520 Zone: 13 UTM Easting (lower): 313255 UTM Northing (lower): 3721407 Zone: 13
19	New Mexico, Socorro County, Rio Grande, ca. 0.9 miles downstream of the former confluence with the Low Flow Conveyance Channel. River Mile 59.8 (upper), 59.7 (lower) PARAJE WELL QUADRANGLE UTM Easting (upper): 308328 UTM Northing (upper): 3717266 Zone: 13 UTM Easting (lower): 308230 UTM Northing (lower): 3717093 Zone: 13
20	New Mexico, Socorro County, Rio Grande, ca. 1.1 miles downstream of the former confluence with the Low Flow Conveyance Channel. River Mile 59.6 (upper), 59.5 (lower) PARAJE WELL QUADRANGLE UTM Easting (upper): 308118 UTM Northing (upper): 3716920 Zone: 13 UTM Easting (lower): 308016 UTM Northing (lower): 3716750 Zone: 13

Appendix B.

Mesohabitat and fish sampling figures for all sampling units mapped during the
Rio Grande silvery minnow Population Estimation Program

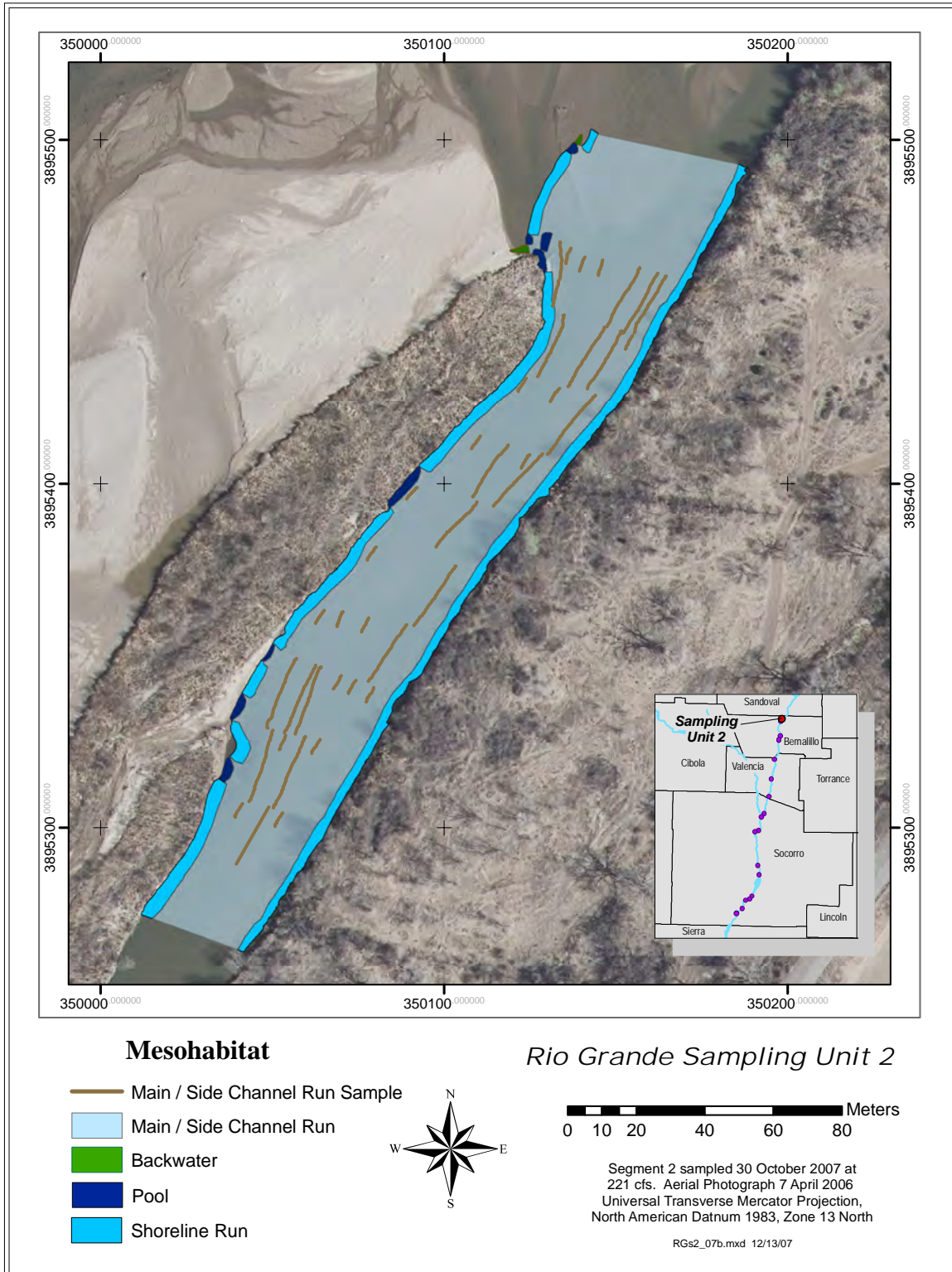


Figure B-1. Map of sampling unit #2 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

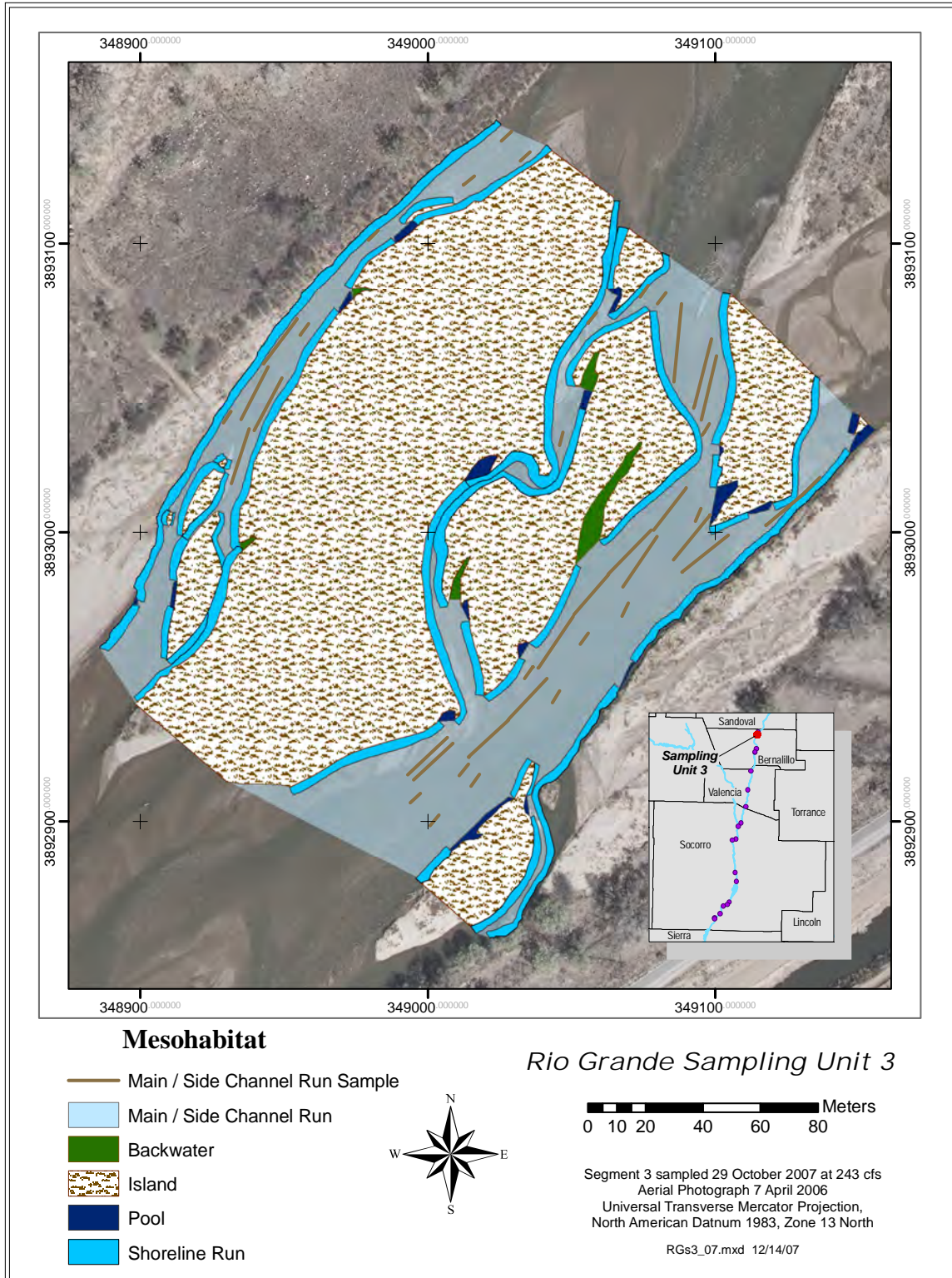


Figure B-2. Map of sampling unit #3 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

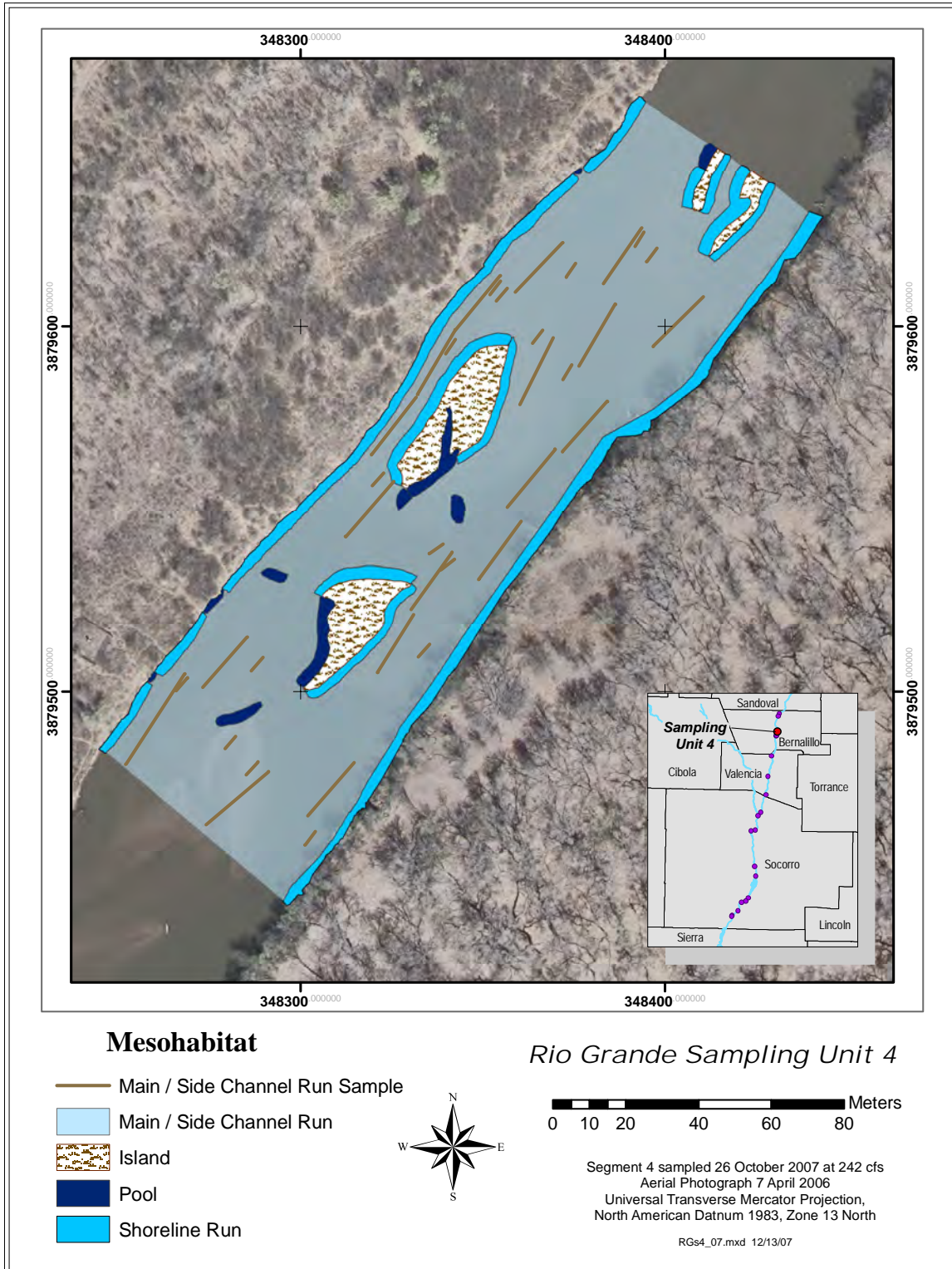


Figure B-3. Map of sampling unit #4 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

