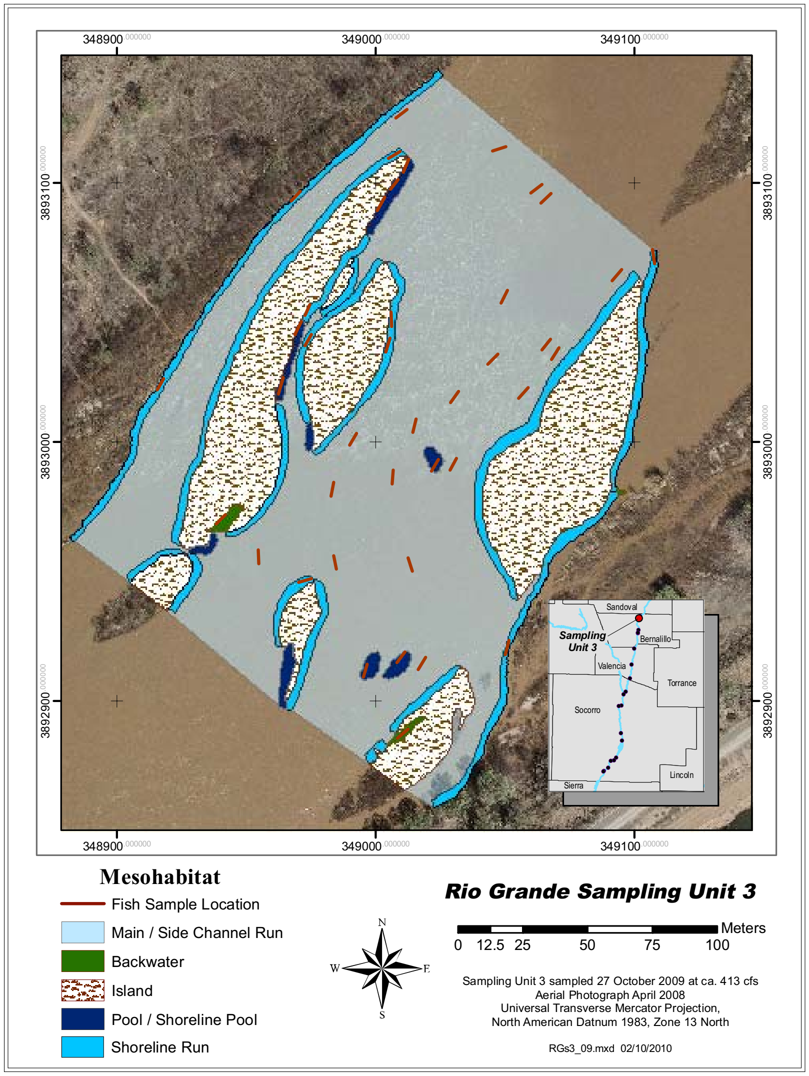
RIO GRANDE SILVERY MINNOW POPULATION ESTIMATION PROGRAM RESULTS FROM OCTOBER 2009

FINAL

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



Robert K. Dudley[1], Gary C. White[2], Steven P. Platania[1], and Donald A. Helfrich[1]

[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

10 February 2011

RIO GRANDE SILVERY MINNOW POPULATION ESTIMATION PROGRAM RESULTS FROM OCTOBER 2009

FINAL

Funded through the Middle Rio Grande Endangered Species Act Collaborative Program

Prepared by:

Robert K. Dudley[1], Gary C. White[2], Steven P. Platania[1], and Donald A. Helfrich[1]

[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

under USBR contract:

Number R09PC40006
U.S. Bureau of Reclamation
Upper Colorado Regional Office
125 South State Street, Room 6107
Salt Lake City, UT 84138-1102

Submitted to:

U. S. Bureau of Reclamation
Albuquerque Area Office
555 Broadway, NE
Suite 100
Albuquerque, New Mexico 87102-2352

10 February 2011

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - continued

APPENDIX A

APPENDIX B

APPENDIX B - continued

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F

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. 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.

Data collected during the 2009 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 seven native fish species. Red shiner was the most abundant native species collected (N = 2,344), followed by Rio Grande silvery minnow (N = 1,688), flathead chub (N = 209), and fathead minnow (N = 165). Rio Grande silvery minnow densities were generally highest in the Isleta Reach. The most abundant introduced species were western mosquitofish (N = 607) and channel catfish (N = 466).

The best model for the mesohabitat-specific depletion data (based on the lowest AIC_C value) was by mesohabitat and location (for BW, PO, SHPO, and SHRU) and was supported by a high model weight. The capture probability estimates (i.e., proportion of fish removed per depletion pass) for the different mesohabitats ranged from 0.6858 (shoreline pools) to 0.8444 (runs). The associated standard errors for estimates were consistent among mesohabitats and ranged from 0.0157 to 0.0382.

Probability of detection and probability of site occupancy estimates during 2009 were calculated for all Rio Grande silvery minnow and for the respective age-classes. The probability of detection estimate for all Rio Grande silvery minnow was 0.6385 while the estimate for age-0 individuals was 0.6292; probability of detection estimates were much lower for age-1 and age-2 individuals (<0.2). The probability of occupancy estimate for all Rio Grande silvery minnow was 0.8275 while the estimate for age-0 individuals was 0.8176. The occupancy estimate for age-1 individuals was 0.4165 and the occupancy estimate for age-2 individuals was 0.1205.

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 2009. The site occupancy estimate was 1.0 for all age-classes combined and for age-0 individuals but was lower for age-1 (0.5647) and age-2 (0.5755) individuals. Estimates of the probability of extinction were relatively low for all age-classes (0.0130) and age-0 (0.0486) individuals. The probability of extinction was higher for both age-1 and age-2 individuals (0.1750 and 0.1234, respectively). Estimates of the probability of colonization were relatively high for age-0 (0.4664) and age-1 (0.7926) individuals.

The 2009 estimate of population was highest in the Isleta Reach (N = 688,257) and lowest in the San Acacia Reach (N = 374,321). The standard errors associated with population estimates for the three reaches were proportionally comparable for the Angostura and Isleta reaches; variation was

notably lower in the Isleta Reach. The overall population estimate was 1,387,948 and had a standard error [SE] of 358,937. The overall proportion of each age-class exhibited a similar pattern among the three reaches (i.e., populations were highest in the Isleta and Angostura reaches and lowest in the San Acacia Reach).

Population estimates were also generated using data from the Population Monitoring Program October 2009 sampling efforts. The population estimates for the study area varied among reaches with the highest numbers recorded in the Isleta Reach (305,976) and the lowest numbers in the Angostura Reach (108,184). The overall population estimate using the Population Monitoring Program data was 619,453 and had a standard error [SE] of 130,760. The population estimates generated using the Population Estimation Program and Population Monitoring Program data showed a similar increasing population trend from 2008 to 2009. While the overall population trend was similar when comparing estimates generated from Population Estimation Program and Population Monitoring Program data, the actual estimates were consistently lower when using the Population Monitoring Program data.

The Population Monitoring Program generated population estimate is based on conservative estimates of mesohabitat area, relies on non-randomly selected sampling units, does not incorporate valid capture probability estimates, will violate numerous statistical assumptions, and thus must be viewed very cautiously. Methodological differences in how the estimates were calculated likely resulted in a substantial underestimate of the population based on the Population Monitoring Program data. The combination of these factors apparently resulted in a subtantially lower estimate based on the Population Monitoring Program data and is the reason that these data were only presented for trend comparison purposes. Rather than a statistical comparison of the actual estimates of population obtained from the Population Monitoring Program and Population Estimation Program data, the purpose of this analysis was to compare the general population trends of Rio Grande silvery minnow over time as inferred from these two studies.

The site occupancy data should be used in combination with Population Estimation Program 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 man-made) 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.

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 = $\#/m^2$) 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 (among months or years) or spatially (among 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, *r*-selected 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 been shown to be reliable for a variety of species (e.g., Royle and Nichols, 2003). 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 (1993–2009) Population Monitoring Program for the Middle Rio Grande ichthyofaunal community (Angostura, NM to Elephant Butte Reservoir). In contrast to population monitoring that documents spatial and temporal trends in abundance 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 km^2 (excluding closed basins). The Rio Chama is the only major perennial tributary of the Rio Grande in New Mexico and confluences with it near the city of Española. Snowmelt from southern Colorado and northern New Mexico yields the majority of water for the Rio Grande, but trans-mountain 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).

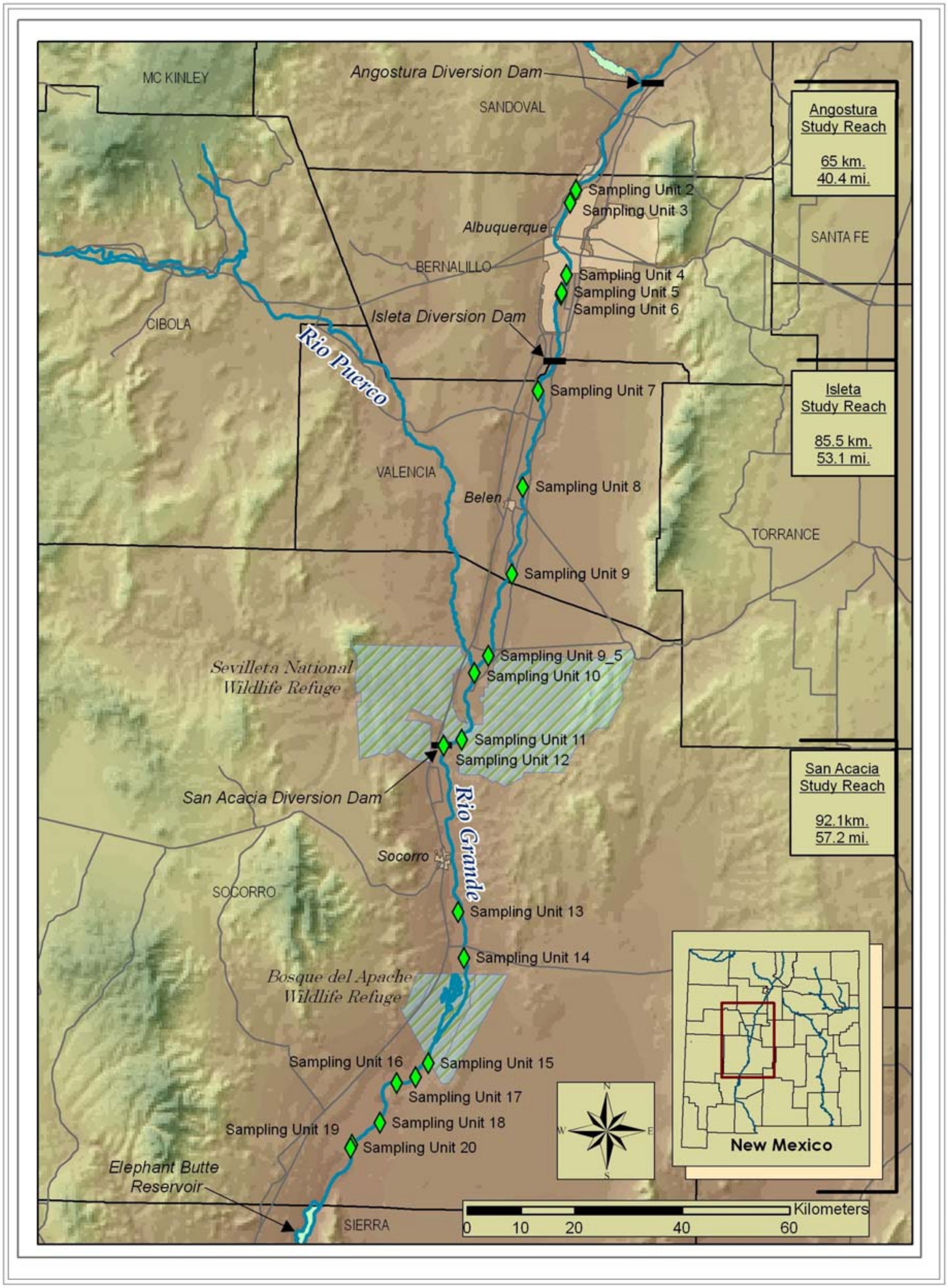


Figure 1. Map of the study area, reaches, and sampling units (numbered) for the Rio Grande silvery minnow Population Estimation Program. Sampling unit information is provided in Appendix A (Table A-1).

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 2008 and 2009, 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 2008 compared to 2009. Flows were notably elevated from April–June 2008 and from May–June 2009. Flow conditions in 2008 and 2009 included periodic intervals of low discharge from July through October. Summer rains contributed little flow to the river in 2008 or 2009. Flows at the Albuquerque Gauge during October 2009 were relatively stable and similar (mean = 411.5 cfs) to historical October flows (mean of available data [1973–2007] = 468 cfs).

METHODS

Sampling and Mapping Methodology

Sampling unit location, selection, and timing

This study was structured to provide an estimate 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 sampling units later while retaining spatial balance of the study design.

The computer program "S-Draw" (Western EcoSystems Technology, Inc. - Trent L. McDonald) was used to randomly select sampling 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

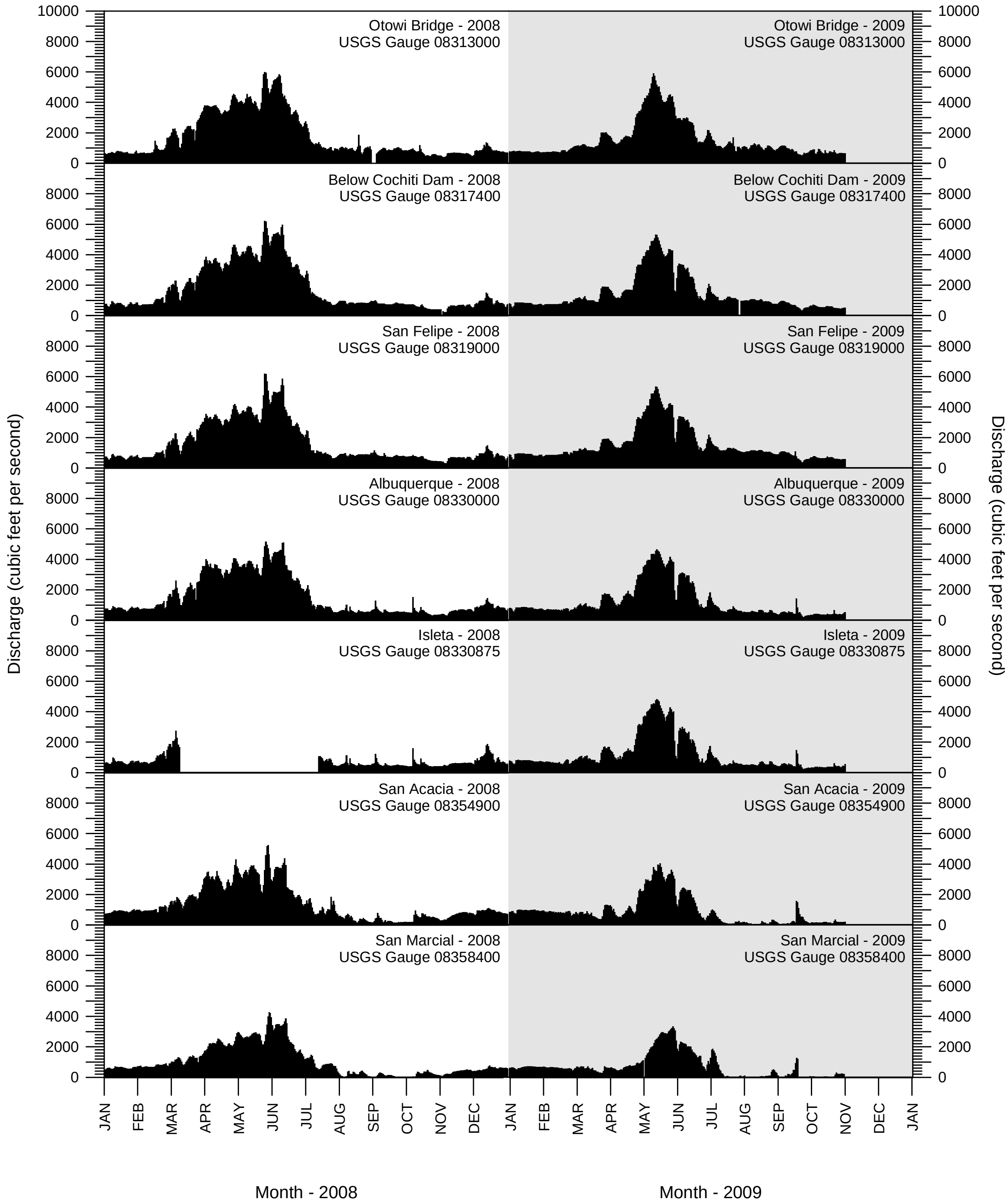


Figure 2. Discharge in the Rio Grande from January 2008 through October 2009 as recorded at seven U. S. Geological Survey (USGS) gauging stations. The Otowi Bridge gauge site is outside of the study area (ca. 25.5 river miles upstream of Cochiti Dam) but is provided for reference. USGS discharge data are provisional and subject to change.

included in this proposed study as all except a very small portion (< 5 km) drains sovereign Native American nations and is 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 (levee reinforcement) proceeded along the original eastern shoreline. This location 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 population trends over time (MRGESACP, 2006). Rio Grande silvery minnow population estimates were generated from October 2009 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. Another 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. Fish and Wildlife Service, 2007).

Mesohabitat mapping and analysis

The October 2009 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, 2009), 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 used for all sampling units in the Angostura and Isleta reaches and most in the San Acacia Reach; near infrared color orthophotography images (0.5 m resolution) were used for the two downstream-most 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 that occurred after the original photography dates.

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 of GPS mapping allowed for accurate calculation of the area, even for small mesohabitats. Two crews worked simultaneously with GPS units 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 (based on GPS mapping). Surveyor flags and bamboo posts were used to delineate the

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.

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 locations 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 sequentially on the same day.

Fish sampling and analysis

Surveyor flags were used to mark the start and stop points for each fish sample location. Likewise, GPS coordinates were acquired for each fish sample location. Each selected mesohabitat 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.

Based on the results of the Population Estimation Program three year pilot study (2006–2008), we collected all data using a closed mesohabitat depletion sampling protocol. Experiments to determine differences in capture probabilities estimates between open and closed mesohabitat sampling in 2007 yielded inconclusive results in non-run mesohabitats. However, similar experiments in run mesohabitats suggested that densities of fish were higher than expected when employing a closed depletion sampling protocol compared with an open first-pass sampling protocol (corrected with run-mesohabitat capture probability estimate). While closed mesohabitat depletion sampling (in 2008) reduced the number and area of mesohabitats sampled (compared to either 2006 or 2007), it provided a point of reference for comparison of the different sampling regimes and statistical correction factors over the duration of the study.

Fish collected from individual mesohabitats 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), measured (standard length range), and 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 2007]). Selected water quality parameters (temperature, conductivity, specific conductance, pH, salinity, and dissolved oxygen) were also obtained at each sampling unit (see Appendix C).

Sampling was conducted within each 200-m unit, using a random stratified subset of the available non-run mesohabitats. The length of each non-run mesohabitat type was measured during sampling (using GPS units) and a running tally of the total number of possible samples was recorded. Depletion samples were five meters in length with a five meter buffer (upstream and downstream) to minimize disturbance prior to sampling. At sampling units where there were five or fewer possible sample locations in a particular mesohabitat, all of the locations were sampled. At sampling units where there were >5 possible sample locations in a particular mesohabitat, a random selection (N=5) of the total number of locations was sampled. The only exception to this sampling protocol was for

Table 2. Scientific and common names and species codes of fish collected in the Middle Rio Grande since 1993.

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

Table 2. Scientific and common names and species codes of fish collected in the Middle Rio Grande since 1993 (continued).