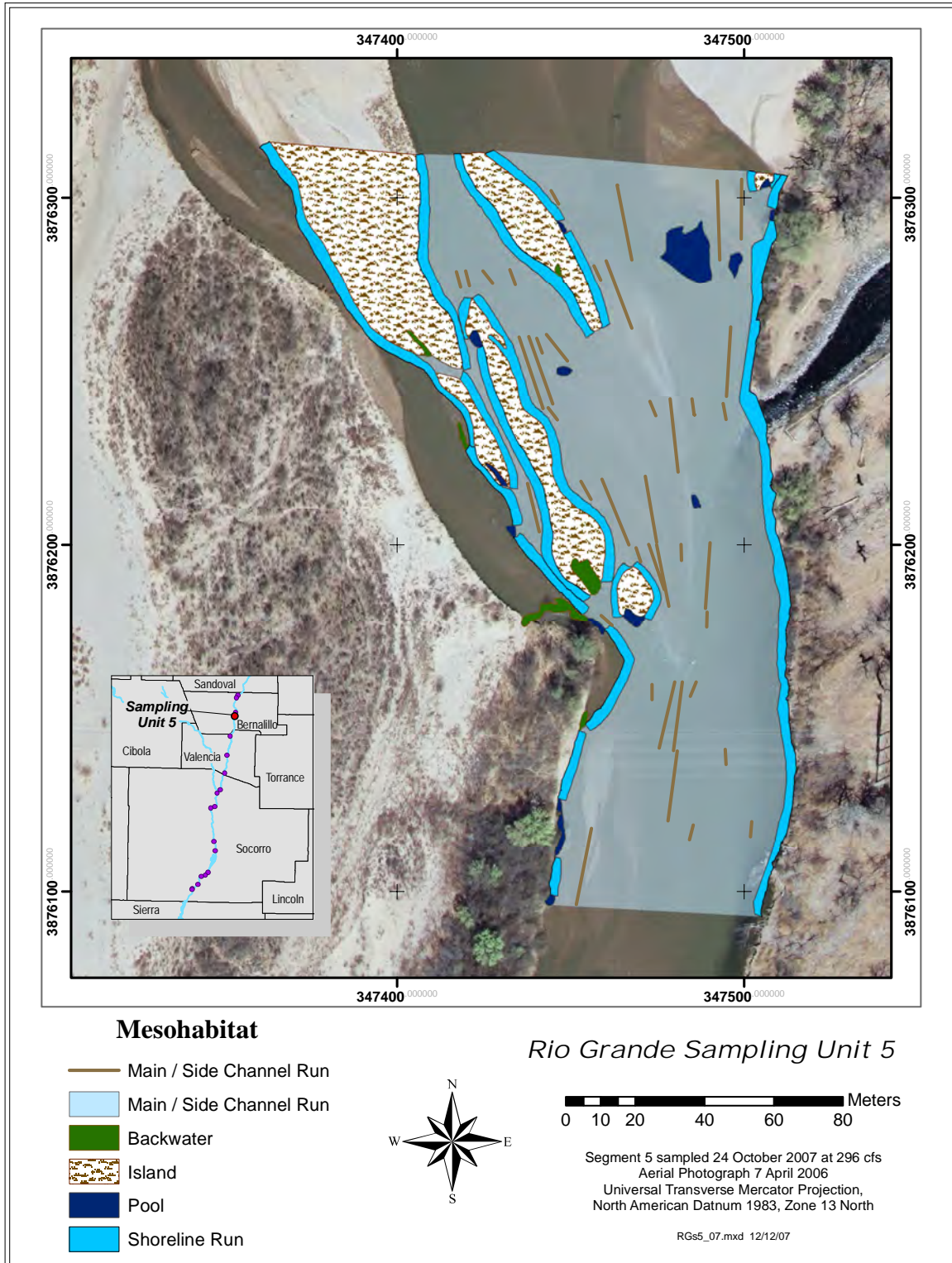


Figure B-4. Map of sampling unit #5 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

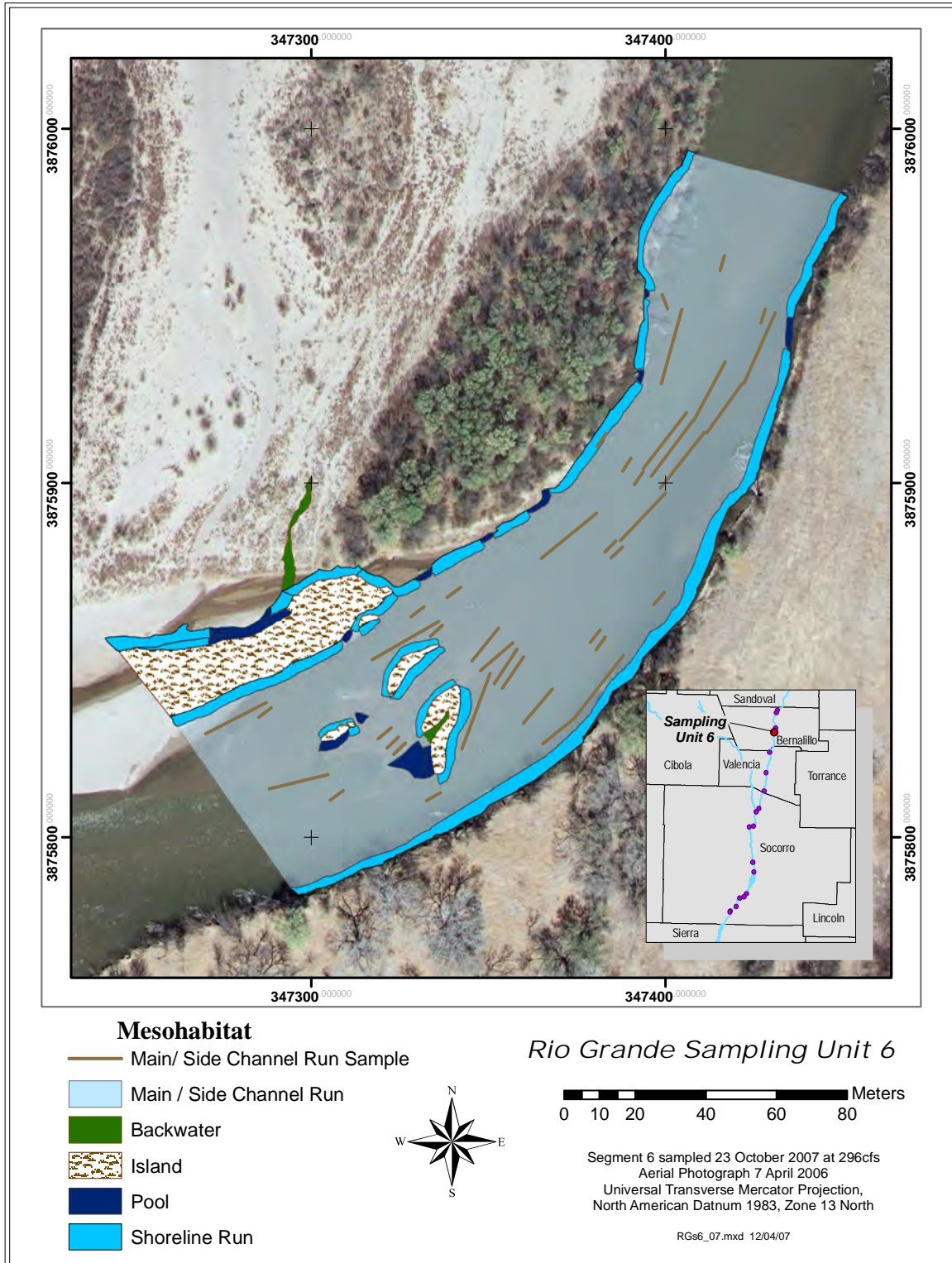


Figure B-5. Map of sampling unit #6 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

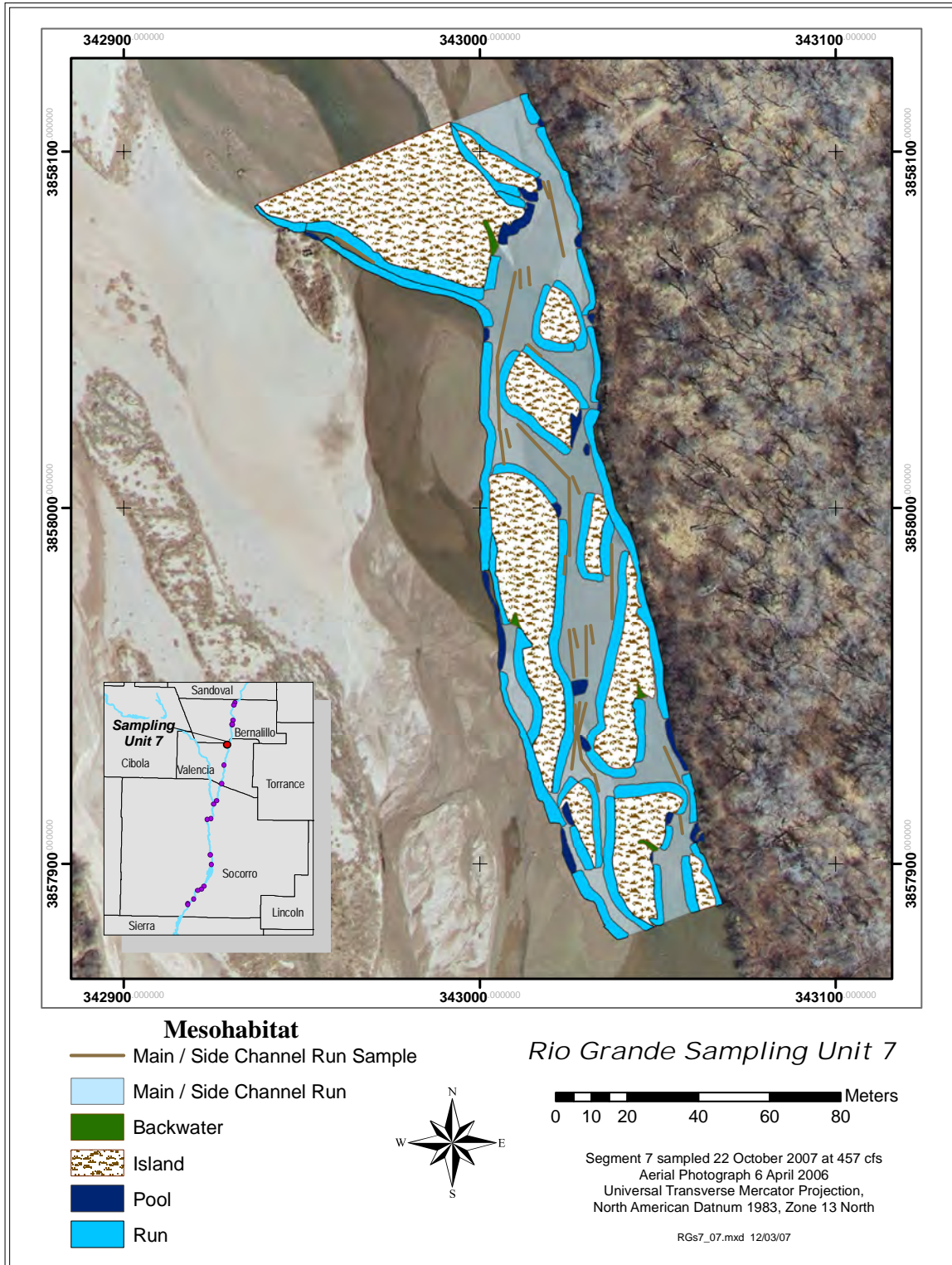


Figure B-6. Map of sampling unit #7 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

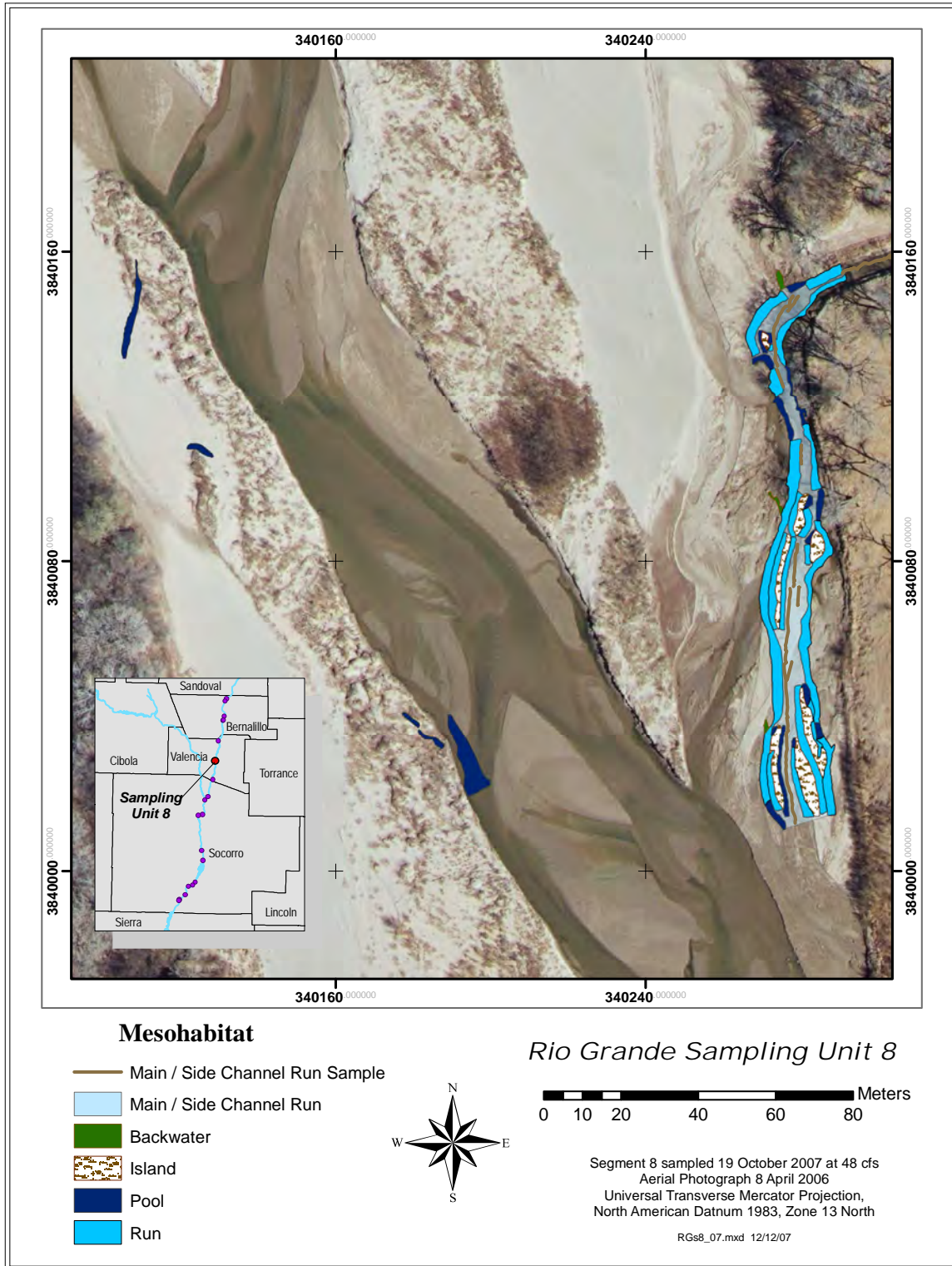


Figure B-7. Map of sampling unit #8 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

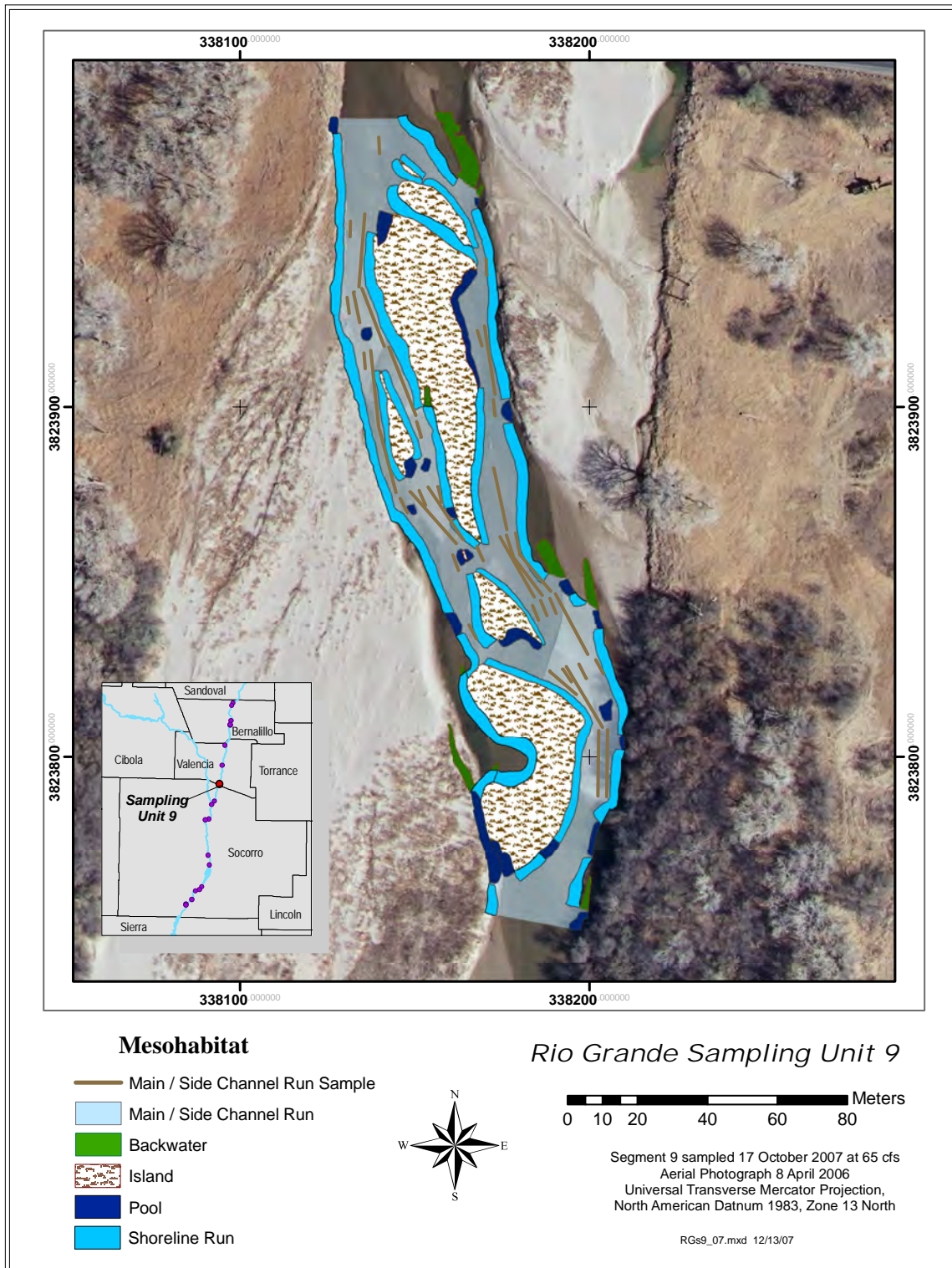


Figure B-8. Map of sampling unit #9 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

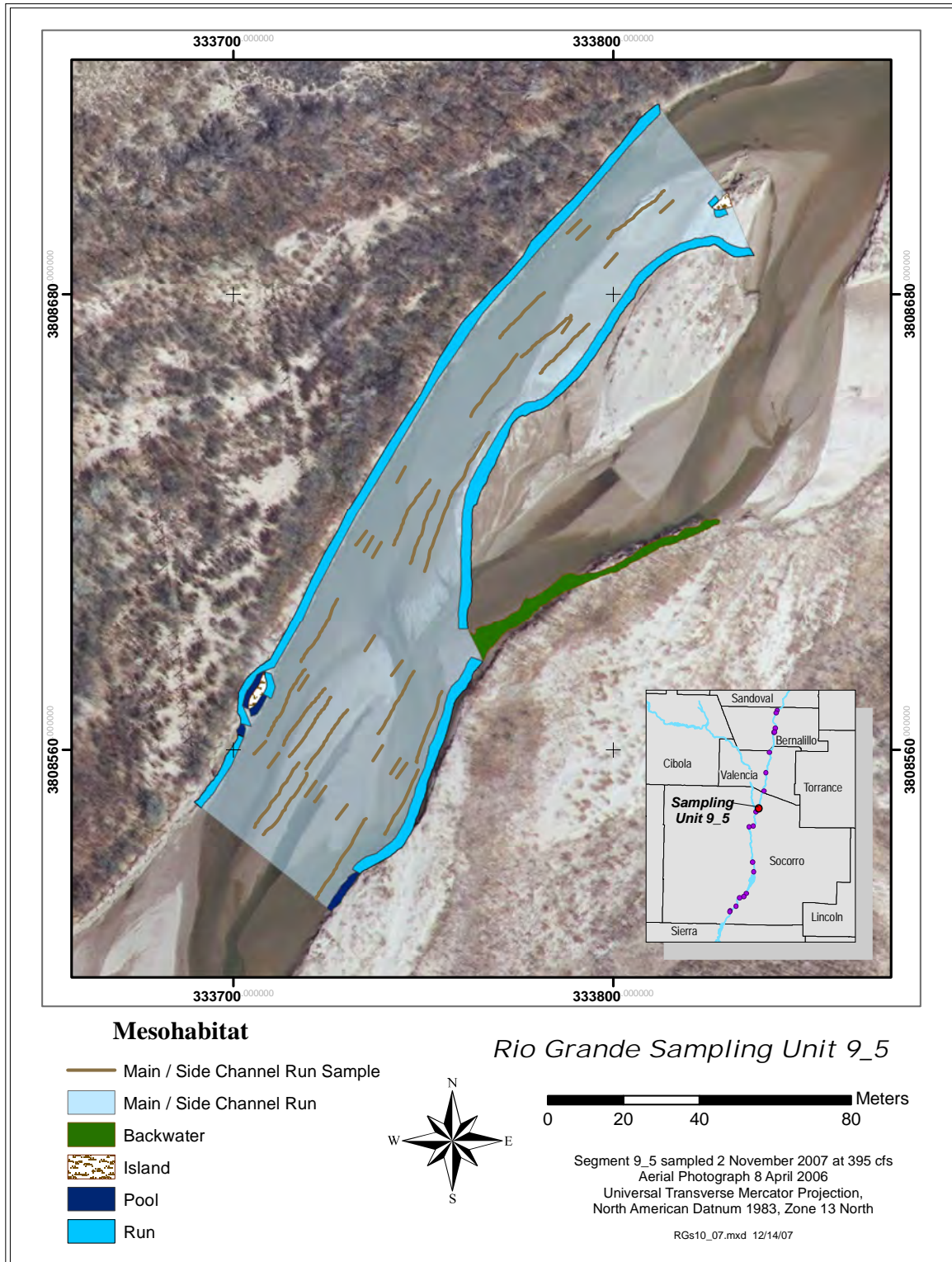


Figure B-9. Map of sampling unit #9_5 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

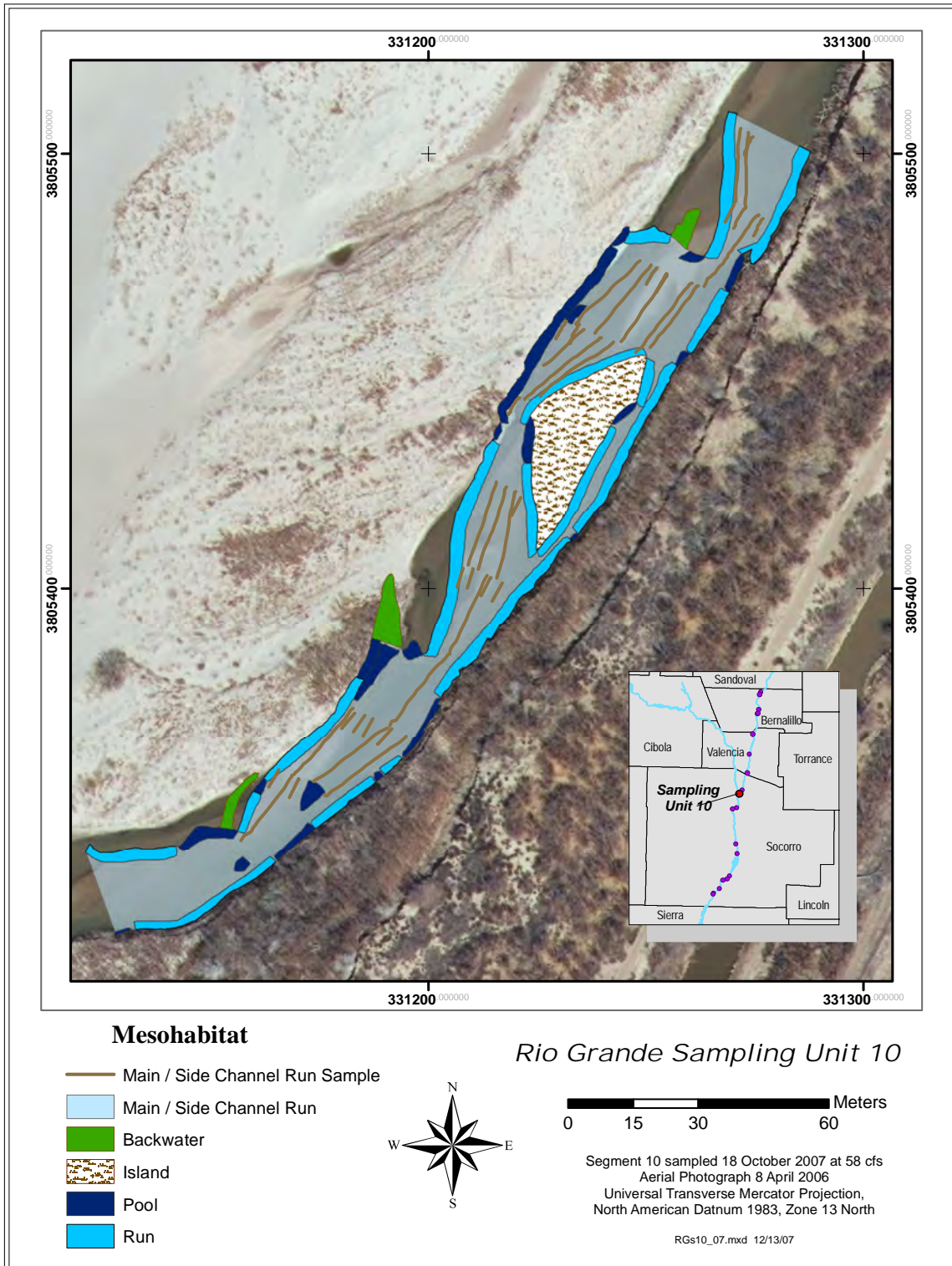


Figure B-10. Map of sampling unit #10 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