Scientific Name	Common Name	Code
Order Perciformes		
Family Percichthyidae	temperate basses	
Morone chrysops	white bass	(WHB)
Order Perciformes		
Family Centrarchidae	sunfishes	
Lepomis cyanellus	green sunfish	(GNS)
Lepomis macrochirus	bluegill	(BGL)
Micropterus salmoides	largemouth bass	(LMB)
Pomoxis annularis	white crappie	(WCR)
Pomoxis nigromaculatus	black crappie	(BCR)
Family Percidae	perches	
Perca flavescens	yellow perch	(YWP)
Perca macrolepida	bigscale logperch	(BLP)
Sander vitreus	walleye	(WLE)

[1] Focal taxa represent the 10 most abundant species present in recent Middle Rio Grande collections and are illustrated in monthly plots of data.

shoreline run habitat (SHRU) where 10 sample locations were selected at random and sampled. The increased sampling in SHRU mesohabitats was implemented because this was the most common non-run mesohabitat present at all sampling units and was sometimes the only non-run mesohabitat available.

The low density of fish in runs, combined with its abundant availability (often >75%), also made it prudent to take random samples in this mesohabitat type. In contrast to the disjointed distribution of non-run mesohabitats, possible sampling locations for runs were distributed both longitudinally and laterally over a continuous area. Thus, the same GRTS method that was used to generate the list of spatially-balanced sampling units 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 5.0 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 locations were kept consistent over time by using the same points selected using the GRTS method in the first year of sampling during subsequent years of sampling. In areas where samples could not be completed (e.g., shift in channel location, formation of islands, etc.), the nearest available GRTS points on the same transect were used. If no additional GRTS points were available on the same transect, the nearest available points on the same transect were used.

Shoreline mesohabitats were blocked off (to prevent immigration or emigration) during depletion efforts by a panel (5 m long and 1.5 m high) that was constructed out of PVC (open-ended to allow rapid sinking and draining) and screened using small mesh (4.8 mm) seine material. The panel was 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 panel. A small mesh seine (4.8 mm), which was staked to bamboo posts and weighted, was used to close off the upstream portion of the panel. Two 3.1 m x 1.8 m small mesh (4.8 mm) seines (two-person) were used to close off the downstream portion of the panel. The panel and attached upstream seine were carried out over the water and then quickly dropped and staked into place at the sampling location (about 2 meters from the shoreline). At the same time, the two downstream seines were set into place and tucked inside a seine flap at the downstream portion of the panel (to ensure complete and simultaneous closure of the sample area). Five personnel were required to operate the shoreline sampler under normal flow conditions (two to hold the panel in place, two to operate the downstream seines, and one to electrofish the inside of the enclosure). The person with the electrofishing unit operated two wands (one on either side of the enclosure) and moved slowly through the box until reaching the downstream end. During electrofishing, one person used a large dipnet to create additional flow within the box, if necessary, and to capture any stunned fish not carried into the downstream seine bag by the current. The two downstream seines were rotated after each pass to allow for additional depletion sampling if necessary. Fish from individual collecting efforts using the shoreline sampler 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.

For closed sampling of non-shoreline run and pool mesohabitats, a box (2 m wide, 5 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 with 4.8 mm mesh) 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). A weighted seine was attached to the top of the downstream portion of the box to allow for subsequent depletion samples if necessary; its purpose was to block any movement of fish when the downstream panel was removed. The sampling box was carried out over the water and 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. During electrofishing, one person used a large dipnet to create additional flow within the box, if necessary, and to capture any stunned fish not carried into the downstream seine bag by the current. 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. For sampling units with a channel width that couldn't accommodate the 20 run mesohabitat samples, the maximum number of possible samples were taken.

Capture probability estimates were generated for the various mesohabitat types by using all closed habitat electrofishing depletion data (collected using the current sampling methodology established in 2008) that were available at the time this report was finalized (i.e., 2008 to 2010). Depletion data collected from 2006 and 2007 (part of an initial research study that employed different sampling methodologies) were not comparable and thus were not included in these global capture probability estimates. From 2008 to 2010, multiple electrofishing depletion efforts within the same closed mesohabitat were taken when the abundance of Rio Grande silvery minnow collected on the first pass was adequate (i.e., ≥10 individuals) to obtain a reliable estimate of capture probability. We employed a depletion-sampling scheme where replicate depletion passes were made in a single closed mesohabitat until ≤5% of the original number of fish captured on the first pass or ≤4 individuals (whichever was higher) were captured on a subsequent pass. In most instances, this only required a second or third pass but sometimes required four passes. The collection of high numbers of Rio Grande silvery minnow in the first pass allowed for development of a more robust model. The Akaike Information Criterion (AIC_c; 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 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 mesohabitat specific initial capture probabilities. Program MARK (White and Burnham, 1999) was used to compute all removal estimates. In mesohabitat 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.

Determining Occupancy Rates from Past Population Monitoring Data

Intensive sampling data from population monitoring efforts (repeated sampling efforts in November [2005–2009]) 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 (2005–2009). 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 notable 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 D, Table D-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 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 November 2005–2009 Population Monitoring Program data sets were used for the purposes of calculating estimates of site occupancy. 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 2009. 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 time allowed for a robust-design model of occupancy (MacKenzie et al. 2003) to estimate the probability of occupancy each year (ψ_i, i = 1,2,3), the probability of extinction given a sampling unit is occupied (ε_i, i = 2,3), and the probability of colonization given a sampling unit is not occupied (γ_i, i = 2,3). Site occupancy models were constructed for age-classes (All Fish, Age-0, Age-1, Age-2; each age class was a separate attribute group [*g*]), with covariates of year (*y* = 2005 to 2009), 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. Associated measures of sampling variance (SE = standard error) and profile likelihood confidence intervals (LCI = 95% lower confidence bound, UCI = 95% upper confidence bound) were generated for all parameter estimates.

Population Estimation of Rio Grande Silvery Minnow

Generating population estimates from October 2009 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 value 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 converted between scales. 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.

Rio Grande silvery minnow population estimates generated in 2009 were based on global capture probability estimates that utilized all comparable closed habitat electrofishing data available at the time this report was finalized (i.e., 2008 to 2010). This approach resulted in more robust depletion models, as compared to using data from only a single year, because the higher sample size among mesohabitats, especially rare mesohabitats, increased the statistical power of these analyses. The use of global capture probability estimates will also result in the continual refinement and presumed accuracy of population estimates made in the past. For this reason, the 2008 population estimates that appear in this report supersede those that appear in all previous reports. Similarly, the 2009 population estimates will continue to be refined in subsequent years (i.e., after the analysis of the 2011 data) as the depletion models become more robust with the inclusion of additional data.

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 density data (#/m^2) from October 2009. Unlike the robust capture probability estimates derived from the closed habitat electrofishing depletion data collected during the Population Estimation Program, the open habitat seining sampling methodology of the Population Monitoring Program did not yield data for calculating capture probability estimates. Thus, a conservative approach was taken in generating population estimates based on the Population Monitoring Program data by setting all capture probability estimates equal to one. This factor along with other factors described below likely contributed to a substantial underestimate of the population based on the Population Monitoring Program data.

An estimate of mesohabitat availability was necessary to complete the calculation of density using Population Monitoring Program data. 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 approximate width of the river channel by the length of the sampling unit. Nearly all non-run mesohabitats were measured and sampled in their entirety, with the exception of shoreline runs. The remaining available shoreline run mesohabitat was calculated as the approximate area of all shoreline mesohabitat minus the area of shoreline mesohabitat that was sampled. This was a conservative approach to estimating non-run mesohabitat area as no available areas were calculated for non-shoreline mesohabitats (e.g., backwaters, pools, shoreline pools) and because shoreline mesohabitat availability was not calculated around islands. Run mesohabitat area was calculated as the approximate 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. However, the lack of detailed mesohabitat maps combined with the simplistic approach to calculating mesohabitat area likely resulted in a substantial underestimate of total mesohabitat availability, which likely contributed to a substantial underestimate of the population based on the Population Monitoring Program data.

Population estimates generated from the 2006 and 2007 Population Estimation Program data (part of an initial research study that employed different sampling methodologies) were not included in this trend comparison because those early data were not comparable with data collected from 2008 to 2009. The data collected in 2006 and 2007 were part of an evolving research study to identify the most statistically valid sampling methodologies to estimate populations of Rio Grande silvery minnow. The change in methodology from primarily open habitat seine samples (2006 and 2007) to exclusively closed habitat electrofishing samples (2008 to 2009) precluded comparisons among population trends derived from all Population Estimation Program data (i.e., 2006 to 2009) with those from the Population Monitoring 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 conservative estimates of mesohabitat area, relies on non-randomly selected sampling units, does not incorporate valid capture probability estimates, will violate numerous statistical assumptions, and thus must be viewed very cautiously. The estimate generated from the Population Monitoring Program data was not designed to provide the same high level of rigor inherent in the statistical methodology used to calculate estimates based Population Estimation Program data. The primary reason for performing this computational exercise was to determine if additional investigation should be pursued regarding a potential relationship between data collected as part of the Population Monitoring Program and the Population Estimation Program. Rather than a statistical comparison of the actual estimates of population obtained from the Population Monitoring Program and Population Estimation Program data, the purpose of this analysis was to compare the general population trends of Rio Grande silvery minnow over time as inferred from these two studies.

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 E, Report E-1). The native ichthyofauna consisted of seven species (red shiner, Rio Grande silvery minnow, flathead chub, fathead minnow, river carpsucker, longnose dace, and bluegill). Bluegill (N = 2) was the least abundant native fish while river carpsucker and longnose dace (N = 41 and N = 4, respectively) were the next least abundant taxa. Red shiner was the most abundant native species collected (N = 2,344), followed by Rio Grande silvery minnow (N = 1,688), flathead chub (N = 209), and fathead minnow (N = 165). The most abundant introduced species were western mosquitofish (N = 607) and channel catfish (N = 466). The ten remaining nonnative fish species were present at lower numbers (i.e., N < 10) than were the aforementioned nonnative species.

Abundance and distribution

The largest numbers of fish were collected in the Isleta Reach (N = 4,174; 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 catch rate of fish (N = 677 in 1,931.79 m^2 sampled). The distribution of fish within the Angostura Reach was uneven with lower densities in the upper and middle portion of the reach. The heavily channelized sampling unit #4 yielded the fewest number of fish (N = 50) of any sampling unit in the Angostura Reach. Fish abundance in the San Acacia Reach was uneven. Sampling unit #20 yielded the fewest number of fish (N = 21) while unit #13 yielded the most fish (N = 346). Rio Grande silvery minnow densities were generally highest in the Isleta Reach. However, 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). Fathead minnow and western mosquitofish were least numerous in the Angostura and San Acacia reaches and most abundant in the Isleta Reach. While flathead chub density was highest in the Angostura Reach, red shiner, Rio Grande silvery minnow, and channel catfish densities were highest in the Isleta Reach. For all reaches combined, red shiner, Rio Grande silvery minnow, western mosquitofish, and channel catfish 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 silvery minnow were recorded in the middle portion of its range within the Middle Rio Grande. The four highest densities recorded for Rio Grande silvery minnow were in the Isleta and San Acacia reaches.

Depletion Sampling

Multiple depletion passes within discrete mesohabitats were used to generate depletion model estimates using closed habitat electrofishing data collected from 2008 to 2010 (Table 5). The best model for the mesohabitat-specific depletion data (based on the lowest AIC_C value) was by mesohabitat and location (for BW, PO, SHPO, and SHRU) and was supported by a high model weight. Riffles (RI) did not yield Rio Grande silvery minnow and so capture probability could not be

Table 3. Summary of the Rio Grande silvery minnow Population Estimation Program fish collections from October 2009.

FAMILY	SPECIES COMMON NAME	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT (%) OF TOTAL	FREQUENCY OF OCCURRENCE[2]	% FREQUENCY OCCURRENCE[2]
Clupeidae	gizzard shad	I	1	0.02	1	5
Clupeidae	threadfin shad	I	-	-	-	-
Cyprinidae	central stoneroller	I	-	-	-	-
Cyprinidae	red shiner	N	2,344	42.16	19	95
Cyprinidae	common carp	I	7	0.13	6	30
Cyprinidae	Rio Grande chub	N	-	-	-	-
Cyprinidae	Rio Grande silvery minnow	N	1,688	30.36	20	100
Cyprinidae	golden shiner	I	-	-	-	-
Cyprinidae	fathead minnow	N	165	2.97	9	45
Cyprinidae	bullhead minnow	I	-	-	-	-
Cyprinidae	flathead chub	N	209	3.76	15	75
Cyprinidae	longnose dace	N	4	0.07	2	10
Catostomidae	river carpsucker	N	41	0.74	7	35
Catostomidae	white sucker	I	7	0.13	5	25
Catostomidae	smallmouth buffalo	N	-	-	-	-
Ictaluridae	black bullhead	I	2	0.04	1	5
Ictaluridae	yellow bullhead	I	3	0.05	2	10
Ictaluridae	blue catfish	I	-	-	-	-
Ictaluridae	channel catfish	I	466	8.38	18	90
Ictaluridae	flathead catfish	I	-	-	-	-
Salmonidae	rainbow trout	I	-	-	-	-
Salmonidae	brown trout	I	-	-	-	-
Poeciliidae	western mosquitofish	I	607	10.92	13	65
Moronidae	white bass	I	5	0.09	3	15
Moronidae	striped bass	I	-	-	-	-
Centrarchidae	green sunfish	I	3	0.05	2	10
Centrarchidae	bluegill	N	2	0.04	2	10
Centrarchidae	longear sunfish	I	-	-	-	-
Centrarchidae	smallmouth bass	I	-	-	-	-
Centrarchidae	largemouth bass	I	1	0.02	1	5
Centrarchidae	white crappie	I	3	0.05	2	10
Centrarchidae	black crappie	I	-	-	-	-
Percidae	yellow perch	I	-	-	-	-
Percidae	bigscale logperch	I	-	-	-	-
Percidae	walleye	I	2	0.04	2	10
TOTAL			5,560			

[1] N = native; I = introduced
[2] Frequency and % frequency of occurrence are based on n=20 sample sites

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 2009 Rio Grande silvery minnow Population Estimation Program.

REACH	SITE #	SITE NAME	TOTAL NUMBER OF RGSM	TOTAL NUMBER OF ALL FISH	SAMPLING EFFORT (m^2)
Angostura	2	Paseo del Norte upper	1	55	339.44
Angostura	3	Paseo del Norte lower	97	224	514.77
Angostura	4	Rio Bravo upper	27	50	383.91
Angostura	5	Rio Bravo middle	20	116	394.30
Angostura	6	Rio Bravo lower	19	232	299.37
Angostura Totals			164	677	1,931.79
Isleta	7	Los Lunas	230	449	388.42
Isleta	8	Belen	64	656	495.38
Isleta	9	Jarales	537	2,569	491.51
Isleta	9.5	Bernardo	6	100	456.95
Isleta	10	S. of Bernardo	126	361	381.89
Isleta	11	Sevilleta	19	39	428.04
Isleta Totals			982	4,174	2,642.19
San Acacia	12	S. of San Acacia	24	71	391.27
San Acacia	13	Socorro	326	346	468.95
San Acacia	14	San Antonio	41	51	585.68
San Acacia	15	Bosque del Apache	6	60	391.31
San Acacia	16	S. of Bosque del Apache	26	36	401.62
San Acacia	17	San Marcial	18	25	440.42
San Acacia	18	S. of San Marcial	28	40	314.47
San Acacia	19	S. of LFCC return A	55	59	329.27
San Acacia	20	S. of LFCC return B	18	21	327.33
San Acacia Totals			542	709	3,650.31
MONTHLY TOTALS			1,688	5,560	8,224.29

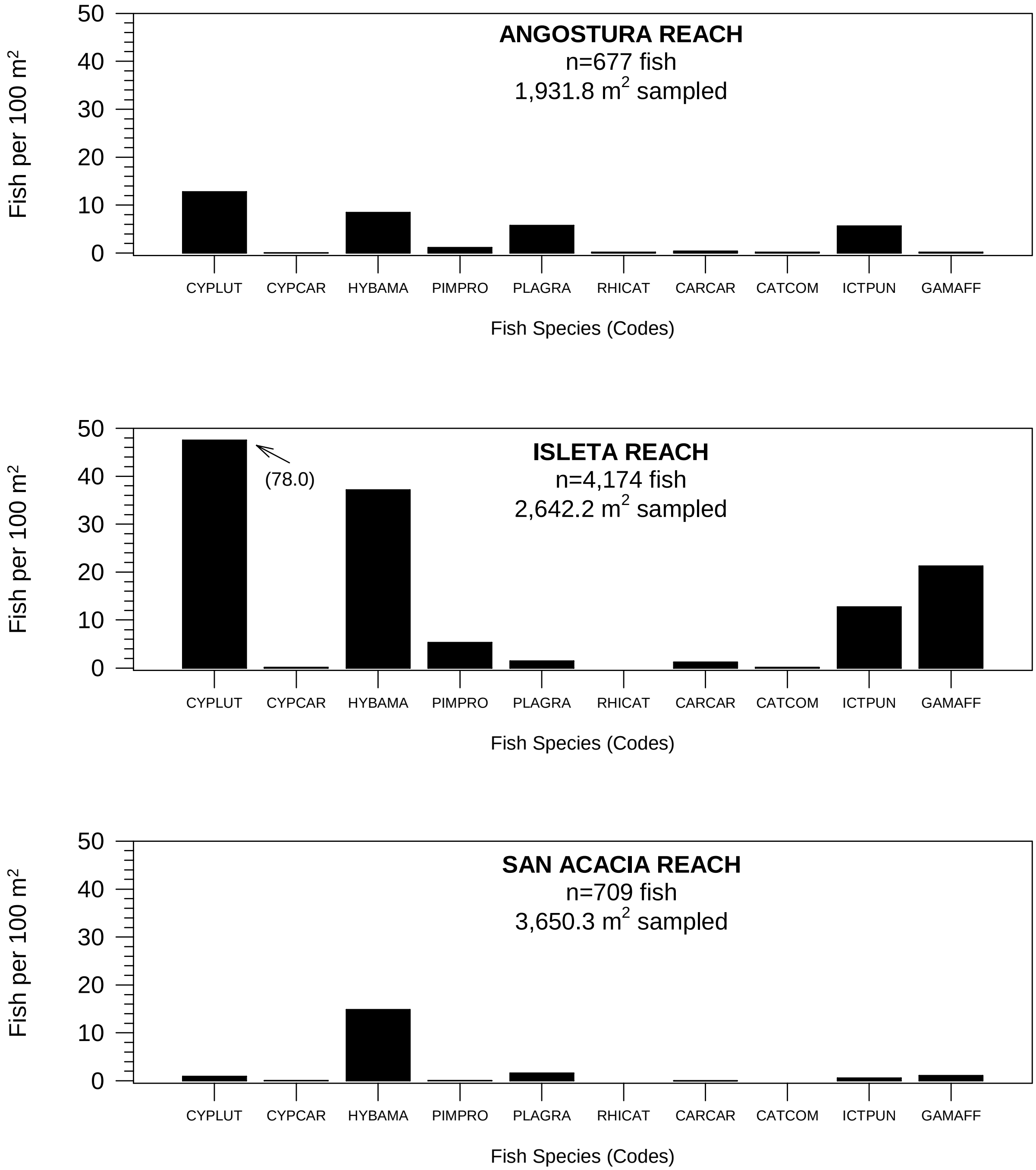
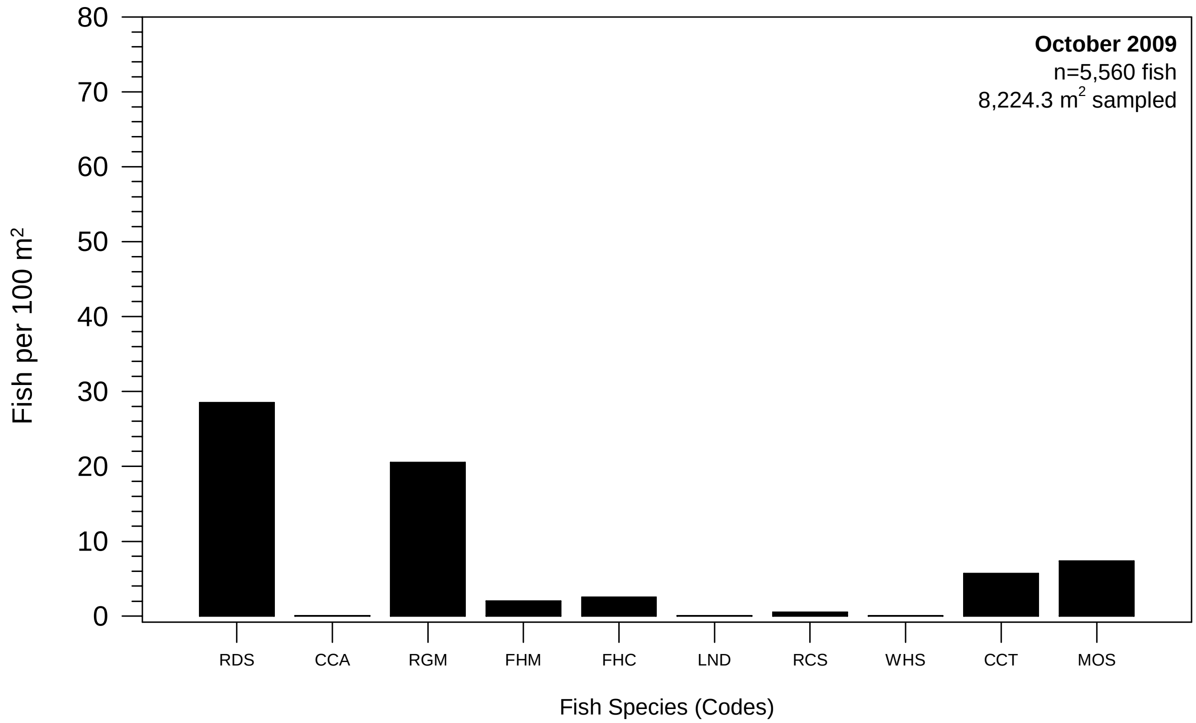


Figure 3. Catch rates, for the 10 focal species, by river reach during October 2009 at Rio Grande silvery minnow Population Estimation Program sampling units (see Table 2 for fish species codes).