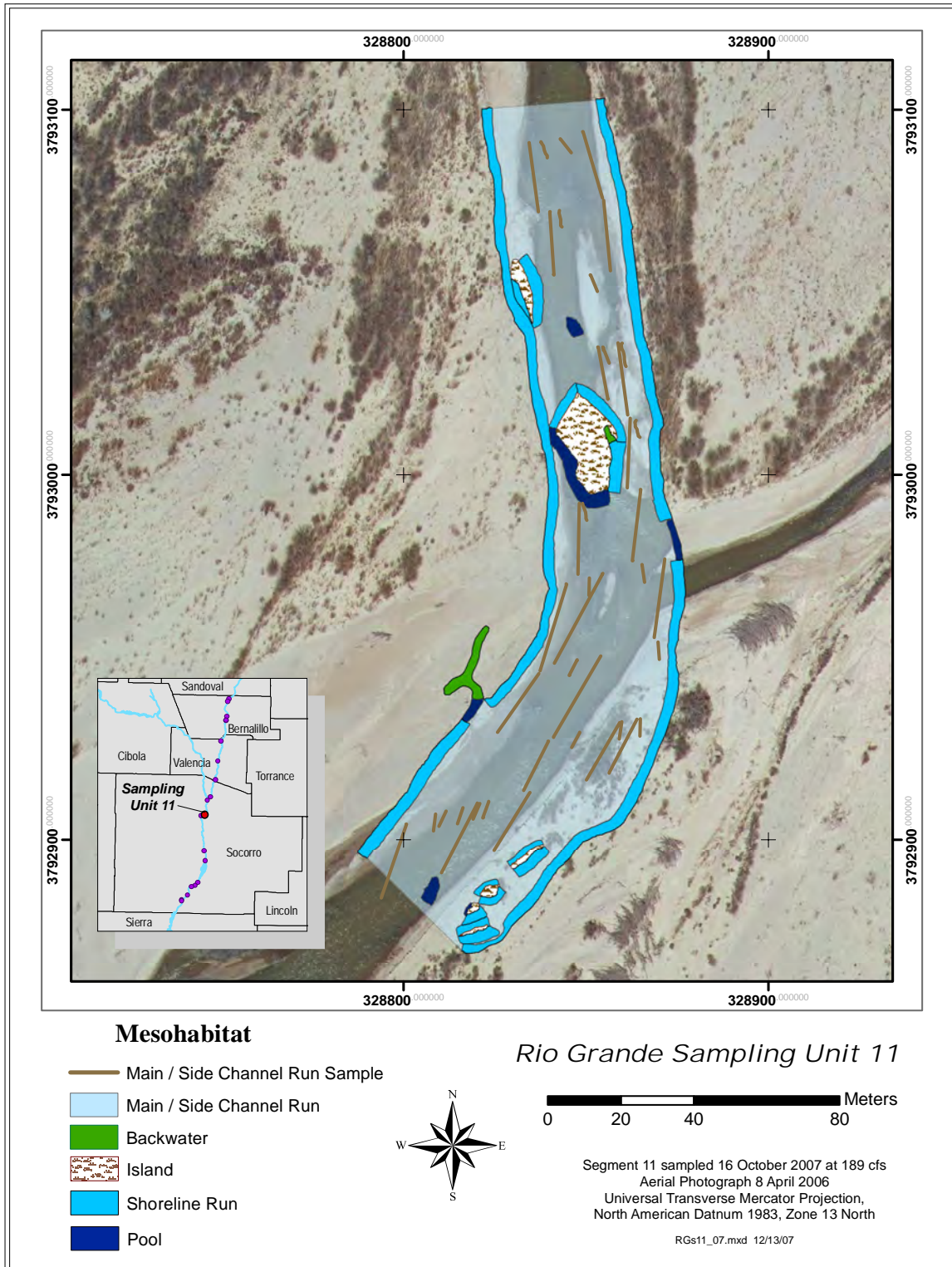


Figure B-11. Map of sampling unit #11 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

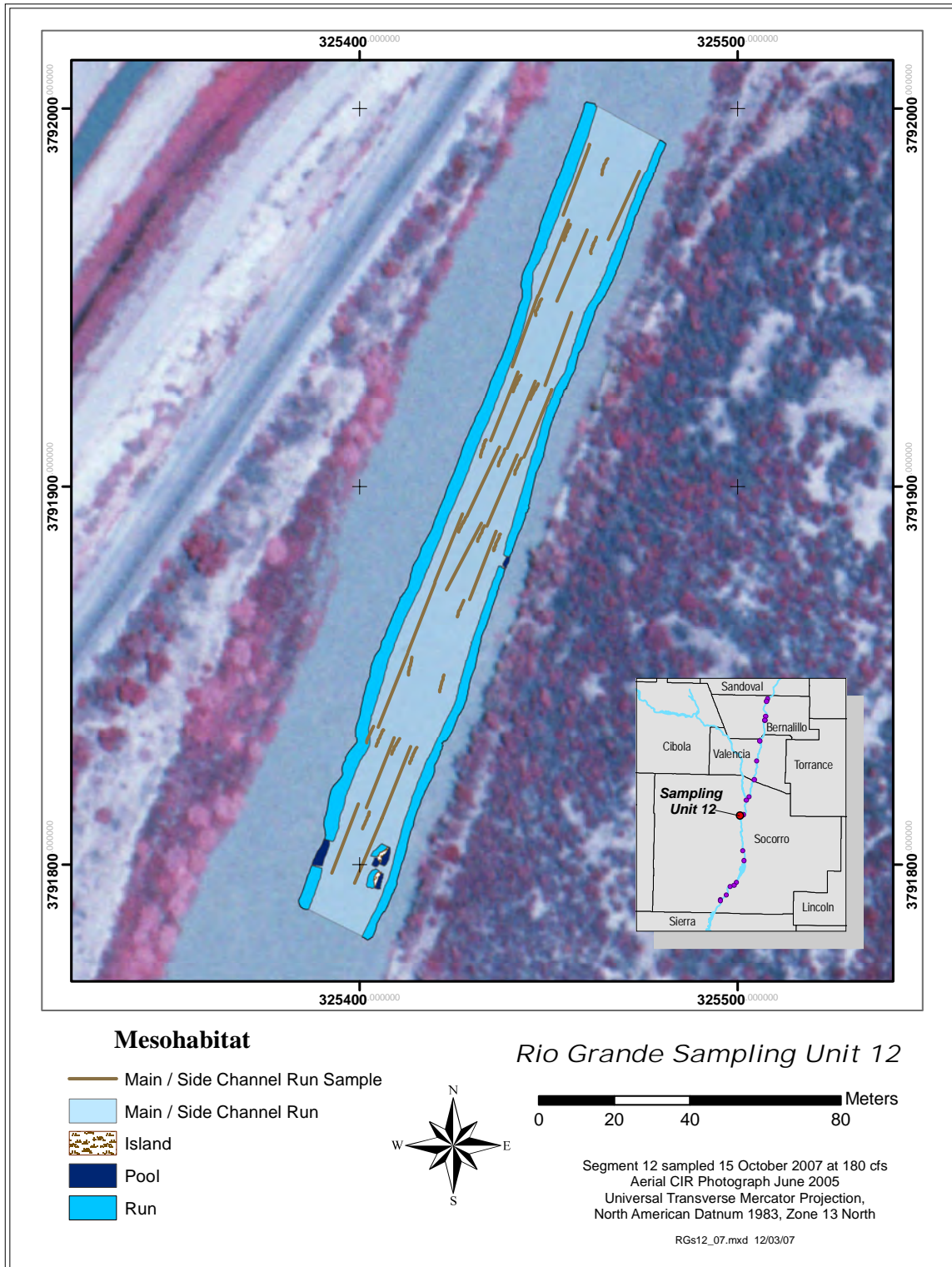


Figure B-12. Map of sampling unit #12 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

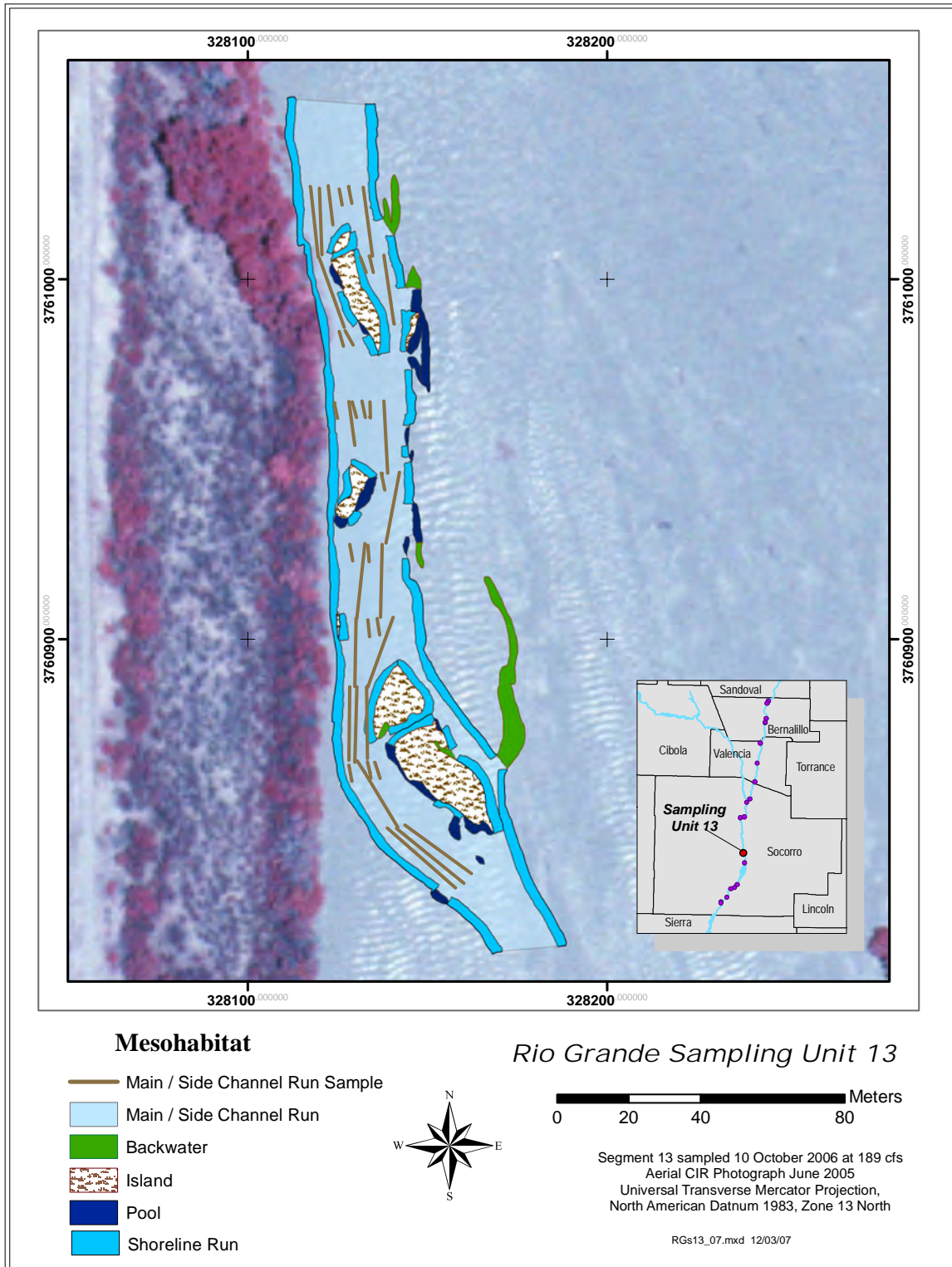


Figure B-13. Map of sampling unit #13 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

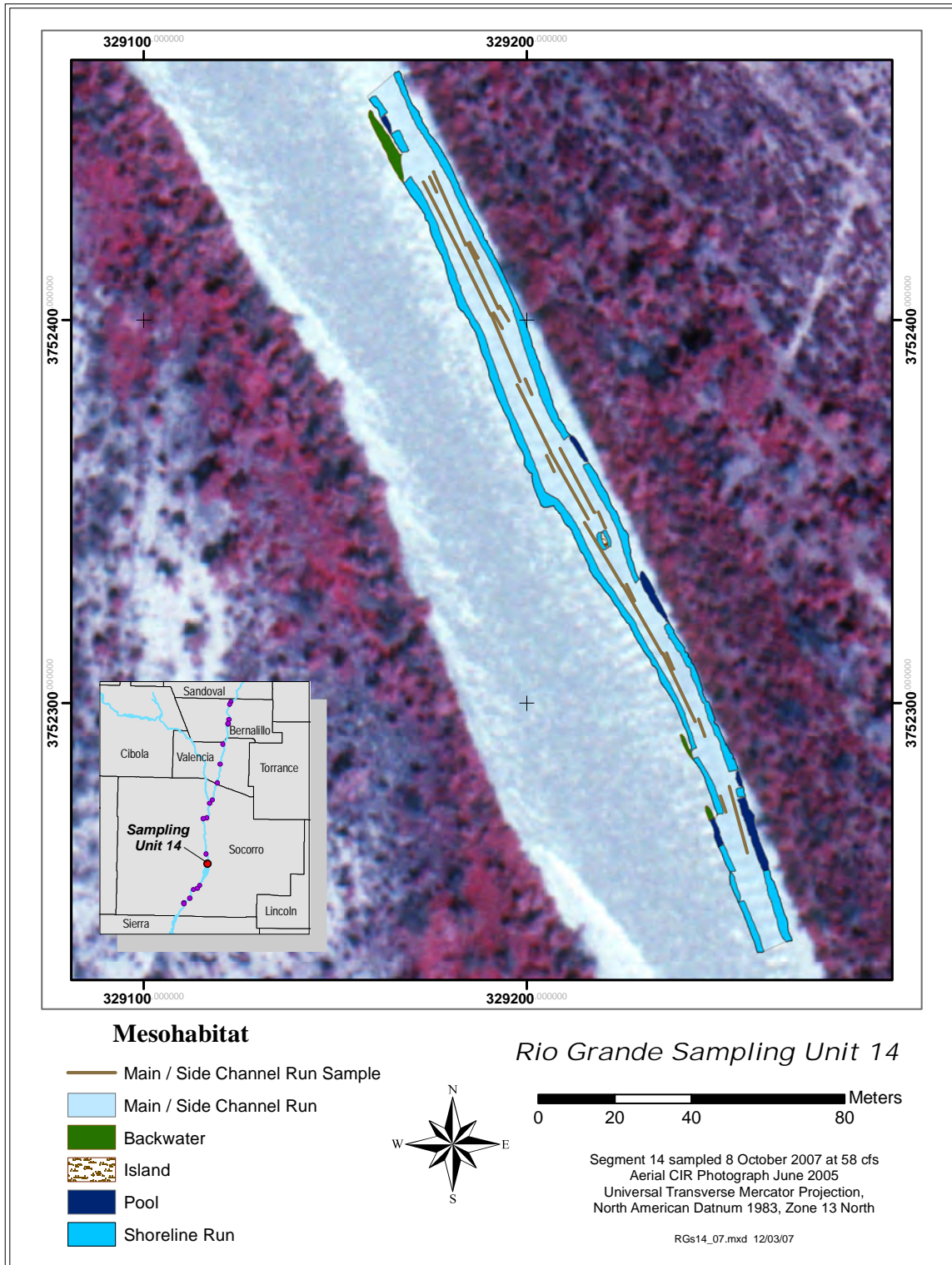


Figure B-14. Map of sampling unit #14 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

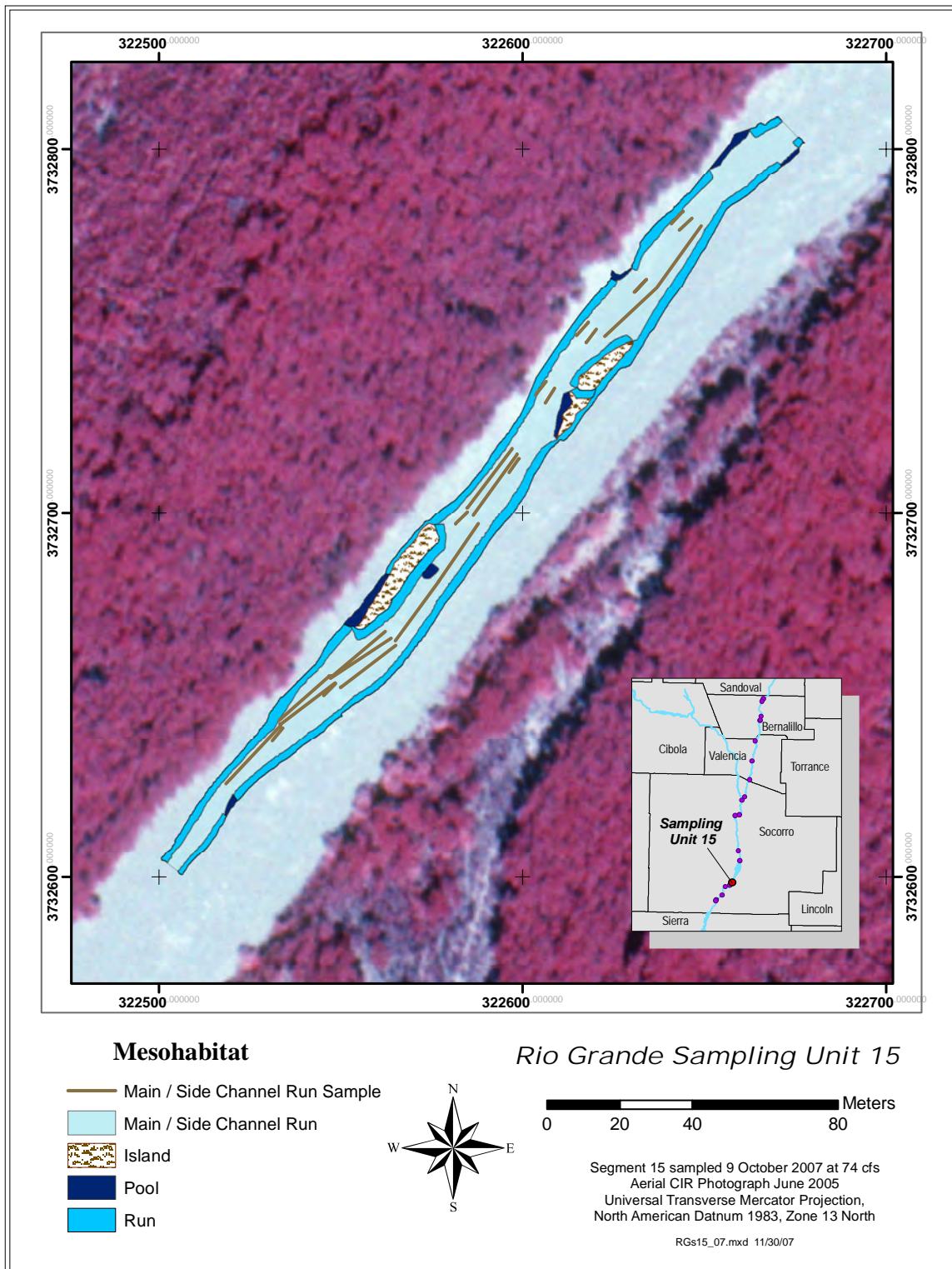


Figure B-15. Map of sampling unit #15 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

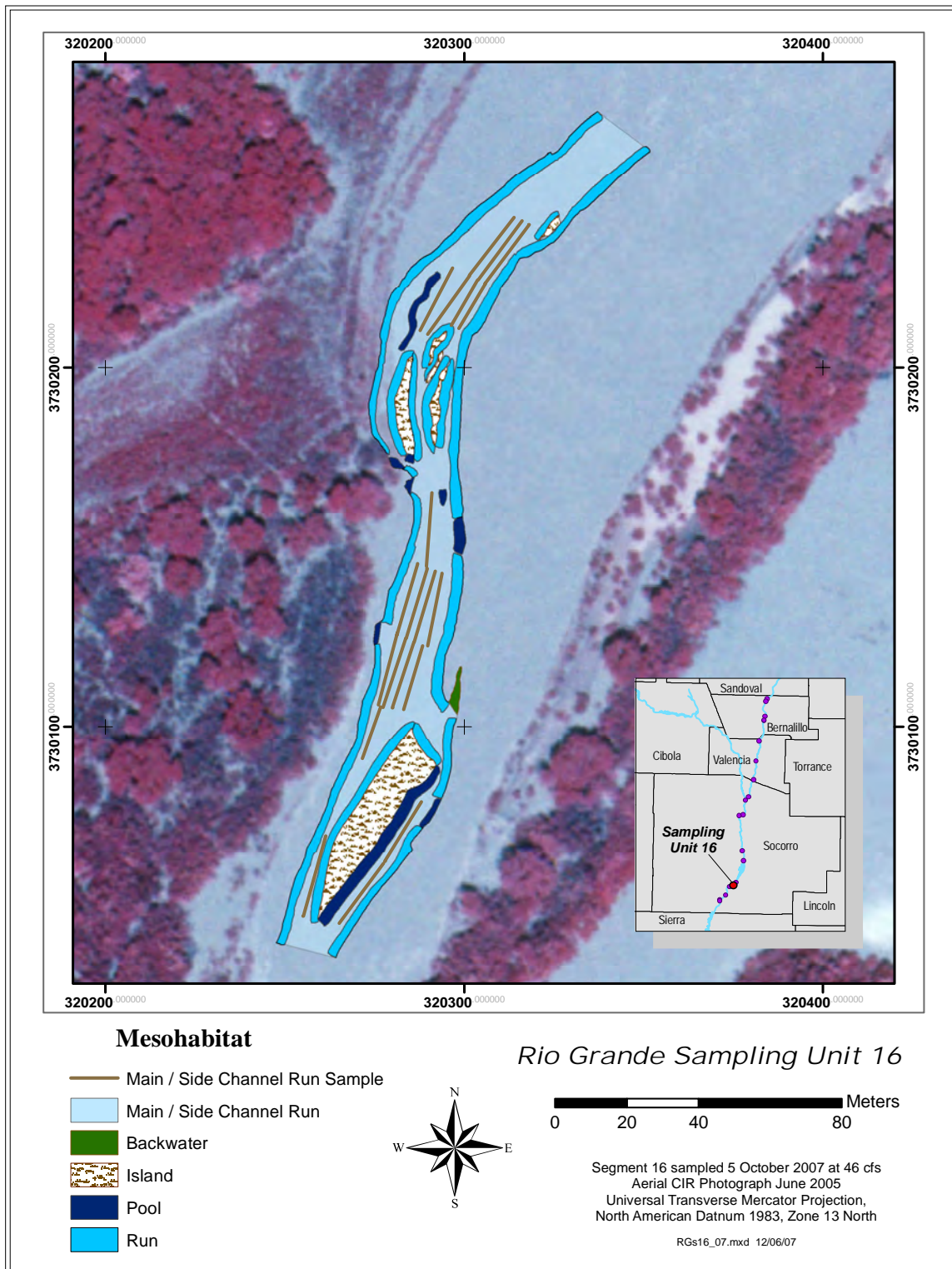


Figure B-16. Map of sampling unit #16 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