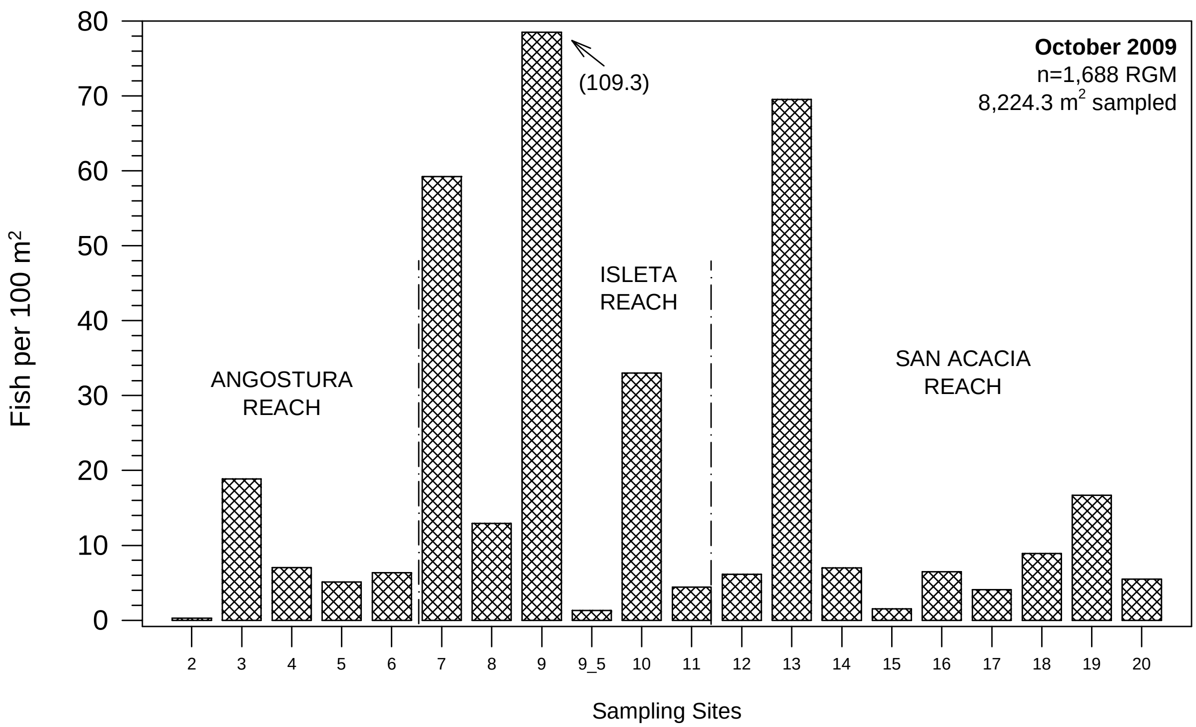


Figure 4. Catch rates for ten focal species (upper graph), including Rio Grande silvery minnow, (RGM; lower graph) during October 2009 at Rio Grande silvery minnow Population Estimation Program sampling units (see Table 2 for fish species codes).

Table 5. Rio Grande silvery minnow multiple depletion removal analysis and modeling results using all comparable closed habitat electrofishing data collected from multiple mesohabitat types and locations in the Middle Rio Grande (2008 to 2010).

RGSM depletion data

Models*	AICc	Delta AICc	AICc Weights	Model Likelihood	Number of Parameters	Deviance
BW - {Mesohabitat+Location}	**-5190.4048**	**0.0000**	**1.0000**	**1.0000**	**38.0000**	**59.6253**
BW - {Mesohabitat}	**-5084.6569**	**105.7479**	**0.0000**	**0.0000**	**39.0000**	**163.2597**
PO - {Mesohabitat+Location}	**-416.5693**	**0.0000**	**0.95776**	**1.0000**	**6.0000**	**4.6590**
PO - {Mesohabitat}	**-410.3267**	**6.2426**	**0.04224**	**0.0441**	**4.0000**	**15.2269**
RU - {Mesohabitat}	**-211.1987**	**0.0000**	**0.99774**	**1.0000**	**8.0000**	**6.6372**
RU - {Mesohabitat+Location}	**-199.0208**	**12.1779**	**0.00226**	**0.0023**	**14.0000**	**2.9928**
SHPO - {Mesohabitat+Location}	**-1392.1697**	**0.0000**	**1.0000**	**1.0000**	**32.0000**	**32.1484**
SHPO - {Mesohabitat}	**-1342.7764**	**49.3933**	**0.0000**	**0.0000**	**17.0000**	**114.2733**
SHRU - {Mesohabitat+Location}	**-2771.7221**	**0.0000**	**1.0000**	**1.0000**	**76.0000**	**70.1683**
SHRU - {Mesohabitat}	**-2692.2084**	**79.5137**	**0.0000**	**0.0000**	**39.0000**	**231.6219**

{Mesohabitat}	Capture Probability Estimate	Standard Error of Estimate	Lower 95% CI of Estimate	Upper 95% CI of Estimate
BW	**0.7037**	**0.0191**	**0.6649**	**0.9010**
PO	**0.7153**	**0.0376**	**0.6363**	**0.8826**
RU	**0.8444**	**0.0382**	**0.7543**	**0.9800**
SHPO	**0.6858**	**0.0276**	**0.6294**	**0.8604**
SHRU	**0.7361**	**0.0157**	**0.7042**	**0.9385**

estimated in this mesohabitat. 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 (for BW, PO, SHPO, and SHRU) was by mesohabitat only but the model weight was substantially lower than the mesohabitat and location model. The best model for RU mesohabitat samples was by mesohabitat only and the second best model was by mesohabitat and location. The capture probability estimates (i.e., proportion of fish removed per depletion pass) for the different mesohabitats ranged from 0.6858 (shoreline pools) to 0.8444 (runs). The associated standard errors for estimates were consistent among mesohabitats and ranged from 0.0157 to 0.0382.

Occupancy Rates from Past Population Monitoring Data

The encounter history for Rio Grande silvery minnow (Table 6) during November 2009 was dominated by one sampling category (1111 [24.0%]). This represented visits to the same mesohabitat location where Rio Grande silvery minnow were collected on all four days of sampling (1111). Another common sampling category was consistent absence of Rio Grande silvery minnow (0000 [21.25%]). The other sampling encounter categories had a relatively even probability distribution and there were not strong patterns in the combinations of encounters. The rarest combinations (1010 and 1001 [1.5%]) was where individuals were collected on day one, not collected on day two, and then collected on either day three or day four.

Probability of detection and probability of occupancy estimates during 2009 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 0.6385 while the estimate for age-0 individuals was 0.6292; probability of detection estimates were much lower for age-1 and age-2 individuals (<0.2). The probability of occupancy estimate for all Rio Grande silvery minnow was 0.8275 while the estimate for age-0 individuals was 0.8176. The occupancy estimate for age-1 individuals was 0.4165 and the occupancy estimate for age-2 individuals was 0.1205.

The availability of data from 2005 to 2009 allowed for a calculation of the probability of occupancy for all sampling units combined based on collections within each sampling unit over time (Table 7). This was different than the preceding analysis (i.e., Table 6) in that the variable of interest was the sampling unit vs. individual mesohabitats within a sampling unit. The minimum AIC_C model had constant occupancy (psi, ψ), extinction (epsilon, ε), and colonization (gamma, 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 (0.5647) and age-2 (0.5755) individuals. Estimates of the probability of extinction were relatively low for all age-classes (0.0130) and age-0 (0.0486) individuals. The probability of extinction was higher for both age-1 and age-2 individuals (0.1750 and 0.1234, respectively). Estimates of the probability of colonization were relatively high for age-0 (0.4664) and age-1 (0.7926) 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 F.

Table 6. Rio Grande silvery minnow encounter history summaries, probability of detection estimates, and probability of occupancy estimates based on repeated sampling efforts in November 2009.

RGSM encounter history (all age-classes)

Encounters*	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1111	96	24.00	96	24.00
1110	17	4.25	113	28.25
1101	20	5.00	133	33.25
1100	19	4.75	152	38.00
1011	15	3.75	167	41.75
1010	6	1.50	173	43.25
1001	6	1.50	179	44.75
1000	16	4.00	195	48.75
0111	25	6.25	220	55.00
0110	13	3.25	233	58.25
0101	15	3.75	248	62.00
0100	12	3.00	260	65.00
0011	18	4.50	278	69.50
0010	16	4.00	294	73.50
0001	21	5.25	315	78.75
0000	85	21.25	400	100.00

*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
p: All RGSM	0.6385	0.0177	0.6038	0.6732
p: Age-0 RGSM	0.6292	0.0180	0.5940	0.6644
p: Age-1 RGSM	0.1755	0.0317	0.1135	0.2376
p: Age-2 RGSM	0.1037	0.0570	-0.0080	0.2154
ψ: All RGSM	0.8275	0.0223	0.7838	0.8712
ψ: Age-0 RGSM	0.8176	0.0227	0.7732	0.8621
ψ: Age-1 RGSM	0.4165	0.0709	0.2776	0.5555
ψ: Age-2 RGSM	0.1205	0.0632	-0.0034	0.2444

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

Table 7. 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 (2005–2009).

RGSM Site Occupancy Models

Models*	AIC_c	Delta AIC_c	AIC_c Weights	Model Likelihood	Number of Parameters	Deviance
A: {$\psi(g)$ $\varepsilon(g)$ $\gamma(g)$ $p(g*y+y*d)$}	850.9604	0.0000	0.7609	1.0000	37	769.1924
B: {$\psi(g)$ $\varepsilon(g)$ $\gamma(g)$ $p(g*y+d)$}	853.9076	2.9472	0.1743	0.2291	33	781.7765
C: {$\psi(g)$ $\varepsilon(g)$ $\gamma(g)$ $p(g*y)$}	855.9445	4.9841	0.0630	0.0827	32	786.1897
D: {$\psi(g)$ $\varepsilon(g*y)$ $\gamma(g)$ $p(g*y)$}	863.0634	12.1030	0.0018	0.0024	44	763.9085
E: {$\psi(g)$ $\varepsilon(g)$ $\gamma(g*y)$ $p(g*y)$}	876.9236	25.9632	0.0000	0.0000	44	777.7686

Parameter Estimates from Minimum AIC_c Model (A)**

Label*	Estimate	SE	LCI	UCI
ψ All Fish (2005)	1.0000	0.0000	0.9085	1.0000
ψ Age-0 (2005)	1.0000	0.0000	0.9085	1.0000
ψ Age-1 (2005)	0.5647	0.1639	0.2976	1.0000
ψ Age-2 (2005)	0.5755	0.3330	0.0528	1.0000
ε All Fish	0.0130	0.0129	0.0007	0.0560
ε Age-0	0.0486	0.0273	0.0075	0.1169
ε Age-1	0.1750	0.0822	0.0000	0.3442
ε Age-2	0.1234	0.1321	0.0000	0.5706
γ All Fish	0.0000	0.0002	0.0000	0.0000
γ Age-0	0.4664	0.2234	0.0020	0.8356
γ Age-1	0.7926	0.1312	0.0940	0.9761
γ Age-2	0.0693	0.1234	0.0000	0.4306

Derived estimates of ψ by Year (last four years) from Minimum AIC_c Model (A)

Group	Year	Estimate	SE	LCI	UCI
All Fish	2006	0.9870	0.0129	0.9617	1.0123
All Fish	2007	0.9742	0.0255	0.9243	1.0241
All Fish	2008	0.9615	0.0377	0.8876	1.0355
All Fish	2009	0.9491	0.0496	0.8518	1.0463
Age-0	2006	0.9514	0.0273	0.8979	1.0048
Age-0	2007	0.9278	0.0392	0.8509	1.0047
Age-0	2008	0.9163	0.0465	0.8251	1.0076
Age-0	2009	0.9108	0.0514	0.8100	1.0115
Age-1	2006	0.8109	0.0597	0.6940	0.9278
Age-1	2007	0.8189	0.0639	0.6936	0.9441
Age-1	2008	0.8191	0.0651	0.6915	0.9468
Age-1	2009	0.8192	0.0652	0.6914	0.9469
Age-2	2006	0.5339	0.2325	0.0782	0.9896
Age-2	2007	0.5003	0.1651	0.1768	0.8239
Age-2	2008	0.4732	0.1334	0.2117	0.7348
Age-2	2009	0.4513	0.1350	0.1867	0.7160

*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 F.

Population Estimation of Rio Grande Silvery Minnow

Population estimates from October 2009 data

Average population estimates of Rio Grande silvery minnow were calculated for each of the 20 units and varied among reaches (Table 8). The lowest average population estimate for sampling units was recorded in the San Acacia Reach (789.71) while the highest was recorded in the Isleta Reach (1,634.81). The average population estimate per sampling unit for all reaches was 1,186.28. The lowest coefficient of variation (CV) was recorded in the Isleta Reach (0.75) while the highest CV was in the San Acacia Reach (1.71). 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 = 688,257) and lowest in the San Acacia Reach (N = 374,321). The standard errors associated with population estimates for the three reaches were proportionally comparable for the Angostura and San Acacia reaches; variation was notably lower in the Isleta Reach. The overall population estimate was 1,387,948 and had a standard error [SE] of 358,937. The upper 95% confidence intervals (CI), especially in the Angostura and San Acacia reaches, reflected the high densities of Rio Grande silvery minnow in several of the sampling units.

An analysis was also conducted for unmarked Rio Grande silvery minnow. However, there were no marked individuals collected in 2009 (unlike in 2006 or 2007). All of the population estimates are therefore the same for the marked-unmarked vs. unmarked-only categories in 2009.

Population estimates were also generated for the different age-classes of Rio Grande silvery minnow (Table 9). The average population estimates of age-0 individuals for the different reaches largely reflected the overall estimates (i.e., both age-0 and age-1 individuals included) with the exception of the Angostura Reach. This was primarily caused by the large numbers of age-0 Rio Grande silvery minnow in all reaches, especially the Isleta and San Acacia reaches. The coefficient of variation for age-0 individuals was highest in the San Acacia Reach (1.71) and lowest in the Isleta Reach (0.79). Values of CV for age-1 individuals were similar between the Angostura and Isleta reaches (1.213 and 1.215, respectively); the low numbers of age-1 individuals in the San Acacia Reach resulted in a slightly elevated CV value (1.93). The overall population estimate for age-0 (N = 1,114,984) Rio Grande silvery minnow was significantly higher than for age-1 (N = 237,217) individuals.

Comparison of RGSM estimates from Population Monitoring and Population Estimation data

Population estimates were also generated using data from the Population Monitoring Program October 2009 sampling efforts but the estimates must be viewed very cautiously (see Methods). For all Rio Grande silvery minnow and only unmarked individuals, the average population estimates per sampling unit were considerably lower using the Population Monitoring Program data (Table 10) than those generated using the Population Estimation Program data. The highest average population estimates per sampling unit were recorded in the Isleta and San Acacia reaches (726.78 and 473.47, respectively) while the lowest was in the Angostura Reach (393.40). Values of CV ranged from 0.82 in the Angostura Reach to 1.03 in the San Acacia Reach. The population estimates for the marked-unmarked vs. unmarked-only categories were identical because, like the Population Estimation Program, no marked individuals were collected in October 2009 during the Population Monitoring Program.

The population estimates for the study area varied among reaches with the highest numbers recorded in the Isleta Reach (305,976) and the lowest numbers in the Angostura Reach (108,184). The standard errors associated with population estimates for the three reaches were proportionally

Table 8. Rio Grande silvery minnow population estimation results for all sampling reaches and the overall study area in the Middle Rio Grande (all individuals and unmarked individuals only).

Rio Grande silvery minnow (all individuals)

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	1,361.87	1,678.49	275	374,515.10	204,762.41	137,452.05	1,020,439.96
Isleta	1,634.81	1,232.85	421	688,256.83	210,608.94	382,896.79	1,237,141.40
San Acacia	789.71	1,354.15	474	374,320.84	212,070.00	133,086.93	1,052,816.28
Combined	1,186.28	1,382.51	1,170	1,387,948.14	358,936.64	842,933.46	2,285,352.43

Rio Grande silvery minnow (unmarked individuals 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	1,361.87	1,678.49	275	374,515.10	204,762.41	137,452.05	1,020,439.96
Isleta	1,634.81	1,232.85	421	688,256.83	210,608.94	382,896.79	1,237,141.40
San Acacia	789.71	1,354.15	474	374,320.84	212,070.00	133,086.93	1,052,816.28
Combined	1,186.28	1,382.51	1,170	1,387,948.14	358,936.64	842,933.46	2,285,352.43

Table 9. 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 individuals)

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	669.51	814.01	275	184,116.52	99,348.95	68,357.99	495,902.40
Isleta	1,442.59	1,144.24	421	607,331.04	195,449.01	328,254.28	1,123,674.61
San Acacia	784.05	1,344.03	474	371,639.17	210,486.95	132,169.62	1,044,988.07
Combined	952.98	1,164.05	1,170	1,114,984.40	302,201.67	661,658.78	1,878,899.31

Rio Grande silvery minnow (age-1 individuals)

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	618.98	750.74	275	170,220.11	91,678.33	63,302.27	457,722.71
Isleta	151.53	184.16	421	63,793.00	31,503.70	25,534.11	159,376.87
San Acacia	5.66	10.93	474	2,681.66	1,728.83	844.44	8,516.04
Combined	202.75	438.69	1,170	237,217.07	113,968.62	97,101.79	579,514.99

Table 10. 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 unmarked individuals only).

Rio Grande silvery minnow (all individuals)

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	393.40	320.93	275	108,183.69	39,362.36	54,203.03	215,923.57
Isleta	726.78	653.04	421	305,975.56	111,777.84	152,900.73	612,299.52
San Acacia	473.47	487.39	474	224,427.01	76,397.67	117,277.83	429,471.47
Combined	529.45	502.58	1,170	619,453.30	130,760.40	411,414.74	932,689.95

Rio Grande silvery minnow (unmarked individuals 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	393.40	320.93	275	108,183.69	39,362.36	54,203.03	215,923.57
Isleta	726.78	653.04	421	305,975.56	111,777.84	152,900.73	612,299.52
San Acacia	473.47	487.39	474	224,427.01	76,397.67	117,277.83	429,471.47
Combined	529.45	502.58	1,170	619,453.30	130,760.40	411,414.74	932,689.95

comparable for the three sampling reaches. The overall population estimate using the Population Monitoring Program data was 619,453 and had a standard error [SE] of 130,760.