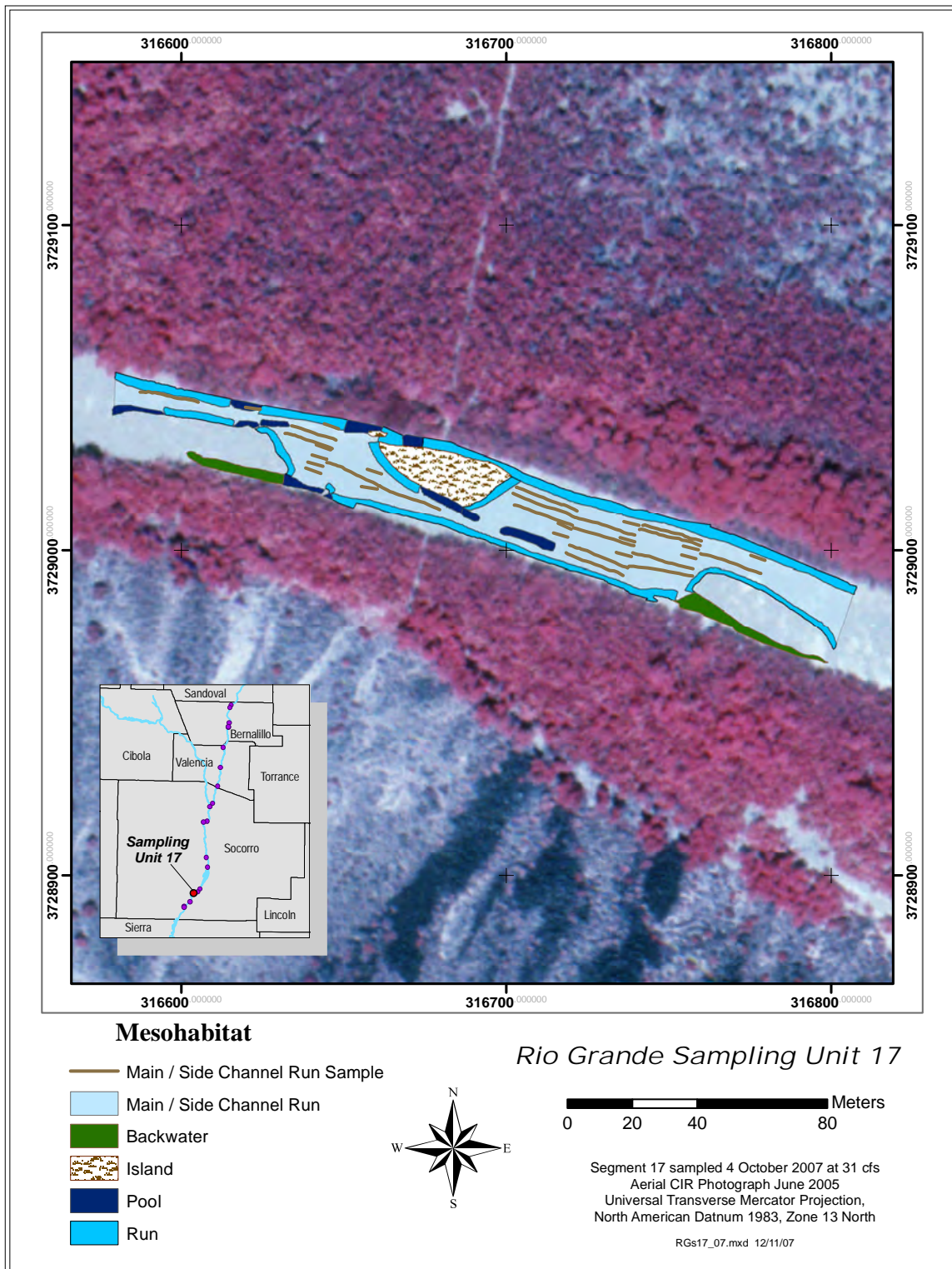


Figure B-17. Map of sampling unit #17 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

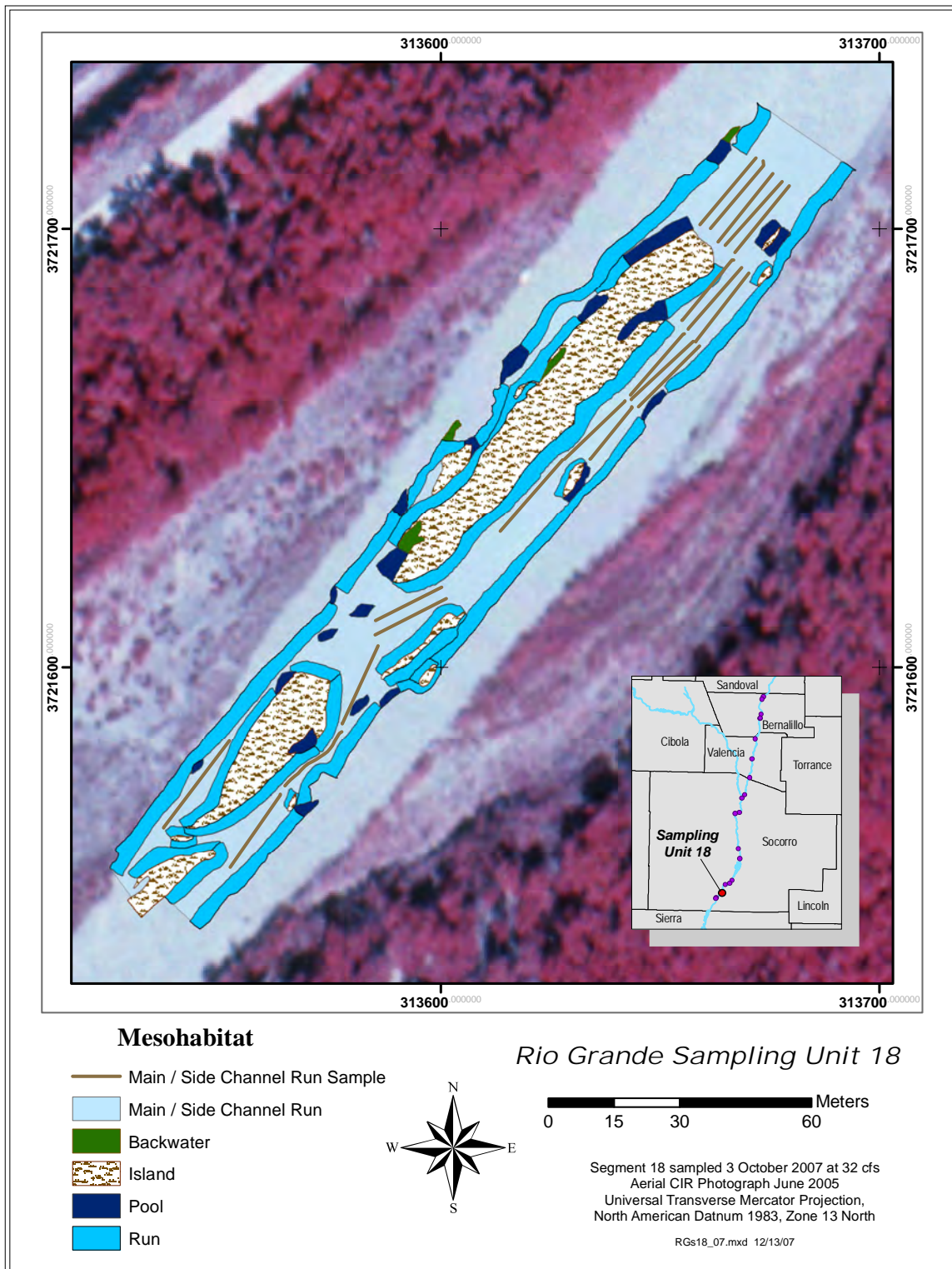


Figure B-18. Map of sampling unit #18 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

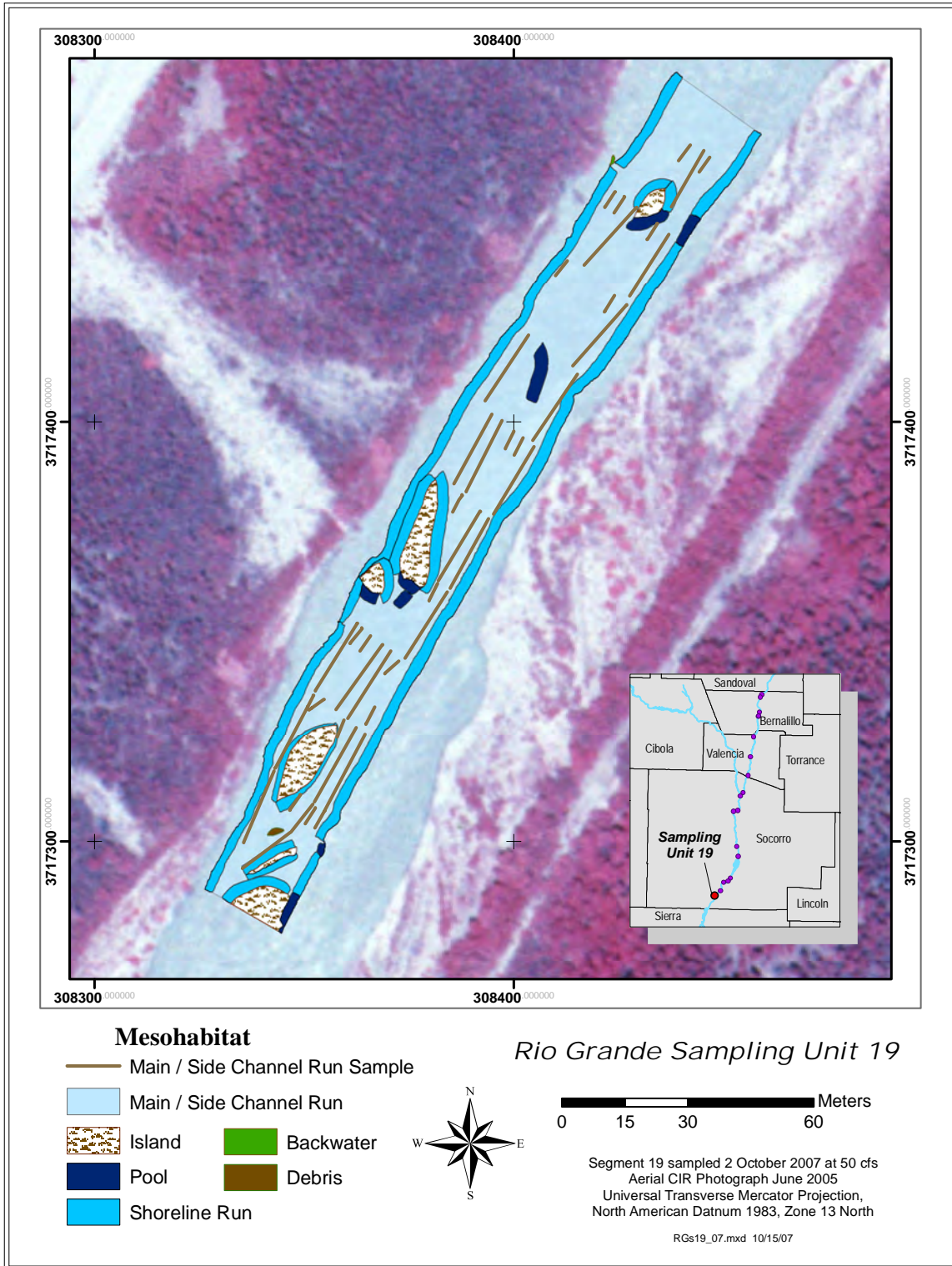


Figure B-19. Map of sampling unit #19 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

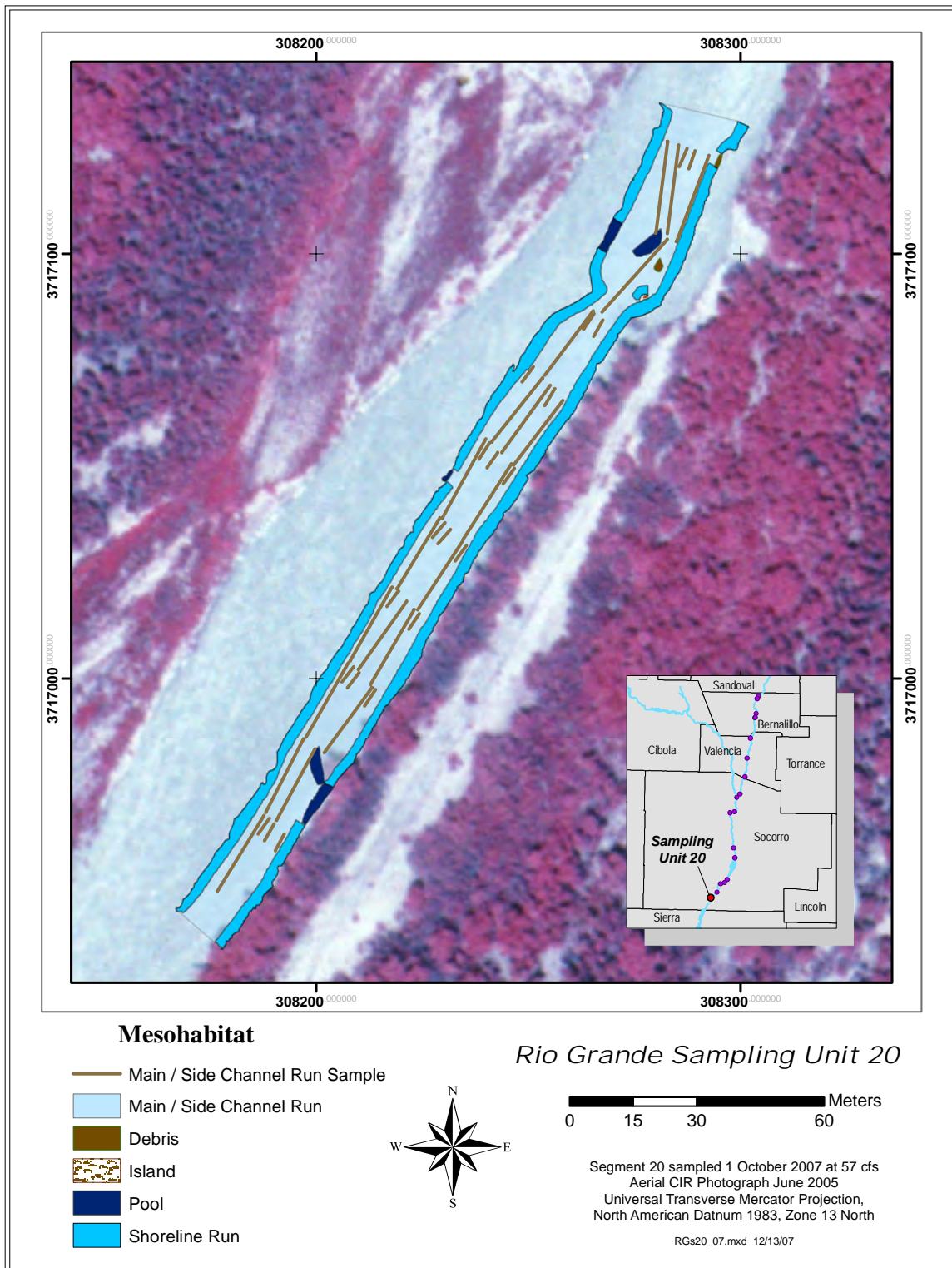


Figure B-20. Map of sampling unit #20 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

Appendix C.

Middle Rio Grande sampling units for the Population Monitoring Program

Table C-1. Sampling unit localities for the Rio Grande silvery minnow Population Monitoring Program.

Sampling Unit #	Sampling Unit 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 C-1. Sampling unit localities for the Rio Grande silvery minnow Population Monitoring Program (continued).

Sampling Unit #	Sampling Unit 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 116.8 LA 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, San Antonio. 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, San Antonio. 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; 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 C-1. Sampling unit localities for the Rio Grande silvery minnow Population Monitoring Program (continued).

Sampling Unit #	Sampling Unit Locality
SAN ACACIA REACH SITES	
18	New Mexico, Socorro County, Rio Grande, ca. 10 miles downstream of San Marcial Railroad bridge crossing. River Mile 57.7 PARAJE WELL QUADRANGLE UTM Easting: 307380 UTM Northing: 3714740 Zone: 13

Appendix D.

Report D-1. Ichthyofaunal composition of the October 2007
Rio Grande silvery minnow Population Estimation Program sampling efforts

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Bernalillo Co., Rio Grande Drainage

Rio Grande, ca. 0.4 miles upstream of Paseo del Norte Bridge crossing, Albuquerque.
30 October 2007

RKD07-192

Sampling Unit: 2
River Mile: 191.6

UTM Easting: 349942 UTM Northing: 3895288 Zone: 13 Quad: Los Griegos

R.K. Dudley, W.H. Brandenburg, C.C. McBride, J.P. Larson, D.A. Helfrich

Effort: 2,585.0 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	485
76	<i>Cyprinus carpio</i>	6
76	<i>Hybognathus amarus*</i>	150
76	<i>Pimephales promelas</i>	21
76	<i>Platygobio gracilis</i>	33
81	<i>Carpoides carpio</i>	13
81	<i>Catostomus commersoni</i>	1
93	<i>Ictalurus punctatus</i>	40
212	<i>Gambusia affinis</i>	73

*** *Hybognathus amarus* by age class:**

age-0: 149

age-1: 1

Rio Grande silvery minnow Population Estimation Program
October 2007

New Mexico: Bernalillo Co., Rio Grande Drainage

Rio Grande, ca. 1.2 miles downstream of Paseo del Norte Bridge crossing, Albuquerque. Sampling Unit: 3
29 October 2007 **RKD07-191** River Mile: 189.9

UTM Easting: 348954 UTM Northing: 3892935 Zone: 13 Quad: Los Griegos

R.K. Dudley, W.H. Brandenburg, J.P. Larson, C.C. McBride, T. Krabenhoff, D.A. Helfrich, Effort: 6,319.2 sq. m
A.L. Barkalow

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	632
76	<i>Cyprinus carpio</i>	3
76	<i>Hybognathus amarus*</i>	254
76	<i>Pimephales promelas</i>	12
76	<i>Platygobio gracilis</i>	241
76	<i>Rhinichthys cataractae</i>	24
81	<i>Carpoides carpio</i>	31
81	<i>Catostomus commersoni</i>	10
93	<i>Ictalurus punctatus</i>	102

*** *Hybognathus amarus* by age class:**

age-0: 253

age-1: 1

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Bernalillo Co., Rio Grande Drainage

Rio Grande, ca. 1.6 miles upstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. Sampling Unit: 4
26 October 2007 **RKD07-190** River Mile: 179.9

UTM Easting: 348261 UTM Northing: 3879455 Zone: 13 Quad: Albuquerque West

R.K. Dudley, S.P. Platania, W.H. Brandenburg, C.C. McBride Effort: 3,078.6 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	742
76	<i>Cyprinus carpio</i>	4
76	<i>Hybognathus amarus*</i>	23
76	<i>Pimephales promelas</i>	1
76	<i>Platygobio gracilis</i>	9
76	<i>Rhinichthys cataractae</i>	2
81	<i>Carpoides carpio</i>	10
81	<i>Catostomus commersoni</i>	1
93	<i>Ictalurus punctatus</i>	120
212	<i>Gambusia affinis</i>	7

*** *Hybognathus amarus* by age class:**

age-0: 19

age-1: 4

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Bernalillo Co., Rio Grande Drainage

Rio Grande, ca. 0.6 miles downstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. Sampling Unit: 5
24 October 2007 **RKD07-188** River Mile: 177.6

UTM Easting: 347381 UTM Northing: 3876106 Zone: 13 Quad: Albuquerque West

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride

Effort: 3,545.0 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	665
76	<i>Hybognathus amarus*</i>	51
76	<i>Pimephales promelas</i>	25
76	<i>Platygobio gracilis</i>	39
76	<i>Rhinichthys cataractae</i>	9
81	<i>Carpoides carpio</i>	70
81	<i>Catostomus commersoni</i>	1
93	<i>Ictalurus punctatus</i>	127
212	<i>Gambusia affinis</i>	205
294	<i>Lepomis macrochirus</i>	1
294	<i>Pomoxis annularis</i>	1

*** *Hybognathus amarus* by age class:**

age-0: 46

age-1: 5

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Bernalillo Co., Rio Grande Drainage

Rio Grande, ca. 1.0 miles downstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. Sampling Unit: 6
23 October 2007 **RKD07-187** River Mile: 177.3

UTM Easting: 347155 UTM Northing: 3875786 Zone: 13 Quad: Albuquerque West

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, J.P. Larson Effort: 2,632.2 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	936
76	<i>Cyprinus carpio</i>	3
76	<i>Hybognathus amarus*</i>	77
76	<i>Pimephales promelas</i>	81
76	<i>Platygobio gracilis</i>	35
76	<i>Rhinichthys cataractae</i>	1
81	<i>Carpoides carpio</i>	128
81	<i>Catostomus commersoni</i>	10
93	<i>Ictalurus punctatus</i>	136
212	<i>Gambusia affinis</i>	127

*** *Hybognathus amarus* by age class:**

age-0: 76

age-1: 1

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Valencia Co., Rio Grande Drainage

Rio Grande, ca. 4.0 miles upstream of Los Lunas Bridge crossing (NM State Highway 49), Los Lunas.

Sampling Unit: 7
River Mile: 164.8

22 October 2007

RKD07-186

UTM Easting: 342969 UTM Northing: 3857901 Zone: 13 Quad: Los Lunas

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, J.P. Larson, A.L. Barkalow

Effort: 3,633.8 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	1435
76	<i>Cyprinus carpio</i>	3
76	<i>Hybognathus amarus*</i>	1925
76	<i>Pimephales promelas</i>	12
76	<i>Platygobio gracilis</i>	12
76	<i>Rhinichthys cataractae</i>	1
81	<i>Carpoides carpio</i>	32
93	<i>Ictalurus punctatus</i>	149
212	<i>Gambusia affinis</i>	83

*** *Hybognathus amarus* by age class:**

age-0: 1923

age-1: 2

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Valencia Co., Rio Grande Drainage

Rio Grande, ca. 2.9 miles upstream of NM 6 bridge crossing, Belen.

19 October 2007

RKD07-185

UTM Easting: 340193 UTM Northing: 3840028 Zone: 13 Quad: Tome

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride

Sampling Unit: 8

River Mile: 152.4

Effort: 1,205.9 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	1458
76	<i>Hybognathus amarus*</i>	112
76	<i>Pimephales promelas</i>	19
81	<i>Carpoides carpio</i>	59
81	<i>Catostomus commersoni</i>	1
93	<i>Ictalurus punctatus</i>	139
212	<i>Gambusia affinis</i>	1171
294	<i>Micropterus salmoides</i>	2

*** *Hybognathus amarus* by age class:**

age-0: 104

age-1: 8

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Valencia Co., Rio Grande Drainage

Rio Grande, ca. 0.1 miles downstream of NM State Highway 346 Bridge crossing,
Jarales.

Sampling Unit: 9
River Mile: 140.6

17 October 2007

RKD07-183

UTM Easting: 338117 UTM Northing: 3823765 Zone: 13 Quad: Veguita

R.K. Dudley, S.P. Platania, W.H. Brandenburg, M.A. Farrington, C.C. McBride,
M. Cummer

Effort: 3,910.2 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	3780
76	<i>Cyprinus carpio</i>	8
76	<i>Hybognathus amarus*</i>	158
76	<i>Pimephales promelas</i>	45
76	<i>Platygobio gracilis</i>	12
81	<i>Carpoides carpio</i>	33
93	<i>Ictalurus punctatus</i>	154
212	<i>Gambusia affinis</i>	947

*** *Hybognathus amarus* by age class:**

age-0: 151

age-1: 7

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 1.0 miles downstream of U.S. Highway 60 bridge crossing, Bernardo. Sampling Unit: 9.5
02 November 2007 **RKD07-193** River Mile: 130.0

UTM Easting: 333822 UTM Northing: 3808533 Zone: 13 Quad: Abeytas

R.K. Dudley, W.H. Brandenburg, C.C. McBride, A.L. Barkalow Effort: 2,274.8 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	3593
76	<i>Cyprinus carpio</i>	3
76	<i>Hybognathus amarus*</i>	101
76	<i>Pimephales promelas</i>	39
81	<i>Carpoides carpio</i>	14
93	<i>Ameiurus natalis</i>	2
93	<i>Ictalurus punctatus</i>	112
212	<i>Gambusia affinis</i>	408

*** *Hybognathus amarus* by age class:**

age-0: 97

age-1: 4

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 3.7 miles downstream of US Highway 60 Bridge crossing, Bernardo. Sampling Unit: 10
18 October 2007 **RKD07-184** River Mile: 126.9

UTM Easting: 330997 UTM Northing: 3805306 Zone: 13 Quad: Abeytas

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride Effort: 2,813.6 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	1742
76	<i>Cyprinus carpio</i>	2
76	<i>Hybognathus amarus*</i>	231
76	<i>Pimephales promelas</i>	5
81	<i>Carpoides carpio</i>	34
93	<i>Ictalurus punctatus</i>	114
212	<i>Gambusia affinis</i>	290

*** *Hybognathus amarus* by age class:**

age-0: 203

age-1: 28

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 1.7 miles upstream of San Acacia Diversion Dam, San Acacia.