The estimated number of age-0 Rio Grande silvery minnow was significantly higher than the estimated number of age-1 individuals (Table 11). The overall population estimate for Rio Grande silvery minnow using Population Monitoring Program data was 593,007 for age-0 individuals and 23,091 for age-1 individuals. The coefficient of variation for age-0 individuals was highest in the San Acacia Reach (1.01) and lowest in the Angostura Reach (0.75). Values of CV for age-1 individuals were similar between the Angostura and Isleta reaches (1.63 and 1.55, respectively); the low numbers of age-1 individuals in the San Acacia Reach resulted in an elevated CV value (3.00).

Despite differences in the actual numbers, the population estimates generated using the Population Estimation Program and Population Monitoring Program data showed a similar increasing population trend from 2008 to 2009 (Figure 5). While the overall population trend was similar when comparing estimates generated from Population Estimation Program and Population Monitoring Program data, the actual estimates were consistently lower when using the Population Monitoring Program data. Reach-specific comparisons between population estimates generated from Population Estimation Program and Population Monitoring Program data also showed similar trends from 2008 to 2009 but were not as closely related as were the combined reach comparisons (Table 12).

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 an annual 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, were 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

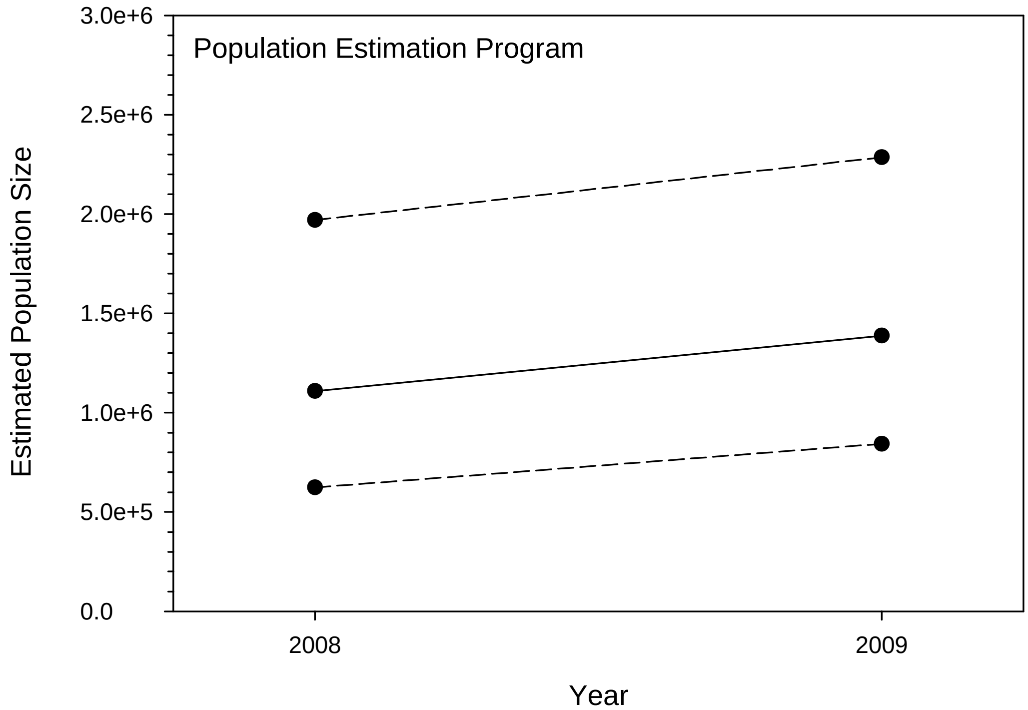
Table 11. Rio Grande silvery minnow population estimation results (**using Population Monitoring Program data**) for all sampling reaches and the overall study area in the Middle Rio Grande (age-0 and age-1 individuals).

Rio Grande silvery minnow (age-0 individuals)

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	349.35	261.94	275	96,071.58	32,194.56	50,687.23	182,092.16
Isleta	699.56	659.18	421	294,513.84	112,814.43	142,606.43	608,236.25
San Acacia	465.86	468.21	474	220,819.34	73,398.20	117,079.32	416,479.89
Combined	506.84	490.04	1,170	593,007.20	127,503.49	390,932.89	899,534.29

Rio Grande silvery minnow (age-1 individuals)

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	44.04	71.88	275	12,112.11	8,809.97	3,376.90	43,443.13
Isleta	17.67	27.37	421	7,437.67	4,711.49	2,382.37	23,220.10
San Acacia	7.61	22.83	474	3,607.67	3,607.17	705.69	18,443.37
Combined	19.74	41.60	1,170	23,091.13	10,861.91	9,613.31	55,464.81



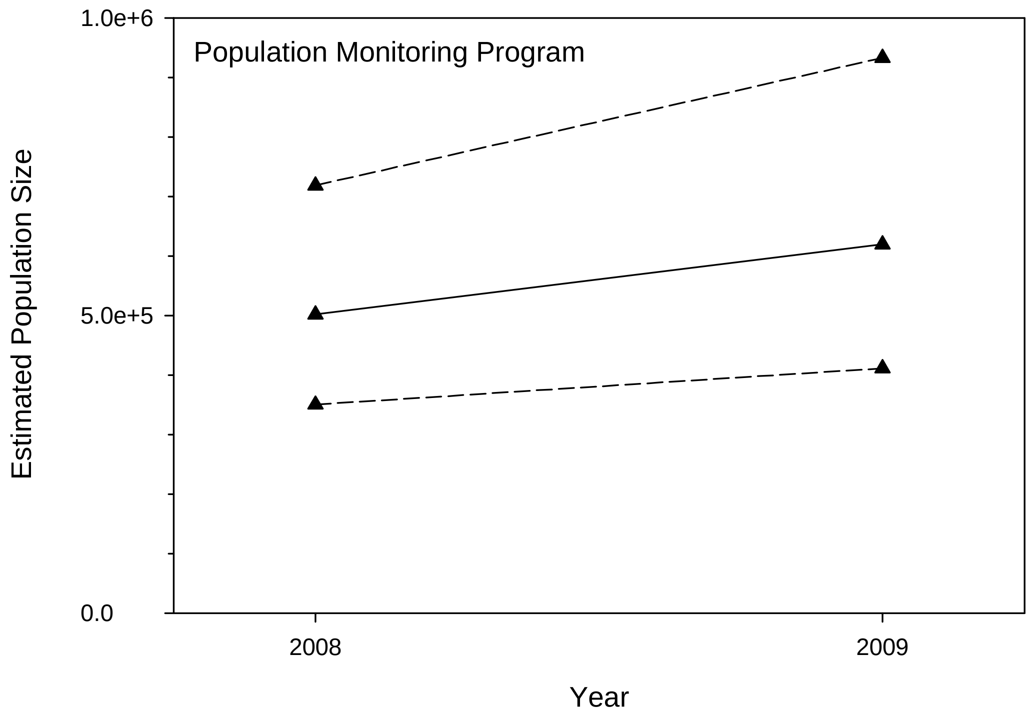


Figure 5. Estimates of Rio Grande silvery minnow population size (unmarked individuals only) calculated from Population Estimation Program and Population Monitoring Program data from 2008 to 2009 (solid line shows estimate and dashed lines show 95% upper and lower confidence bounds).

Table 12. Estimates of Rio Grande silvery minnow population size (unmarked individuals only) calculated from Population Estimation Program and Population Monitoring Program data by reach and for all reaches combined from 2008 to 2009.

Estimates of Rio Grande silvery minnow population size (unmarked individuals only)

Project	Year	Reach	Estimate	Lower 95% CI	Upper 95% CI
Population Estimation	2008	Angostura	429,544.58	166,651.59	1,107,151.46
Population Estimation	2009	Angostura	374,515.10	137,452.05	1,020,439.96
Population Estimation	2008	Isleta	453,266.74	152,384.15	1,348,242.14
Population Estimation	2009	Isleta	688,256.83	382,896.79	1,237,141.40
Population Estimation	2008	San Acacia	246,362.30	139,867.89	433,940.80
Population Estimation	2009	San Acacia	374,320.84	133,086.93	1,052,816.28
Population Estimation	2008	Combined	1,108,430.23	623,544.06	1,970,378.12
Population Estimation	2009	Combined	1,387,948.14	842,933.46	2,285,352.43
Population Monitoring	2008	Angostura	58,991.04	24,483.06	142,136.75
Population Monitoring	2009	Angostura	108,183.69	54,203.03	215,923.57
Population Monitoring	2008	Isleta	209,044.46	105,491.13	414,248.90
Population Monitoring	2009	Isleta	305,975.56	152,900.73	612,299.52
Population Monitoring	2008	San Acacia	276,512.41	200,984.23	380,423.46
Population Monitoring	2009	San Acacia	224,427.01	117,277.83	429,471.47
Population Monitoring	2008	Combined	544,170.27	393,990.38	751,595.22
Population Monitoring	2009	Combined	619,453.30	411,414.74	932,689.95

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 and trend of fish populations, as is employed for in the Population Monitoring Program, 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 likely 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 help ensure adequate genetic variation within a population or to reduce the risks of an isolated population becoming extinct). 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 periods of relatively lower abundance, can be obtained when sampling over a large geographical area. A high degree of precision was obtained in mapping mesohabitats and determining the areas and densities of this species in specific mesohabitats. The methodology employed allowed for calculations of population size of Rio Grande silvery minnow among reaches and age-classes. The sampling of 20 randomly selected units yielded overall population estimates with seemingly reasonable associated measures of variance given the substantial variability in the abundance of Rio Grande silvery minnow observed since 1993 (Dudley and Platania, 2009) and the widely variable observed densities of Rio Grande silvery minnow among sampling units. 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. There were constraints on the number of sampling units and the amount of sampling allocated per unit based on the extensive sampling effort required and the limitations inherent within the scope of this project. However, a power analysis of existing data revealed that even doubling the sampling effort (i.e., adding 20 sampling units) would likely only result in a modest decrease in the variation associated with existing population estimates (unpubl. data).

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 2009 (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 notable decline in the percentage of sites occupied by age-0 Rio Grande silvery minnow from 2005 to 2006. Probability of detection estimates for Rio Grande silvery minnow (all age-classes combined) in 2009 were similar to those recorded in 2008 and notably higher than those recorded in 2006. Site occupancy estimates for 2009 reflected consistency in the encounter histories and were similar to those recorded over the past four years.

Detailed site occupancy models at the sampling unit level were generated based on the availability of extensive data spanning from 2005 to 2009. 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 the other years (2005, 2007–2009). It is unknown if this pattern will remain consistent over time as 2006 was also the year with the lowest discharge. 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-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 based on data collected over the past four years. Estimates of site occupancy suggest a minor decline from 2005 to 2009 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 period of relatively stable discharge (i.e., modest spring runoff and the avoidance of massive river drying).

While large numbers of Rio Grande silvery minnow have been periodically stocked into the river since 2002, there was no significant positive correlation between recent stocking numbers and population estimates from 2006–2009 (unpubl. data). While populations of Rio Grande silvery minnow have increased or decreased over several orders of magnitude in the past few years, this variation was explained almost entirely from critical aspects of the annually dynamic hydraulic regime (Dudley and Platania, 2009) as opposed to the periodic input of hatchery fish. No Rio Grande silvery minnow were stocked from January 2008 to November 2009 and none of the sampling units of this study yielded marked individuals. Mortality rate of Rio Grande silvery minnow stocked in December 2007 would be expected to be high, especially if those individuals had spawned in either 2008 or 2009. However, the young of those marked fish would be included in our population estimate as wild fish. Increased sampling in the areas where stocked fish were spot-released would likely 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, 2009). It is possible that the stresses inflicted on fish during the capture, handling, and transport activities prior to 2007 could have resulted in very high rates of initial mortality (C. Caldwell, NMSU, pers. comm.). In addition, many of the salvaged individuals were 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 that many of these fish perished before recruiting into the population.

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 = ca. 30 to 90 mm SL or ca. 38 to 116 mm TL).

The population estimates from October 2009 data were generated following a period of improved Rio Grande silvery minnow spawning and recruitment as compared with 2006 (Dudley and Platania, 2009). There have been multiple massive changes in the abundance of Rio Grande silvery minnow within a relatively short period (1999–2009). Recent changes have been some of the most dramatic during the period of record; populations have changed by about an order of magnitude (10X) every year from 2003 to 2007 (Dudley and Platania, 2009). 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 and has stabilzed since that time (Dudley and Platania, 2009). 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 2007–2009 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. However, low flow conditions during the summer of 2009, in portions of the Isleta and San Acacia reaches, resulted in limited river drying or 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.

The population estimates generated using the Population Estimation Program and Population Monitoring Program data showed a similar increasing population trend from 2008 to 2009. However, the actual estimates were consistently lower when using the Population Monitoring Program data as compared with the Population Estimation Program data. Numerous methodological differences in how the estimates were calculated likely resulted in a substantial underestimate of the population based on the Population Monitoring Program data (see Methods). The conservative approach to estimating population size using the Population Monitoring Program data (based on the lack of depletion data and habitat mapping data) meant that capture probability estimates were much higher than would be expected and that mesohabitat availability was much lower than would be expected. The combination of these factors apparently resulted in a substantially lower estimate based on the Population Monitoring Program data and is the reason that these data were only presented for trend comparison purposes.

Reach-specific comparisons between population estimates generated from Population Estimation Program and Population Monitoring Program data generally showed similar trends from 2008 to 2009 but were not as closely related as were the combined reach comparisons. Some of this difference could be attributable to the nonrandom selection of mesohabitats and sampling units during the Population Monitoring Program. For the purposes of this study, the total population estimate (as opposed to reach-specific or age-specific population estimates) will likely yield the most useful and robust trend comparison between the two population estimation methods over time.

The estimates of Rio Grande silvery minnow population size using a common sampling methodology (2008 to 2010) should be viewed cautiously as they are only a few data points and are preceded by the 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 and 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.

ACKNOWLEDGMENTS

Many people collaborated with us to make this project possible. Adam L. Barkalow, Mary A. Brandenburg, W. Howard Brandenburg, Michael A. Farrington, Jennifer L. Hester, Richard C. Keller, and Kevin M. Schaus (American Southwest Ichthyological Researchers, L.L.C.; Museum of Southwestern Biology-UNM) were instrumental in field and laboratory portions of this study. Continued assistance with all aspects of curation of specimens and database management was provided by Alexandra M. Snyder (Museum of Southwestern Biology-UNM). Much of the logistical support for this project was provided by Jeanne L. Dye and Jericho E. Lewis (U. S. Bureau of Reclamation). This work was funded as part of the Middle Rio Grande Endangered Species Act Collaborative Program and administered by the U. S. Bureau of Reclamation Area Offices (Albuquerque, New Mexico and Salt Lake City, Utah).

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.

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. 2009. Rio Grande silvery minnow population monitoring program results from December 2007 to October 2008. Report to the Middle Rio Grande Endangered Species Act Collaborative Program and the U.S. Bureau of Reclamation, Albuquerque, New Mexico. 152 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.

Middle Rio Grande Endangered Species Act Collaborative Program (MRGESACP). 2006. Interim Monitoring Plan: Appendix A. Rio Grande fish community monitoring. Report to the Middle Rio Grande Endangered Species Act Collaborative Program from the Population Monitoring Group (Science Subcommittee). 48 pp.

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. 135 pp.

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. 28 pp.

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. 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.

Appendix A.

Middle Rio Grande sampling units for the Population Estimation Program

Table A-1. Sampling unit localities for the 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 (NM Highway 423), 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 (NM Highway 423), 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 (NM Highway 500), 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 (NM Highway 500), 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 (NM Highway 500), 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 6), 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 309 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 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 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

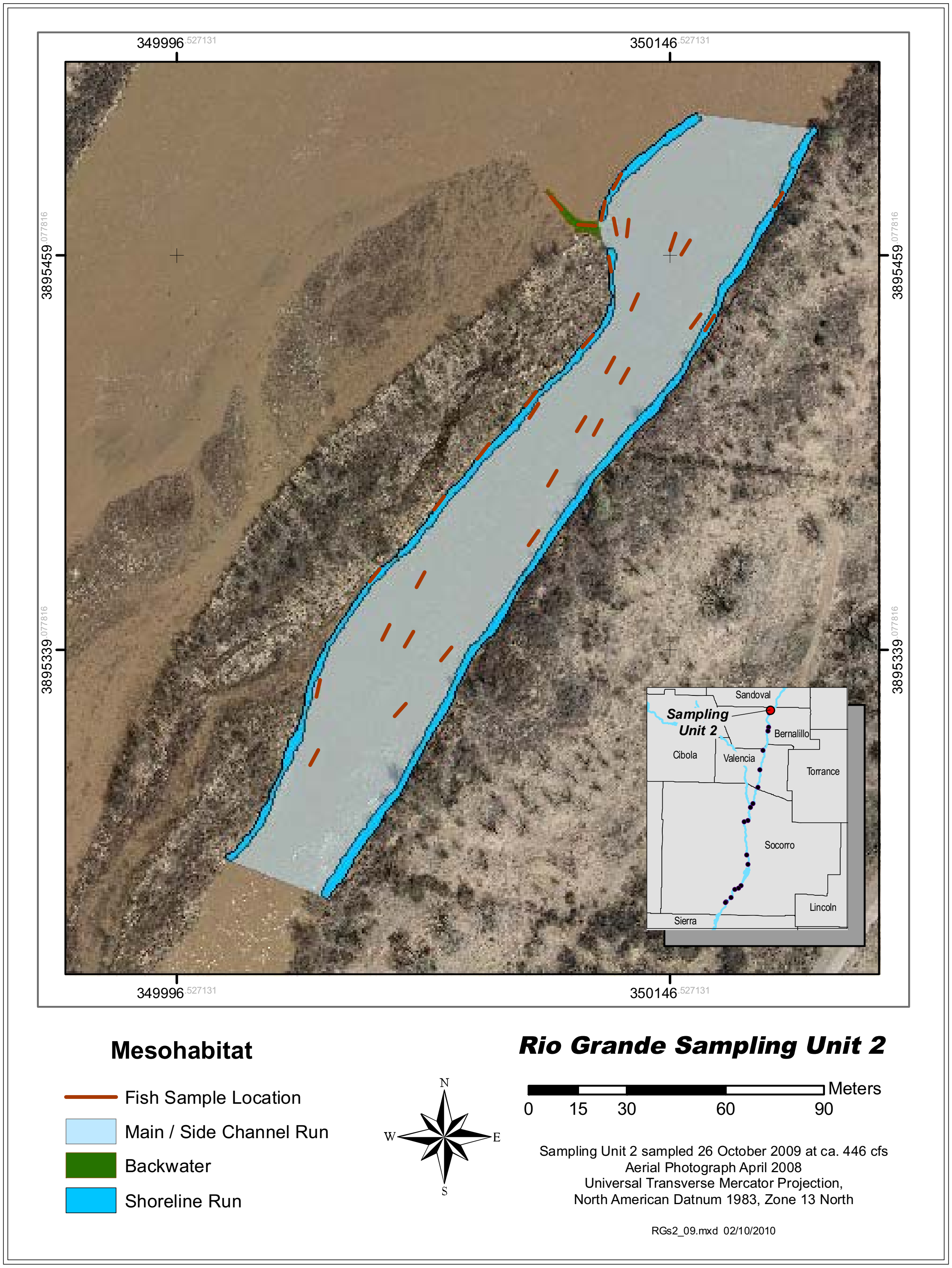


Figure B-1. Map of sampling unit #2 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

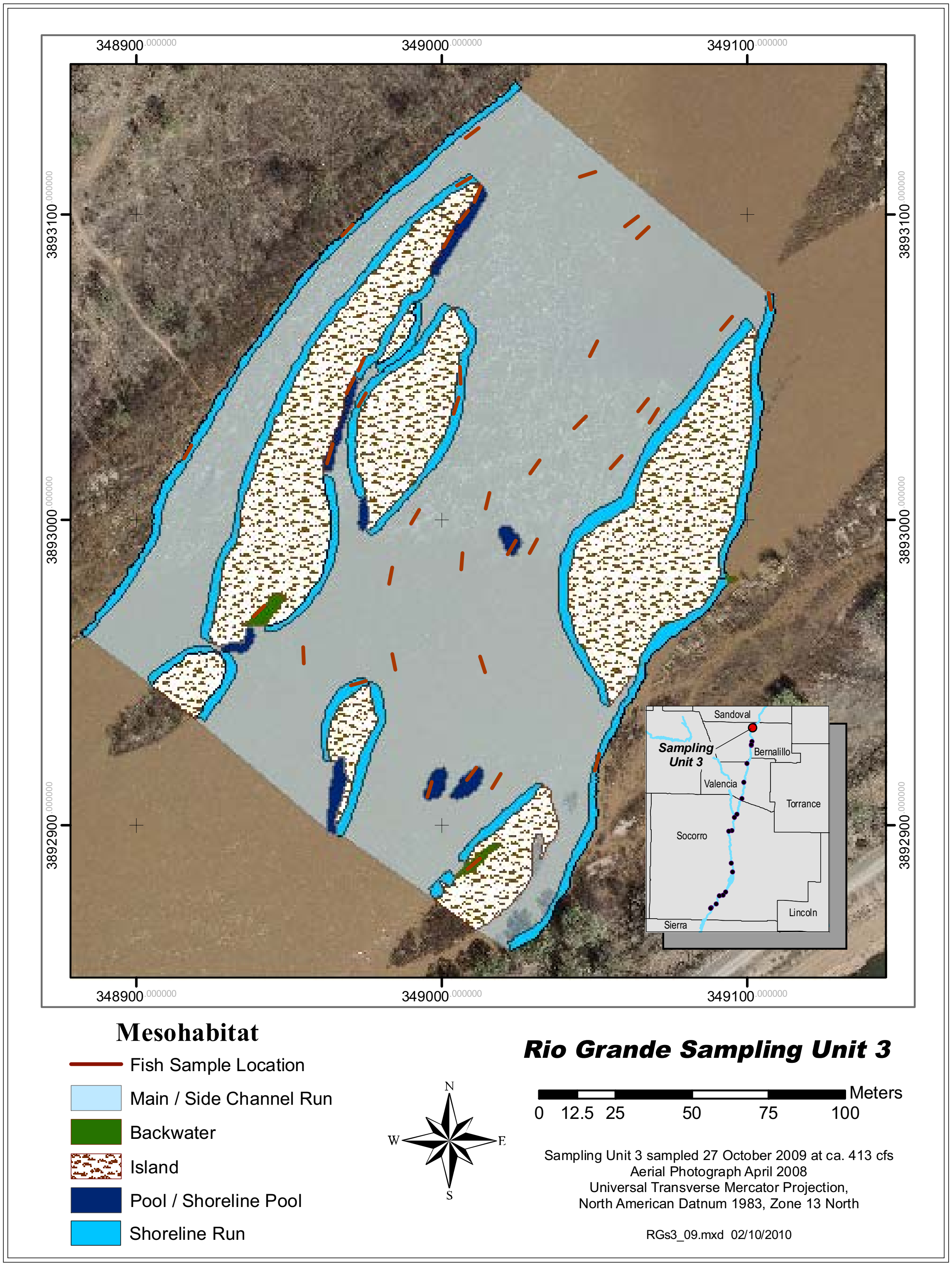


Figure B-2. Map of sampling unit #3 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

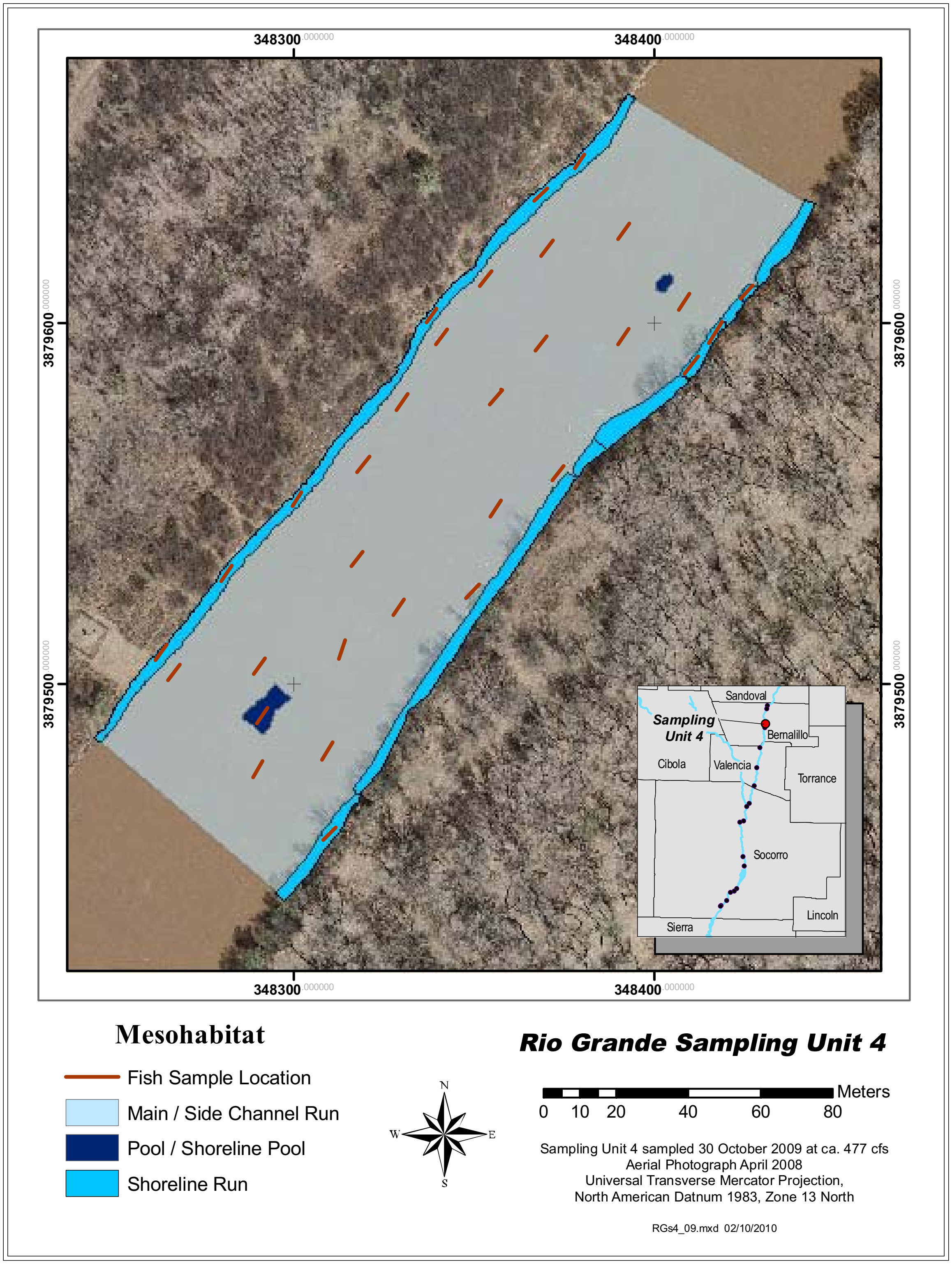


Figure B-3. Map of sampling unit #4 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

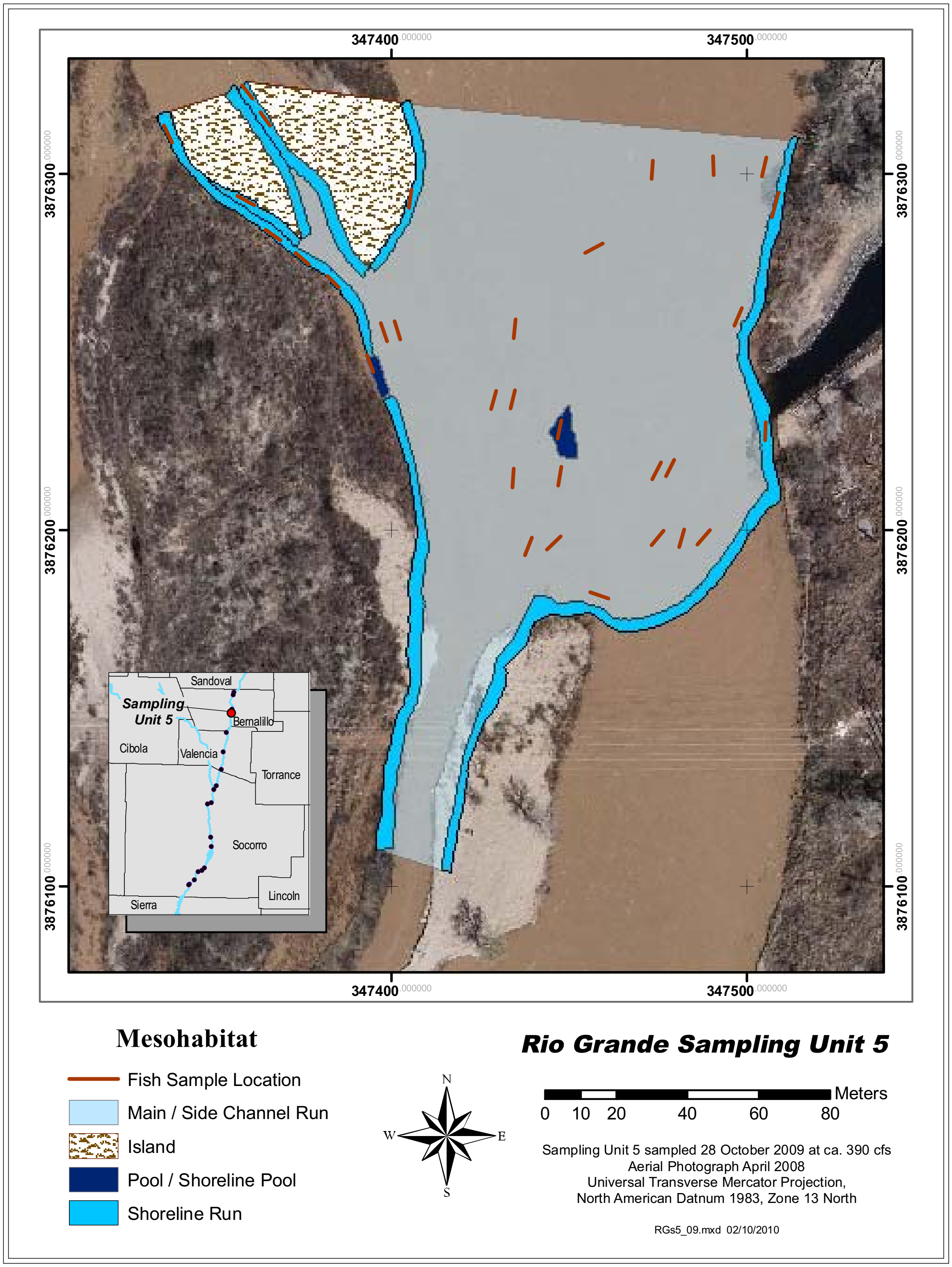


Figure B-4. Map of sampling unit #5 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

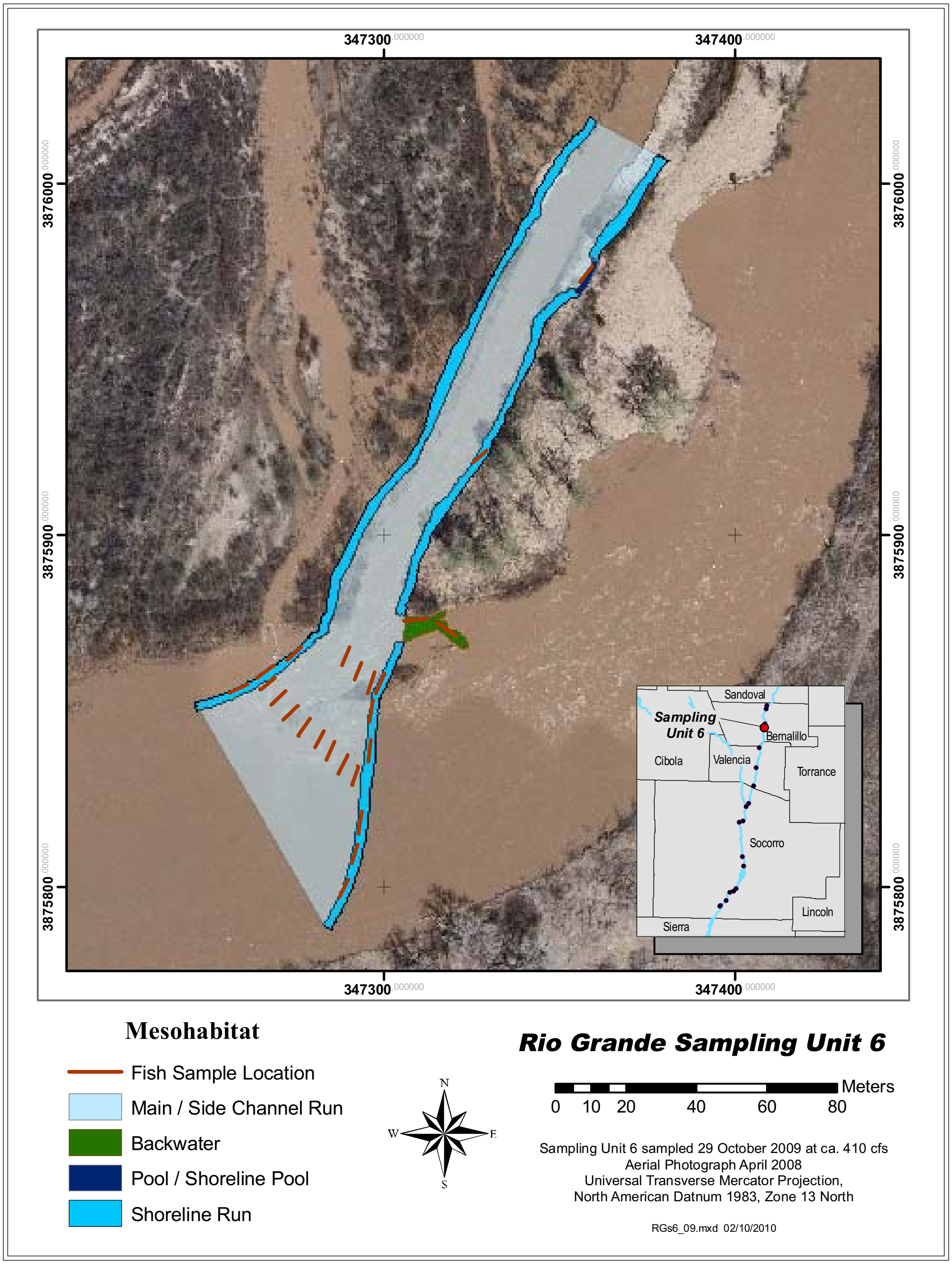


Figure B-5. Map of sampling unit #6 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

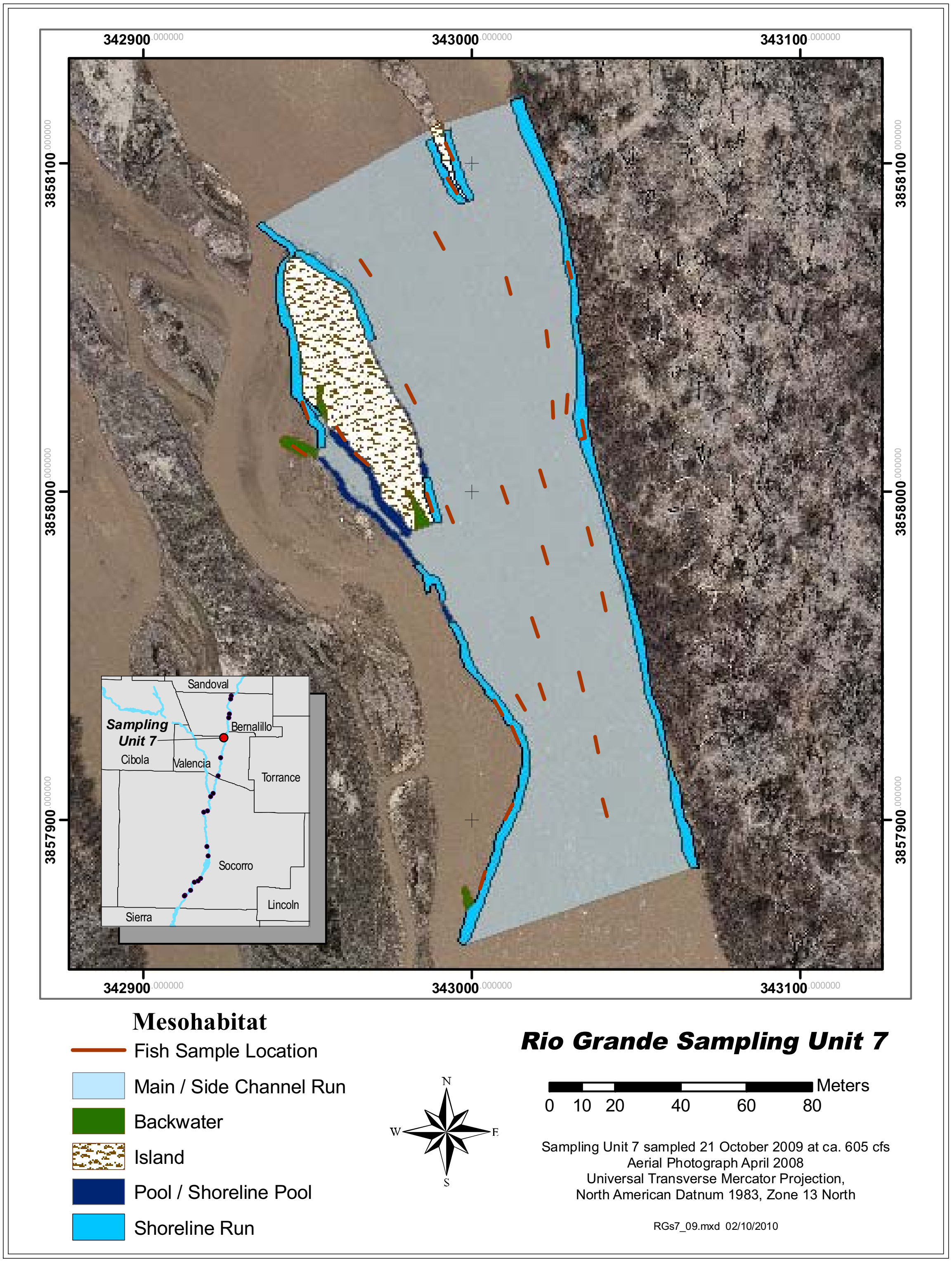


Figure B-6. Map of sampling unit #7 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