16 October 2007

RKD07-182

Sampling Unit: 11

River Mile: 117.9

UTM Easting: 328767 UTM Northing: 3792883 Zone: 13 Quad: La Joya

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, J.P. Larson

Effort: 3,084.6 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	15
76	<i>Hybognathus amarus*</i>	4
76	<i>Platygobio gracilis</i>	213
76	<i>Rhinichthys cataractae</i>	2
93	<i>Ictalurus punctatus</i>	6
212	<i>Gambusia affinis</i>	1

*** *Hybognathus amarus* by age class:**

age-0: 4

age-1:

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 0.8 miles downstream of San Acacia Diversion Dam, San Acacia.

15 October 2007

RKD07-181

Sampling Unit: 12

River Mile: 115.4

UTM Easting: 325363 UTM Northing: 3791796 Zone: 13 Quad: San Acacia

R.K. Dudley, S.P. Platania, W.H. Brandenburg, M.A. Farrington, C.C. McBride, N.D.

Zymonas

Effort: 2,506.9 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	176
76	<i>Cyprinus carpio</i>	1
76	<i>Hybognathus amarus*</i>	7
76	<i>Pimephales promelas</i>	3
76	<i>Platygobio gracilis</i>	160
81	<i>Ictiobus bubalus</i>	1
93	<i>Ictalurus punctatus</i>	67
212	<i>Gambusia affinis</i>	3

*** *Hybognathus amarus* by age class:**

age-0: 7

age-1:

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 4.5 miles upstream of US Highway 380 Bridge crossing, San Antonio. Sampling Unit: 13
10 October 2007 **RKD07-180** River Mile: 91.6

UTM Easting: 328199 UTM Northing: 3760830 Zone: 13 Quad: San Antonio

R.K. Dudley, S.P. Platania, W.H. Brandenburg, M.A. Farrington, C.C. McBride Effort: 3,187.9 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	125
76	<i>Hybognathus amarus*</i>	12
76	<i>Pimephales promelas</i>	2
76	<i>Platygobio gracilis</i>	5
81	<i>Carpoides carpio</i>	2
93	<i>Ictalurus punctatus</i>	5
212	<i>Gambusia affinis</i>	4

*** *Hybognathus amarus* by age class:**

age-0: 12

age-1:

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 1.5 miles downstream of US Highway 380 Bridge crossing, San Antonio. Sampling Unit: 14
08 October 2007 **RKD07-178** River Mile: 85.7

UTM Easting: 329256 UTM Northing: 3752209 Zone: 13 Quad: San Antonio

S.P. Platania, W.H. Brandenburg, M.A. Farrington, C.C. McBride, A.L. Barkalow, J.P. Larson Effort: 1,685.9 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	142
76	<i>Hybognathus amarus*</i>	4
76	<i>Pimephales promelas</i>	2
81	<i>Carpoides carpio</i>	1
93	<i>Ictalurus punctatus</i>	5
212	<i>Gambusia affinis</i>	3

*** *Hybognathus amarus* by age class:**

age-0: 4

age-1:

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 0.2 miles downstream of the south boundary of the Bosque del Apache National Wildlife Refuge. Sampling Unit: 15
River Mile: 73.6

09 October 2007

RKD07-179

UTM Easting: 322489 UTM Northing: 3732572 Zone: 13 Quad: San Marcial

W.H. Brandenburg, M.A. Farrington, C.C. McBride, J.P. Larson

Effort: 1,900.7 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	400
76	<i>Hybognathus amarus*</i>	1
76	<i>Pimephales promelas</i>	6
76	<i>Platygobio gracilis</i>	14
93	<i>Ictalurus punctatus</i>	8
212	<i>Gambusia affinis</i>	47

*** *Hybognathus amarus* by age class:**

age-0: 1

age-1:

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 2.2 miles downstream of the south boundary of the Bosque del Apache National Wildlife Refuge. Sampling Unit: 16
River Mile: 71.6

05 October 2007

RKD07-177

UTM Easting: 320044 UTM Northing: 3730043 Zone: 13 Quad: San Marcial

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride

Effort: 2,917.6 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	507
76	<i>Hybognathus amarus*</i>	3
76	<i>Platygobio gracilis</i>	38
93	<i>Ictalurus punctatus</i>	3

*** *Hybognathus amarus* by age class:**

age-0: 3

age-1:

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 0.9 miles upstream of San Marcial Railroad Bridge crossing, San Marcial. Sampling Unit: 17
River Mile: 69.5

04 October 2007

RKD07-176

UTM Easting: 316840 UTM Northing: 3728978 Zone: 13 Quad: San Marcial

R.K. Dudley, S.P. Platania, W.H. Brandenburg, M.A. Farrington, C.C. McBride,

Effort: 2,485.9 sq. m

L.E. Renfro

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	482
76	<i>Hybognathus amarus*</i>	3
76	<i>Platygobio gracilis</i>	2
81	<i>Carpiodes carpio</i>	1
93	<i>Ictalurus punctatus</i>	2
212	<i>Gambusia affinis</i>	8

*** *Hybognathus amarus* by age class:**

age-0: 3

age-1:

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 5.0 miles downstream of San Marcial Railroad Bridge crossing, San Marcial. Sampling Unit: 18
River Mile: 63.6

03 October 2007

RKD07-175

UTM Easting: 313417 UTM Northing: 3721520 Zone: 13 Quad: Paraje Well

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride

Effort: 3,669.0 sq. m

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	1136
76	<i>Cyprinus carpio</i>	1
76	<i>Hybognathus amarus*</i>	1
76	<i>Platygobio gracilis</i>	2
81	<i>Carpiodes carpio</i>	1
93	<i>Ictalurus punctatus</i>	18
212	<i>Gambusia affinis</i>	2

*** *Hybognathus amarus* by age class:**

age-0: 1

age-1:

**Rio Grande silvery minnow Population Estimation Program
October 2007**

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 0.9 miles downstream of the former confluence with the Low Flow
Conveyance Channel.

Sampling Unit: 19

River Mile: 59.8

02 October 2007

RKD07-174

UTM Easting: 308328 UTM Northing: 3717266 Zone: 13 Quad: Paraje Well

R.K. Dudley, S.P. Platania, W.H. Brandenburg, M.A. Farrington, C.C. McBride,

Effort: 2,620.5 sq. m

J.P. Larson

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	228
76	<i>Cyprinus carpio</i>	1
76	<i>Hybognathus amarus*</i>	5
76	<i>Platygobio gracilis</i>	31
93	<i>Ictalurus punctatus</i>	28
212	<i>Gambusia affinis</i>	11

*** *Hybognathus amarus* by age class:**

age-0: 5

age-1:

New Mexico: Socorro Co., Rio Grande Drainage

Rio Grande, ca. 1.1 miles downstream of the former confluence with the Low Flow
Conveyance Channel.

Sampling Unit: 20

River Mile: 59.6

01 October 2007

RKD07-173

UTM Easting: 308118 UTM Northing: 3716920 Zone: 13 Quad: Paraje Well

R.K. Dudley, S.P. Platania, W.H. Brandenburg, M.A. Farrington, C.C. McBride,

Effort: 2,354.4 sq. m

J.P. Larson

<u>FAMILY</u>		<u>N</u>
76	<i>Cyprinella lutrensis</i>	147
76	<i>Cyprinus carpio</i>	2
76	<i>Hybognathus amarus*</i>	0
76	<i>Platygobio gracilis</i>	6
93	<i>Ictalurus punctatus</i>	16
212	<i>Gambusia affinis</i>	7

*** *Hybognathus amarus* by age class:**

age-0:

age-1:

Appendix E

Table E-1. Rio Grande silvery minnow detection probability estimates among years for all sampling segments combined (from Population Monitoring Program data) in the Middle Rio Grande based on repeated sampling efforts in November (2005-2007).

Detection Probability Estimates from Minimum AIC_c Model (A)				
Label*	Estimate	SE	LCI	UCI
<i>p</i> Year 05 All Fish Day 1	0.975456	0.017150	0.907059	0.993859
<i>p</i> Year 05 All Fish Day 2	0.975398	0.017192	0.906856	0.993844
<i>p</i> Year 05 All Fish Day 3	0.975308	0.017253	0.906542	0.993821
<i>p</i> Year 05 All Fish Day 4	0.975001	0.017460	0.905473	0.993742
<i>p</i> Year 05 Age-0 Day 1	0.975456	0.017153	0.907059	0.993859
<i>p</i> Year 05 Age-0 Day 2	0.975398	0.017192	0.906856	0.993844
<i>p</i> Year 05 Age-0 Day 3	0.975308	0.017253	0.906542	0.993821
<i>p</i> Year 05 Age-0 Day 4	0.975001	0.017460	0.905473	0.993742
<i>p</i> Year 05 Age-1 Day 1	0.327755	0.099979	0.166903	0.542652
<i>p</i> Year 05 Age-1 Day 2	0.327221	0.099899	0.166562	0.542057
<i>p</i> Year 05 Age-1 Day 3	0.326394	0.099775	0.166033	0.541138
<i>p</i> Year 05 Age-1 Day 4	0.323620	0.099362	0.164255	0.538058
<i>p</i> Year 05 Age-2 Day 1	0.076864	0.133623	0.002073	0.769469
<i>p</i> Year 05 Age-2 Day 2	0.076692	0.133347	0.002068	0.769030
<i>p</i> Year 05 Age-2 Day 3	0.076426	0.132921	0.002060	0.768349
<i>p</i> Year 05 Age-2 Day 4	0.075538	0.131495	0.002035	0.766049
<i>p</i> Year 06 All Fish Day 1	0.902102	0.033133	0.815397	0.950552
<i>p</i> Year 06 All Fish Day 2	0.885148	0.036700	0.791592	0.939895
<i>p</i> Year 06 All Fish Day 3	0.883250	0.037150	0.788758	0.938756
<i>p</i> Year 06 All Fish Day 4	0.879017	0.038194	0.782318	0.936260
<i>p</i> Year 06 Age-0 Day 1	0.846141	0.046097	0.733146	0.916725
<i>p</i> Year 06 Age-0 Day 2	0.821415	0.050891	0.699725	0.900782
<i>p</i> Year 06 Age-0 Day 3	0.818679	0.051505	0.695797	0.899120
<i>p</i> Year 06 Age-0 Day 4	0.812602	0.052929	0.686920	0.895506
<i>p</i> Year 06 Age-1 Day 1	0.733307	0.054542	0.614162	0.826080
<i>p</i> Year 06 Age-1 Day 2	0.696943	0.055890	0.577895	0.794364
<i>p</i> Year 06 Age-1 Day 3	0.693013	0.056193	0.573597	0.791162
<i>p</i> Year 06 Age-1 Day 4	0.684348	0.056976	0.563865	0.784280
<i>p</i> Year 06 Age-2 Day 1	0.062868	0.034450	0.020880	0.174265
<i>p</i> Year 06 Age-2 Day 2	0.053128	0.029711	0.017326	0.151502
<i>p</i> Year 06 Age-2 Day 3	0.052203	0.029275	0.016978	0.149400
<i>p</i> Year 06 Age-2 Day 4	0.050239	0.028357	0.016234	0.144974
<i>p</i> Year 07 All Fish Day 1	0.987926	0.012018	0.919076	0.998306
<i>p</i> Year 07 All Fish Day 2	0.986589	0.013321	0.910919	0.998114
<i>p</i> Year 07 All Fish Day 3	0.986589	0.013321	0.910919	0.998114
<i>p</i> Year 07 All Fish Day 4	0.986589	0.013321	0.910919	0.998114
<i>p</i> Year 07 Age-0 Day 1	0.987926	0.012018	0.919076	0.998306
<i>p</i> Year 07 Age-0 Day 2	0.986589	0.013321	0.910919	0.998114
<i>p</i> Year 07 Age-0 Day 3	0.986589	0.013321	0.910919	0.998114
<i>p</i> Year 07 Age-0 Day 4	0.986589	0.013321	0.910919	0.998114
<i>p</i> Year 07 Age-1 Day 1	0.096077	0.034695	0.046326	0.188687
<i>p</i> Year 07 Age-1 Day 2	0.087232	0.031791	0.041868	0.172881
<i>p</i> Year 07 Age-1 Day 3	0.087232	0.031791	0.041868	0.172881
<i>p</i> Year 07 Age-1 Day 4	0.087232	0.031791	0.041868	0.172881
<i>p</i> Year 07 Age-2 Day 1	0	0	0	0
<i>p</i> Year 07 Age-2 Day 2	0	0	0	0
<i>p</i> Year 07 Age-2 Day 3	0	0	0	0
<i>p</i> Year 07 Age-2 Day 4	0	0	0	0

*Where *p*=detection probability and Day is the sampling occasion sequence for a particular year.