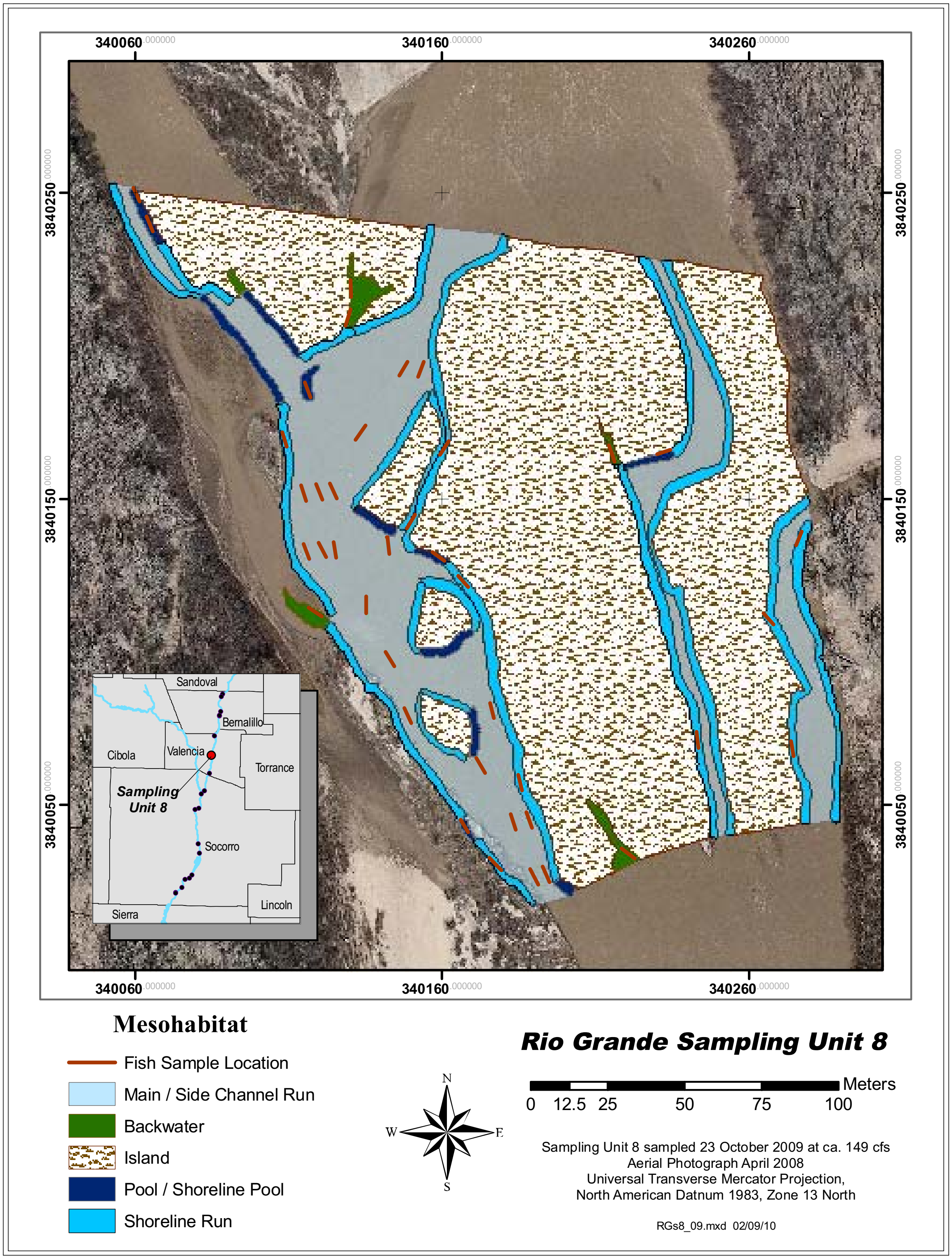


Figure B-7. Map of sampling unit #8 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

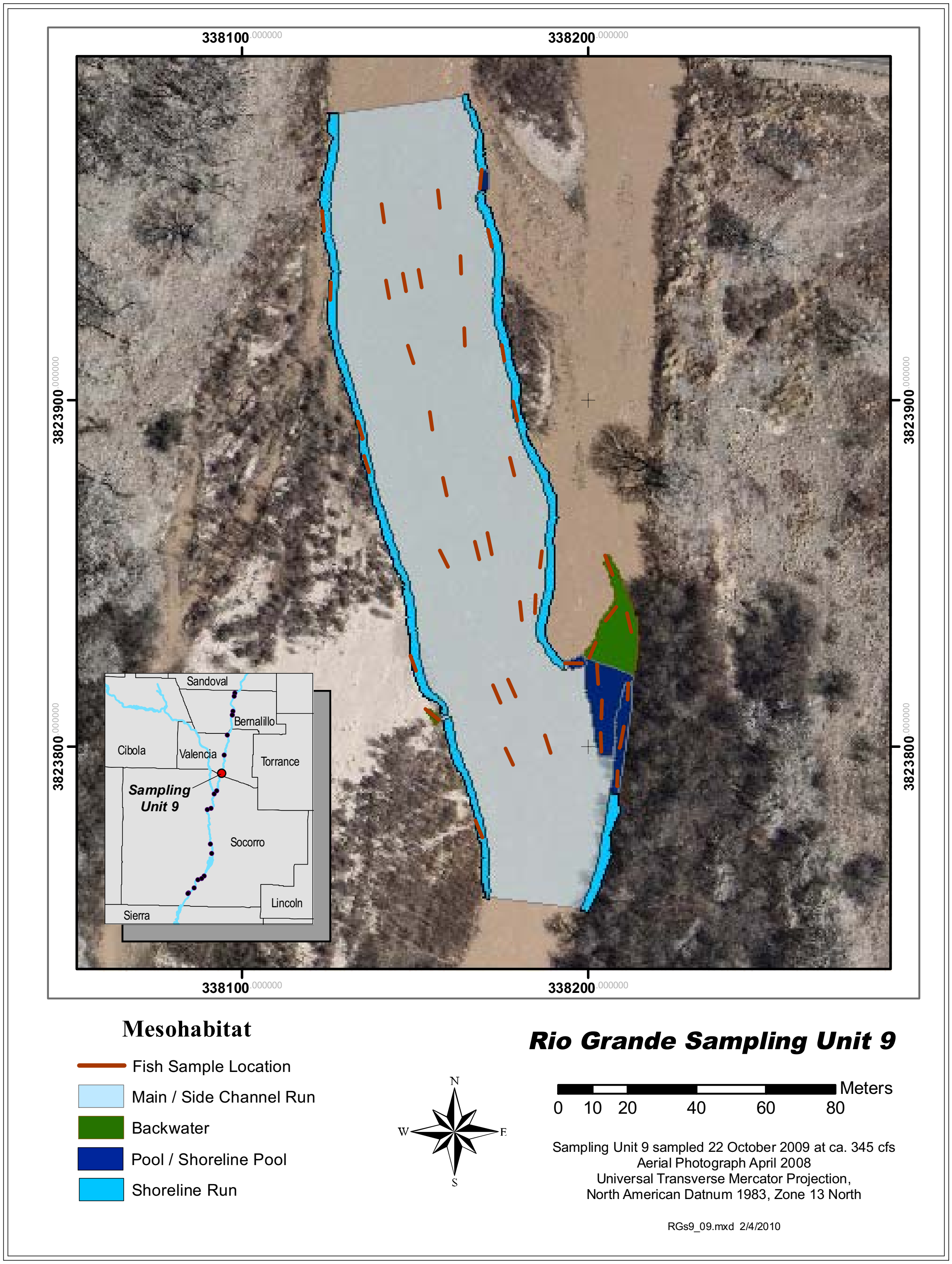


Figure B-8. Map of sampling unit #9 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

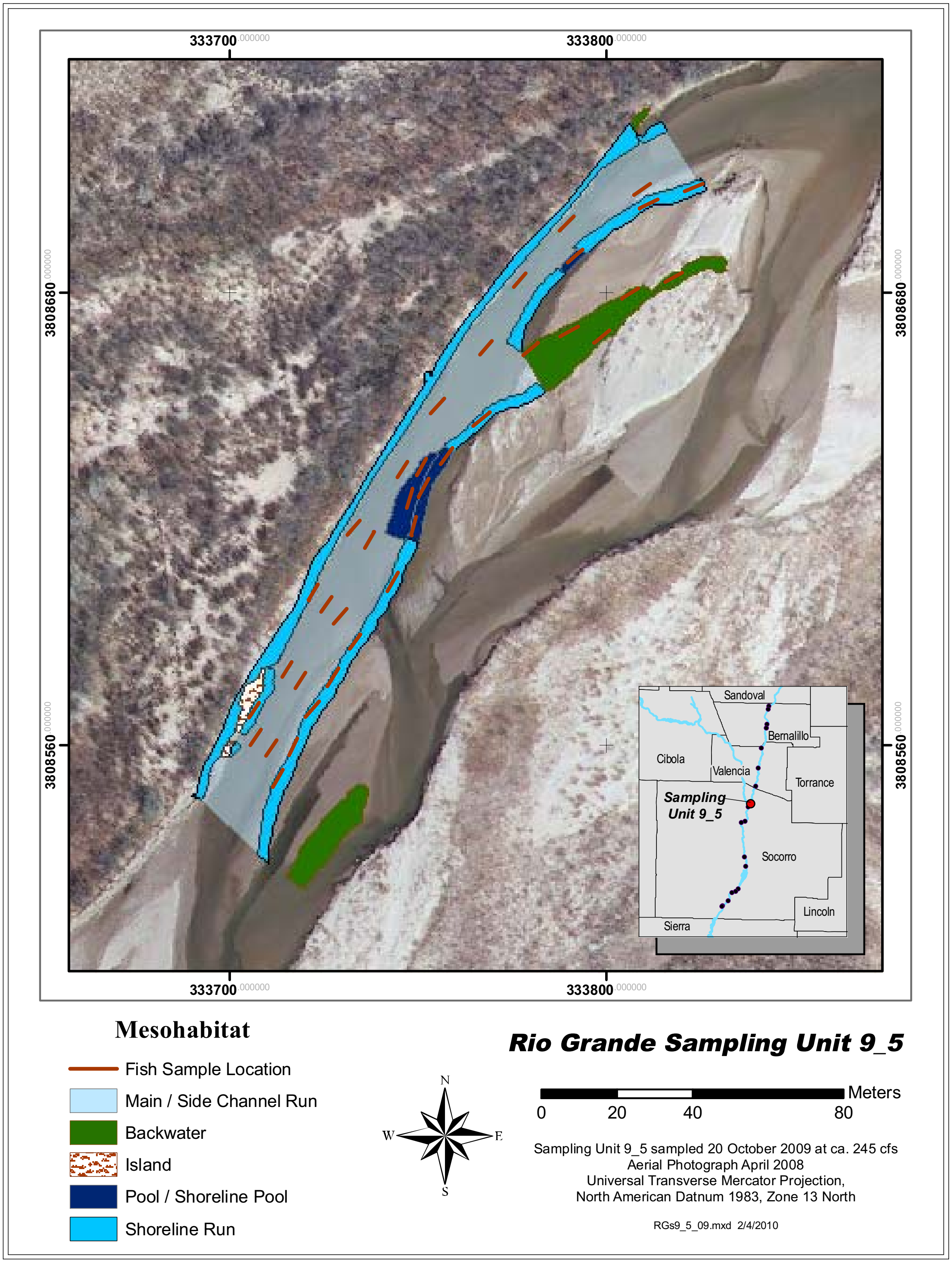


Figure B-9. Map of sampling unit #9_5 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

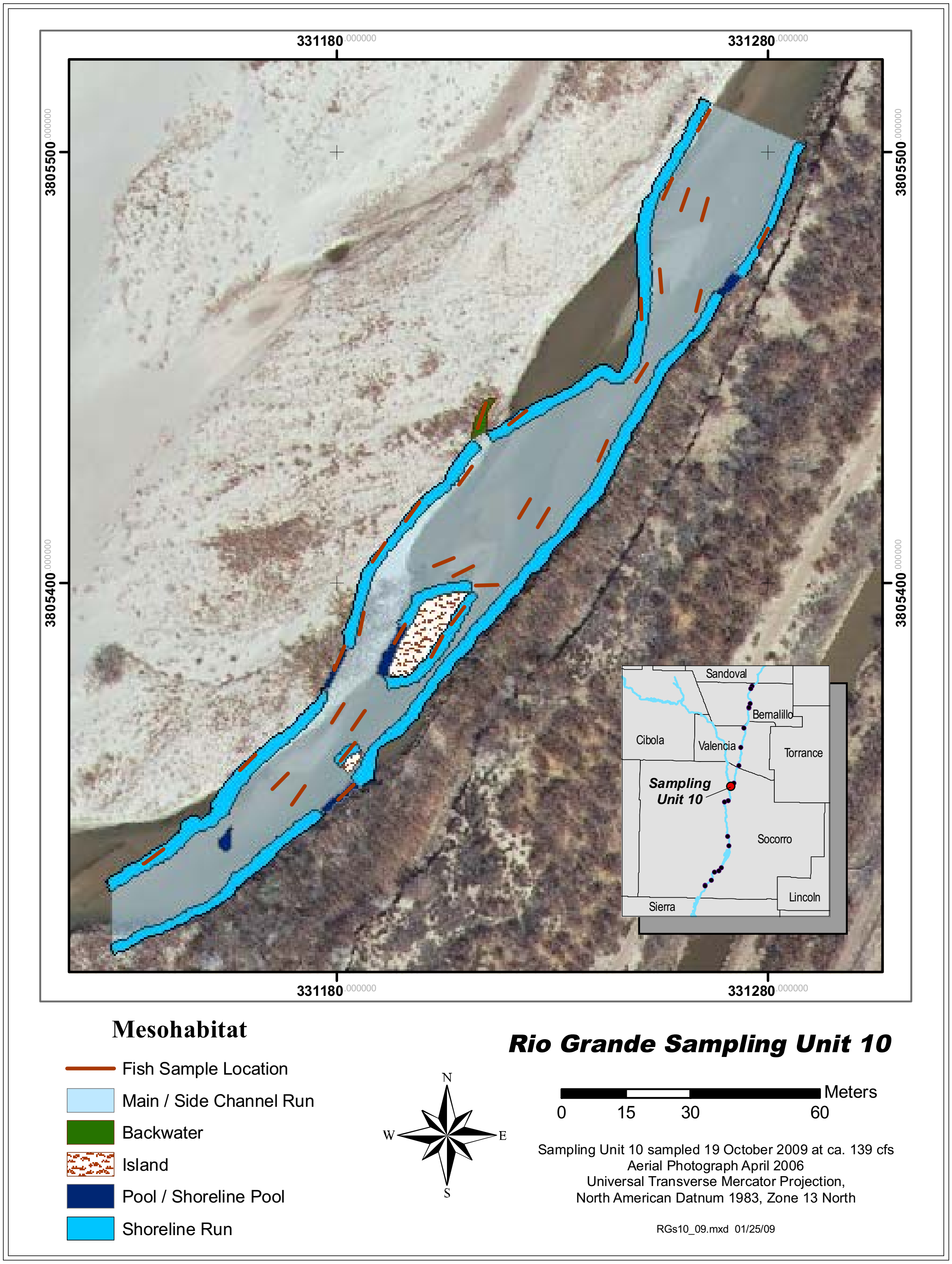


Figure B-10. Map of sampling unit #10 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

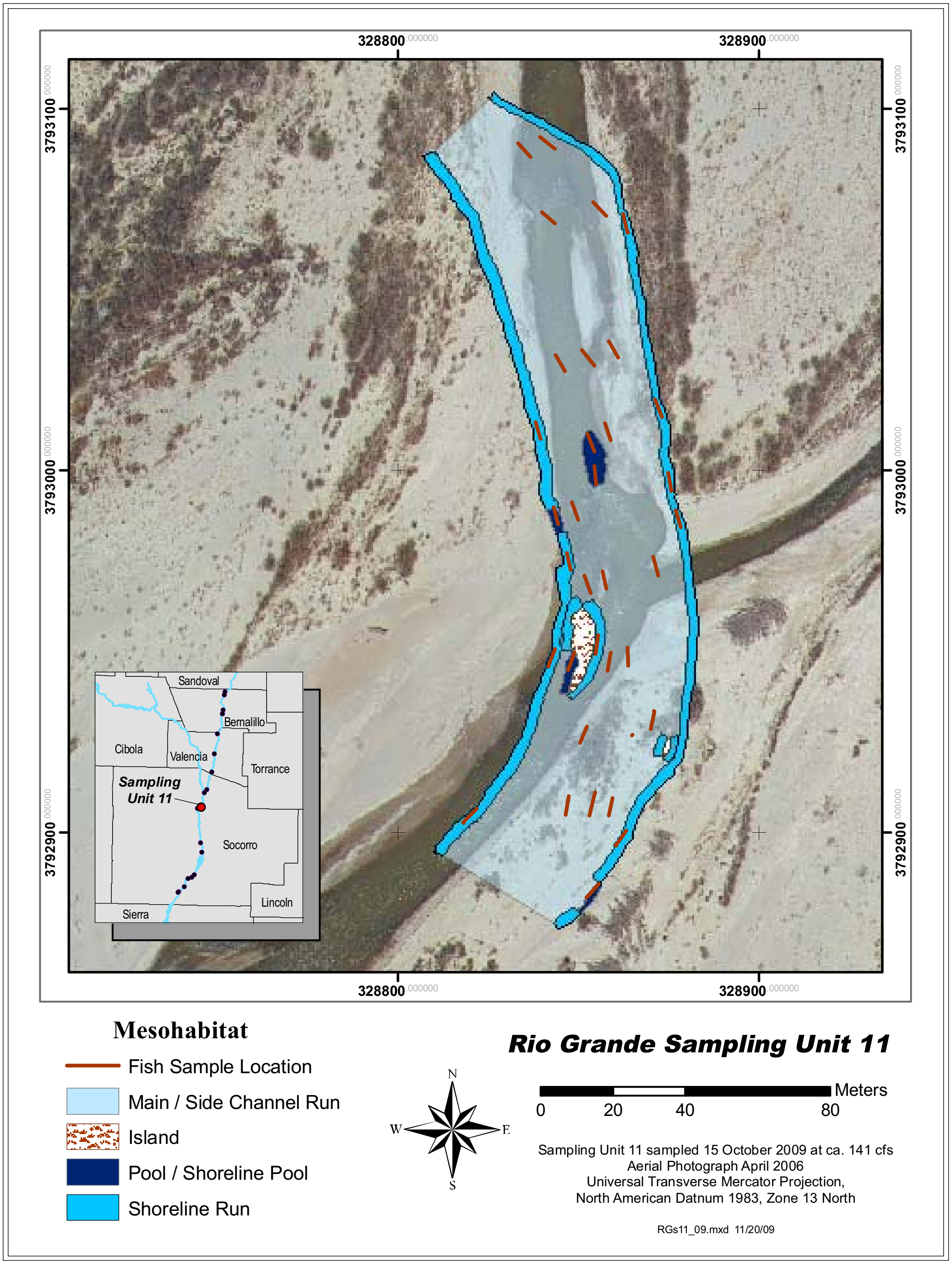


Figure B-11. Map of sampling unit #11 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

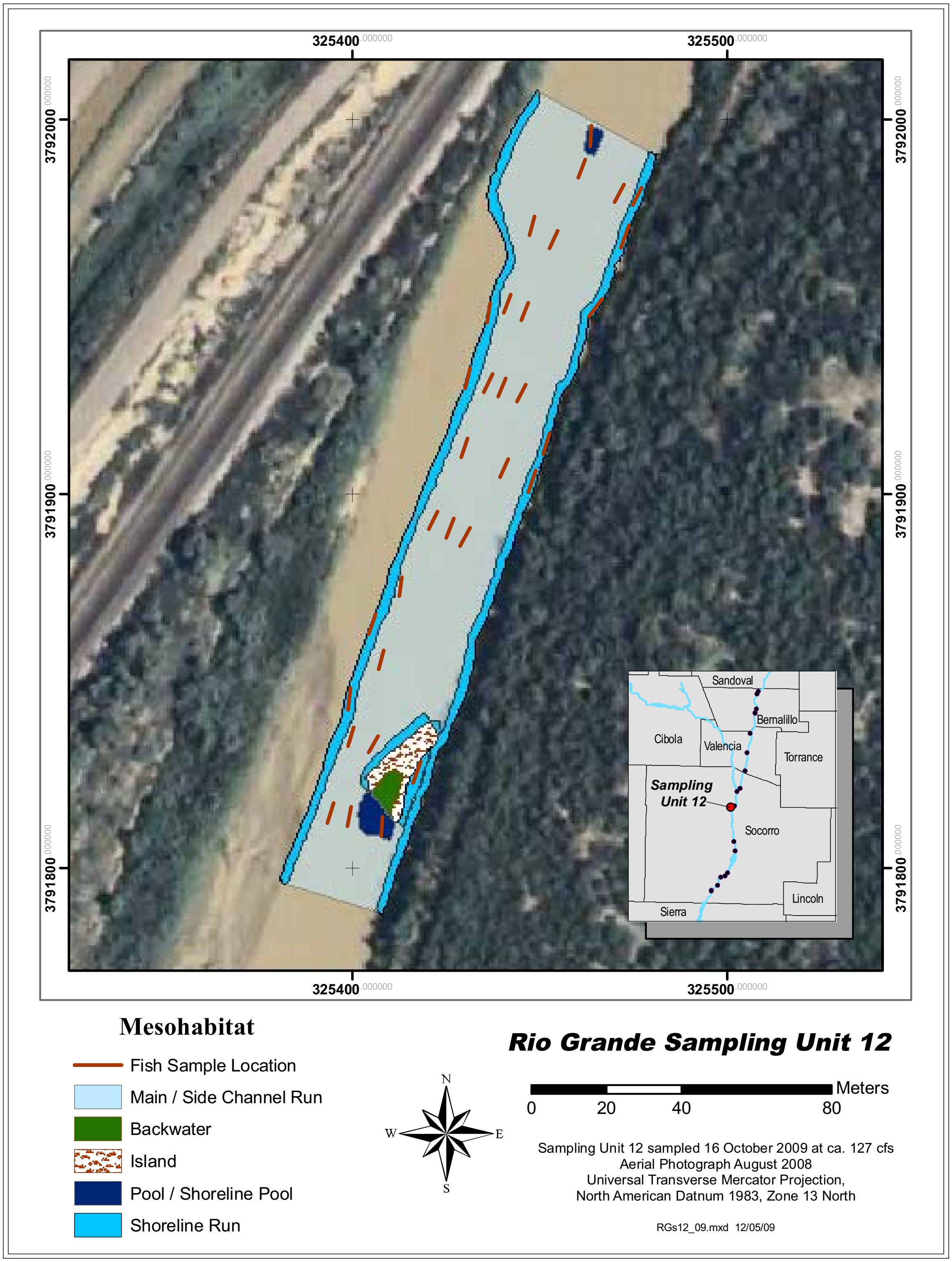


Figure B-12. Map of sampling unit #12 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

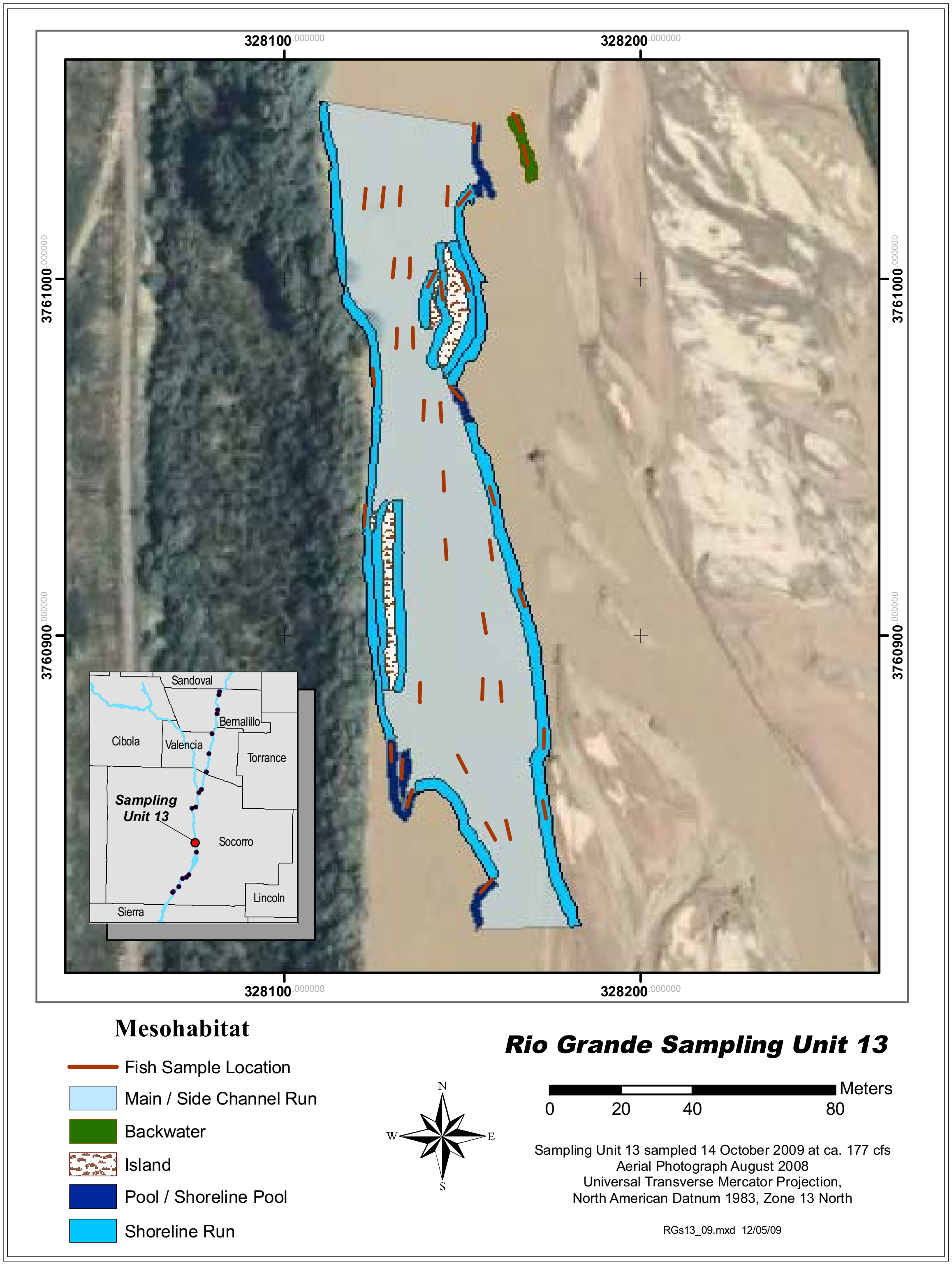


Figure B-13. Map of sampling unit #13 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

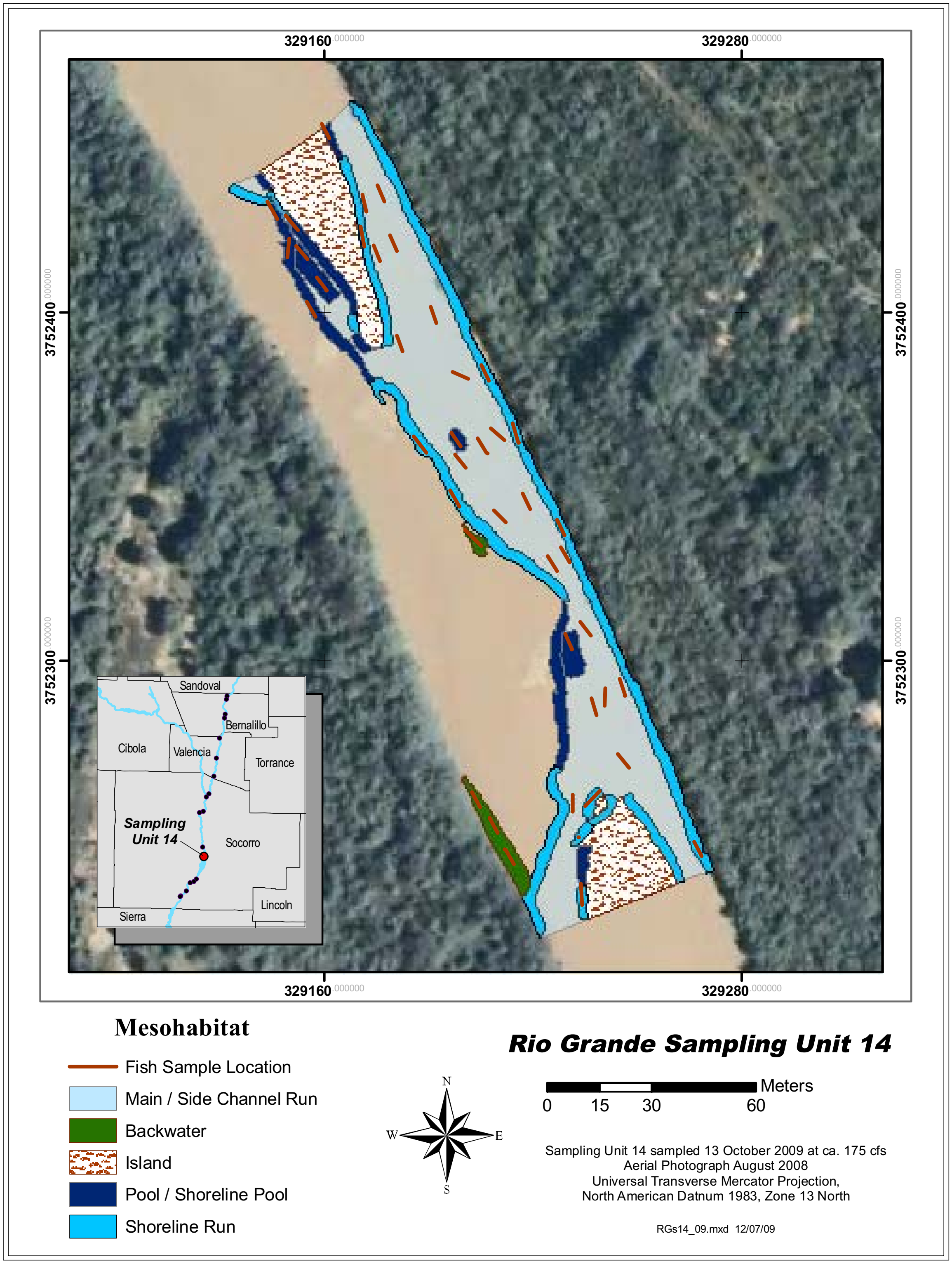


Figure B-14. Map of sampling unit #14 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

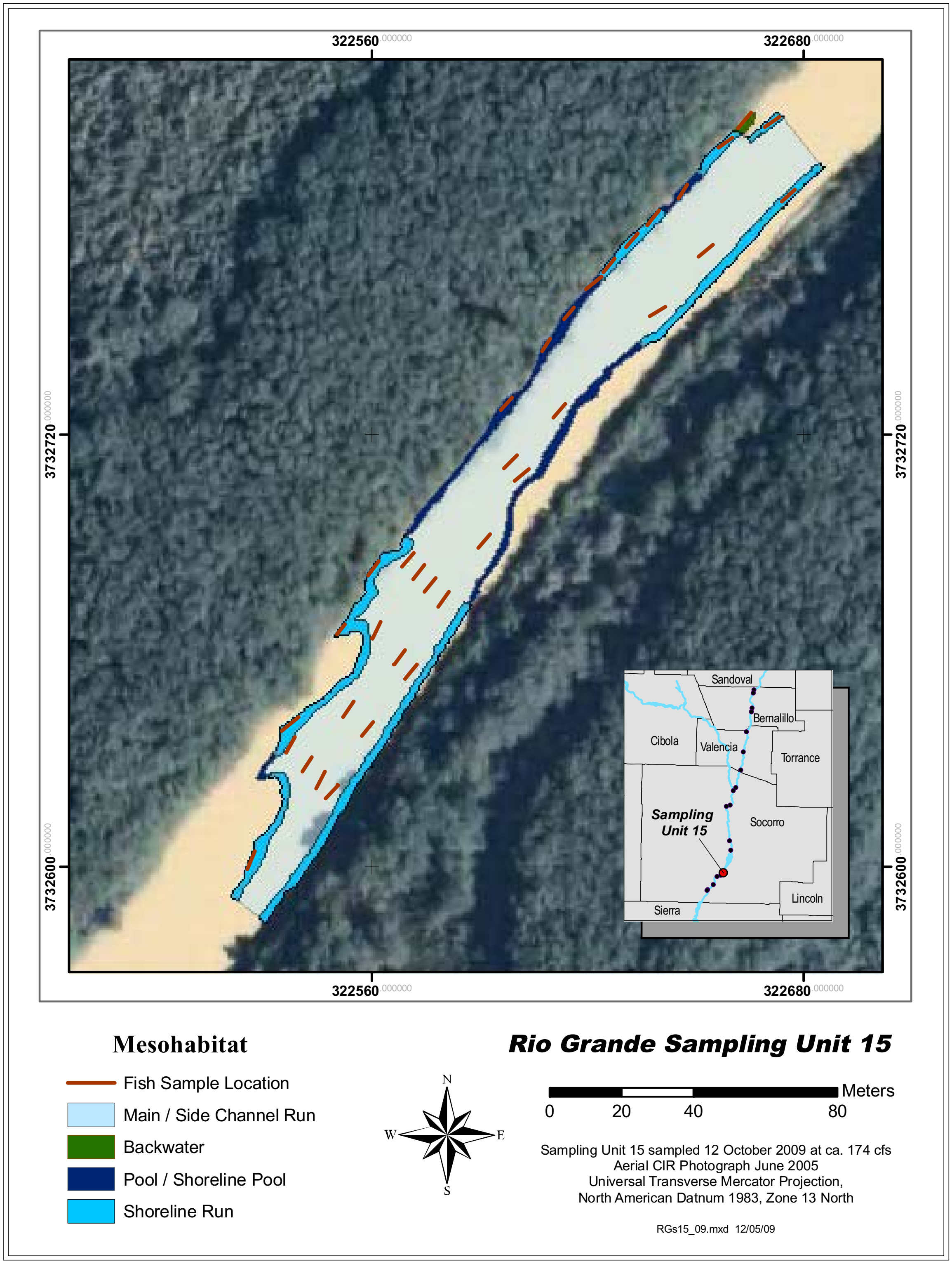


Figure B-15. Map of sampling unit #15 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

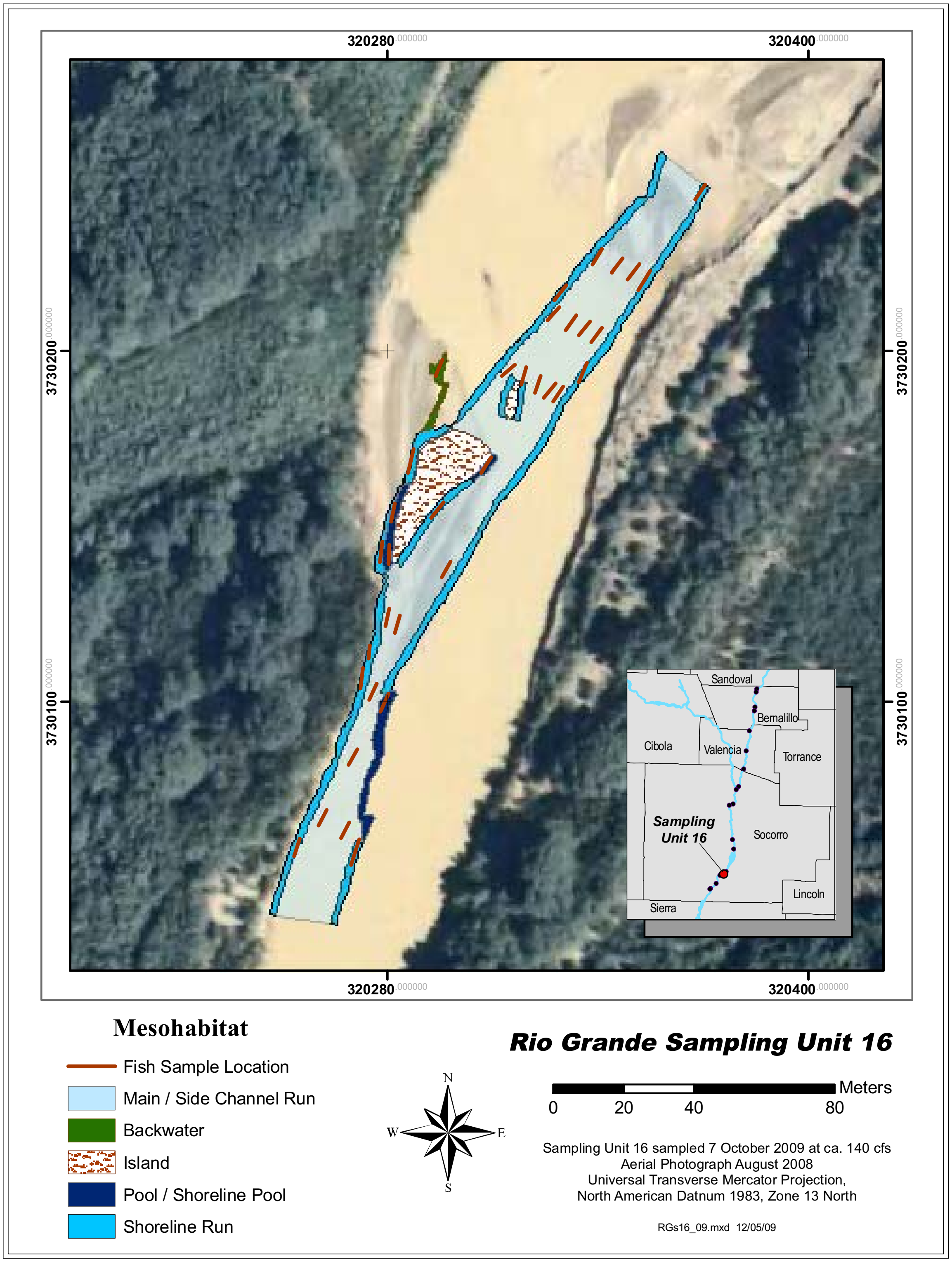


Figure B-16. Map of sampling unit #16 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

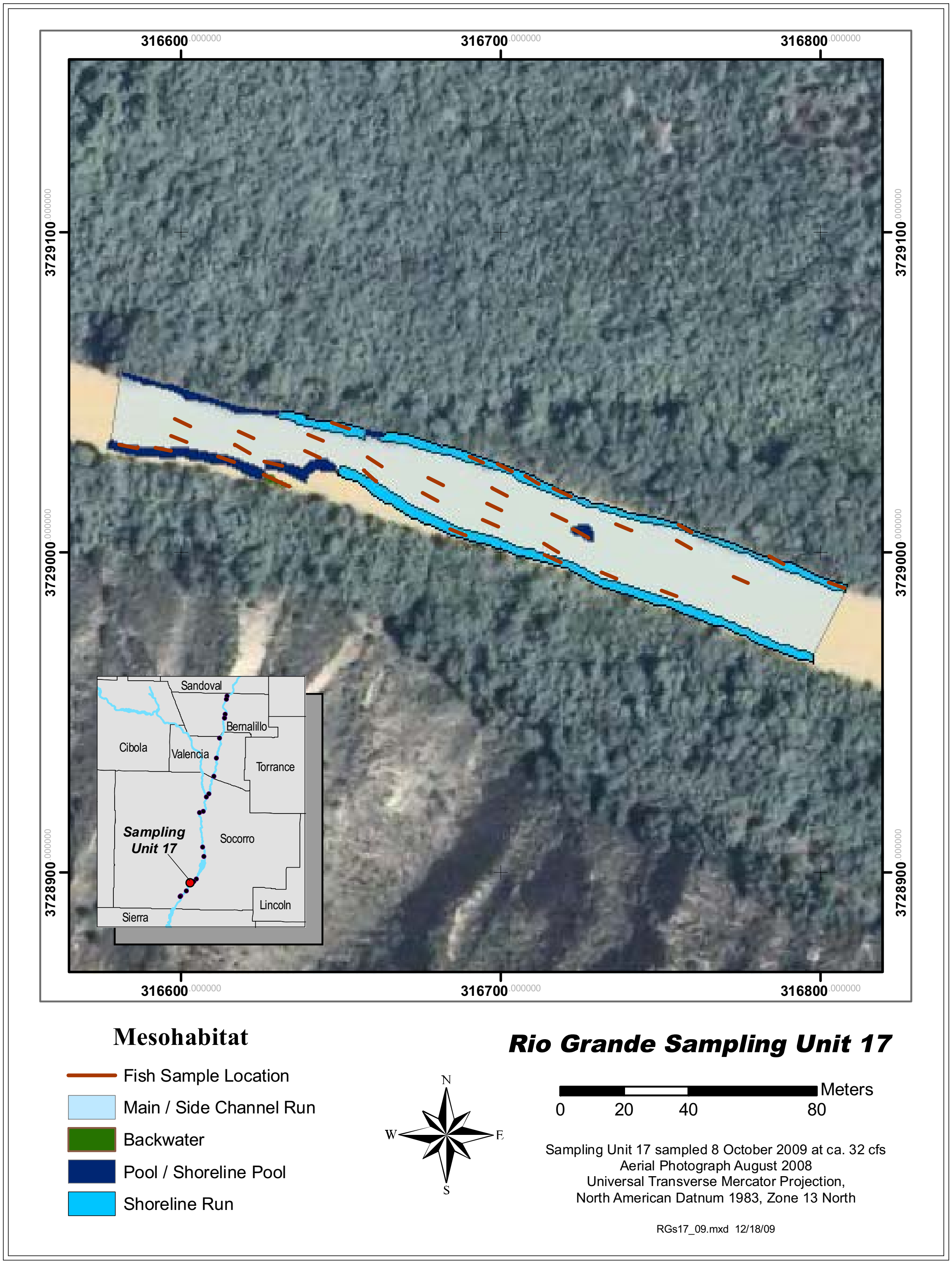


Figure B-17. Map of sampling unit #17 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

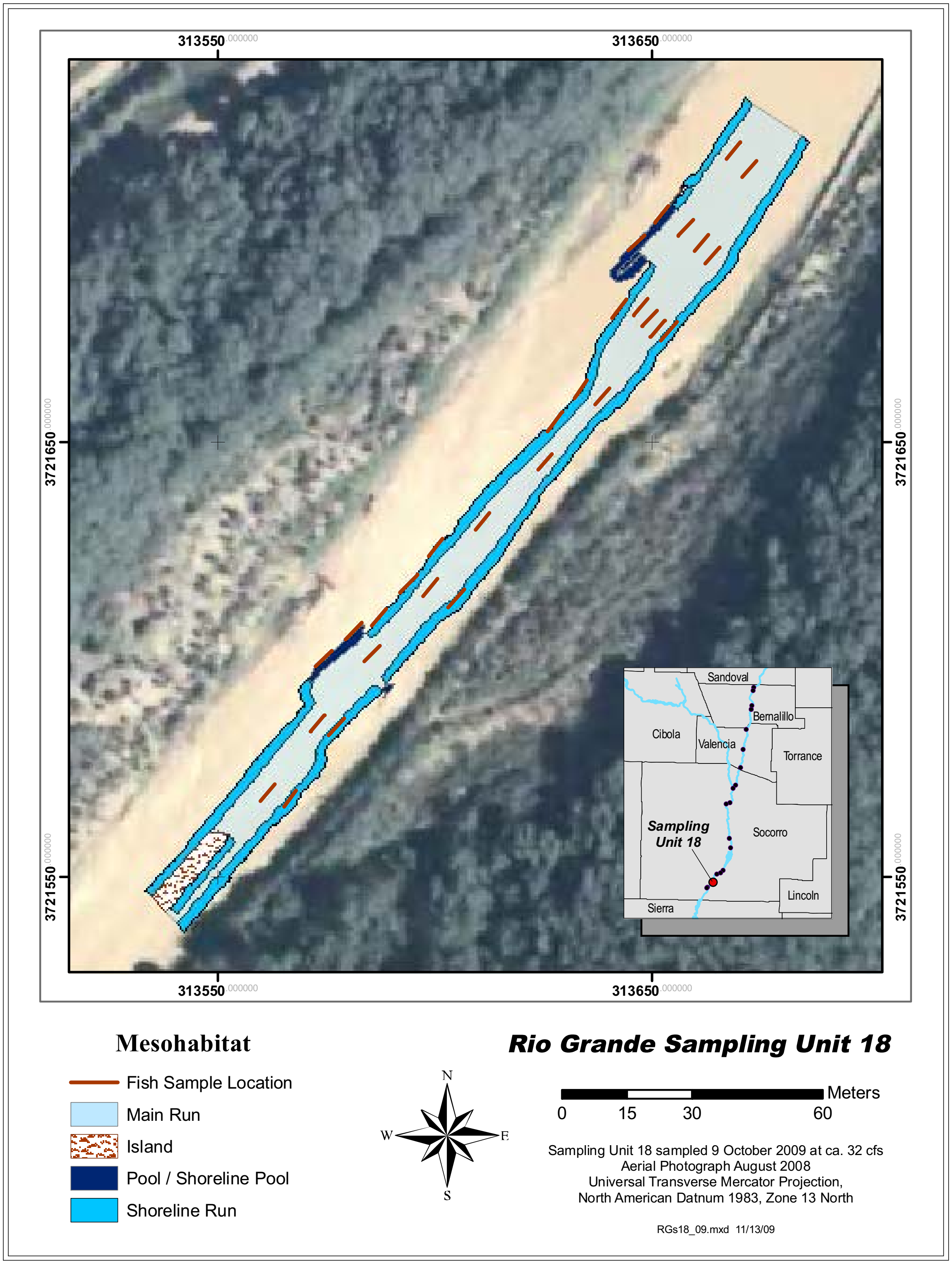


Figure B-18. Map of sampling unit #18 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

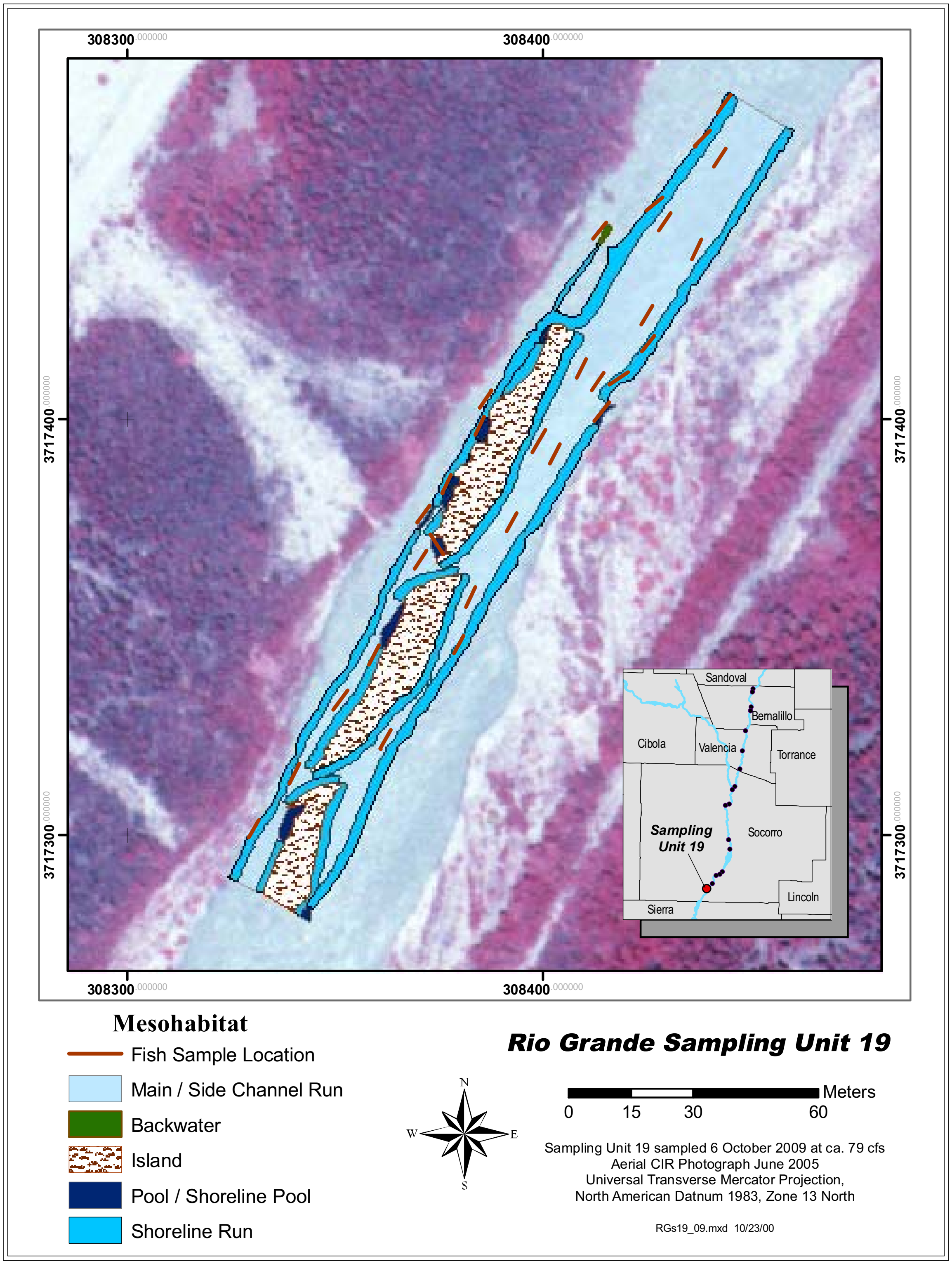


Figure B-19. Map of sampling unit #19 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

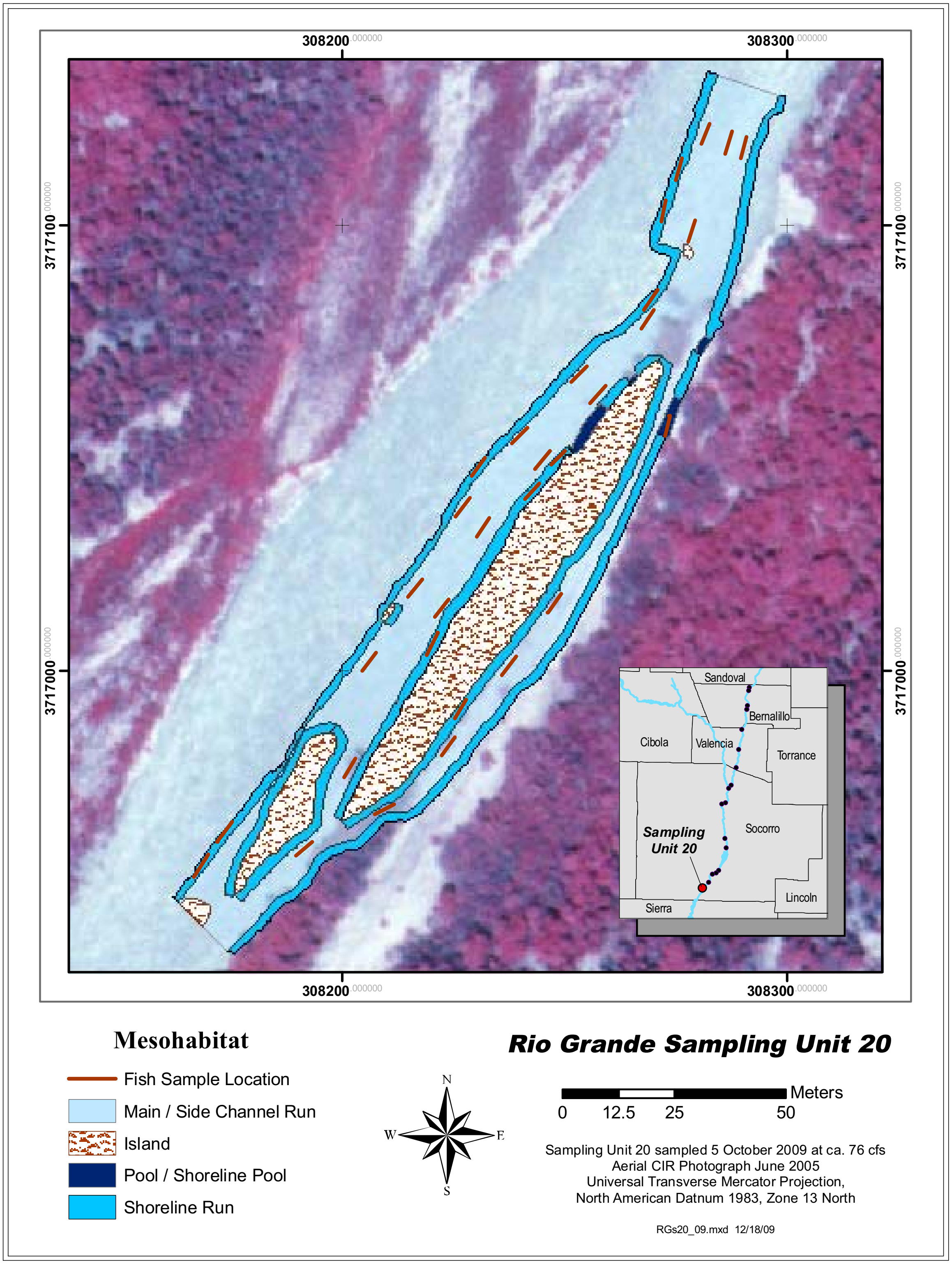


Figure B-20. Map of sampling unit #20 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

Appendix C

Table C-1. Water quality* information, by sampling unit and reach, during the 2009 Rio Grande silvery minnow Population Estimation Program.

REACH Sampling Unit and Name	Sec.	Temp.	Sal.	D.O.	Con. T.	Con.S.	pH
ANGOSTURA REACH							
2 Paseo del Norte upper	14	10.2	0.16	9.29	233.0	325.0	8.60
3 Paseo del Norte lower	20	9.1	0.16	9.15	224.7	330.1	8.57
4 Rio Bravo upper	15	3.7	0.16	10.55	197.1	332.2	8.60
5 Rio Bravo middle	20	7.9	0.16	9.27	222.4	330.6	8.62
6 Rio Bravo lower	22	11.6	0.26	7.88	389.4	524.4	8.02
ISLETA REACH							
7 Los Lunas	2	14.1	0.18	6.89	294.0	372.9	8.51
8 Belen	9	10.8	0.18	9.09	269.7	370.3	8.47
9 Jarales	4	11.2	0.17	7.87	262.5	356.4	8.44
9.5 Bernardo	20	12.7	0.23	7.98	362.2	473.5	8.66
10 S. of Bernardo	22	14.5	0.26	8.16	431.8	540.6	8.44
11 Sevilleta	12	15.4	0.28	8.22	474.5	582.7	8.47
SAN ACACIA REACH							
12 S. of San Acacia	20	14.6	0.29	8.50	480.0	598.0	8.56
13 Socorro	9	13.9	0.30	8.50	478.0	608.0	8.67
14 San Antonio	4	15.8	0.30	8.28	497.7	604.4	8.26
15 Bosque del Apache	14	14.7	0.42	8.04	680.0	848.0	8.23
16 S. of Bosque del Apache	18	17.3	0.42	8.25	728.0	854.0	8.49
17 San Marcial	20	15.6	0.40	8.50	670.0	816.0	8.50
18 S. of San Marcial	16	11.9	0.41	9.20	625.0	832.0	8.74
19 S. of LFCC return A	12	16.6	0.43	8.14	733.0	873.0	8.67
20 S. of LFCC return B	9	17.9	0.44	7.90	773.0	894.0	8.59

*Water quality codes:
Sec. = Secchi depth (cm)
Temp. = Water Temperature (°C)
Sal. = Salinity (ppt)
D.O. = Dissolved Oxygen (mg/l)
Con. T. = True Conductivity (µs)
Con. S. = Specific Conductance (µs)
pH = pH (dimensionless measure of the acidity or basicity of a solution)

Appendix D.

Middle Rio Grande sampling units for the Population Monitoring Program

Table D-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 US Highway 550 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 US Highway 550 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 6), 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 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 D-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 (Otero Avenue East), 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 D-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 E.

Report E-1. Ichthyofaunal composition of the October 2009 Rio Grande silvery minnow Population Estimation Program sampling efforts

Rio Grande silvery minnow Population Estimation
October 2009

NEW MEXICO: BERNALILLO Co., RIO GRANDE Drainage
Rio Grande, ca. 0.4 miles upstream of Paseo del Norte Bridge crossing, Albuquerque. Sampling Unit: 2
26 October 2009 **RKD09-056** River Mile: 191.6
UTM Easting: 349942 UTM Northing: 3895288 Zone: 13 Quad: Los Griegos
R.K. Dudley, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 339.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	28
76	*Hybognathus amarus**	1
76	*Pimephales promelas*	1
76	*Platygobio gracilis*	15
93	*Ictalurus punctatus*	8
283	*Morone chrysops*	1
295	*Sander vitreus*	1

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

age-0:
age-1:
age-2: 1

NEW MEXICO: BERNALILLO Co., RIO GRANDE Drainage
Rio Grande, ca. 1.2 miles downstream of Paseo del Norte Bridge crossing, Albuquerque. Sampling Unit: 3
27 October 2009 **RKD09-057** River Mile: 189.9
UTM Easting: 348954 UTM Northing: 3892935 Zone: 13 Quad: Los Griegos
R.K. Dudley, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus, J.L. Hester Effort: 514.8 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	41
76	*Hybognathus amarus**	97
76	*Platygobio gracilis*	69
76	*Rhinichthys cataractae*	3
81	*Catostomus commersoni*	1
93	*Ictalurus punctatus*	11
212	*Gambusia affinis*	1
283	*Morone chrysops*	1

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

age-0: 69
age-1: 23
age-2: 5

Rio Grande silvery minnow Population Estimation
October 2009

NEW MEXICO: BERNALILLO Co., RIO GRANDE Drainage
Rio Grande, ca. 1.6 miles upstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. Sampling Unit: 4
30 October 2009 **RKD09-060** River Mile: 179.9
UTM Easting: 348261 UTM Northing: 3879455 Zone: 13 Quad: Albuquerque West
R.K. Dudley, M.A. Farrington, A.L. Barkalow, R.C. Keller, K.M. Schaus Effort: 383.9 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	9
76	*Hybognathus amarus**	27
76	*Platygobio gracilis*	4
93	*Ictalurus punctatus*	10

***Hybognathus amarus* by age class:**
age-0: 10
age-1: 17
age-2:

NEW MEXICO: BERNALILLO Co., RIO GRANDE Drainage
Rio Grande, ca. 0.6 miles downstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. Sampling Unit: 5
River Mile: 177.6
28 October 2009 **RKD09-058**
UTM Easting: 347381 UTM Northing: 3876106 Zone: 13 Quad: Albuquerque West
R.K. Dudley, M.A. Farrington, A.L. Barkalow, R.C. Keller, K.M. Schaus, M.A. Brandenburg Effort: 394.3 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	52
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	20
76	*Pimephales promelas*	1
76	*Platygobio gracilis*	19
76	*Rhinichthys cataractae*	1
93	*Ictalurus punctatus*	20
212	*Gambusia affinis*	2

***Hybognathus amarus* by age class:**
age-0: 13
age-1: 7
age-2:

Rio Grande silvery minnow Population Estimation
October 2009

NEW MEXICO: BERNALILLO Co., RIO GRANDE Drainage
Rio Grande, ca. 1.0 miles downstream of Rio Bravo Blvd. Bridge crossing, Albuquerque.
Sampling Unit: 6
River Mile: 177.3
29 October 2009 **RKD09-059**
UTM Easting: 347155 UTM Northing: 3875786 Zone: 13 Quad: Albuquerque West
R.K. Dudley, M.A. Farrington, A.L. Barkalow, R.C. Keller, K.M. Schaus, J.L. Hester
Effort: 299.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	117
76	*Hybognathus amarus**	19
76	*Pimephales promelas*	20
76	*Platygobio gracilis*	4
81	*Carpiodes carpio*	8
81	*Catostomus commersoni*	2
93	*Ictalurus punctatus*	60
212	*Gambusia affinis*	1
294	*Lepomis cyanellus*	1

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

age-0: 15
age-1: 4
age-2:

Rio Grande silvery minnow Population Estimation
October 2009

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

21 October 2009 **RKD09-053**

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

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus

Effort: 388.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	115
76	*Hybognathus amarus**	230
76	*Platygobio gracilis*	6
81	*Carpiodes carpio*	3
93	*Ictalurus punctatus*	87
212	*Gambusia affinis*	8

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

age-0: 207
age-1: 15
age-2: 8

Rio Grande silvery minnow Population Estimation
October 2009

NEW MEXICO: VALENCIA Co., RIO GRANDE Drainage
Rio Grande, ca. 2.9 miles upstream of NM 6 bridge crossing, Belen. Sampling Unit: 8
23 October 2009 **RKD09-055** River Mile: 152.4
UTM Easting: 340193 UTM Northing: 3840028 Zone: 13 Quad: Tome
R.K. Dudley, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 495.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	340
76	*Cyprinus carpio*	2
76	*Hybognathus amarus**	64
76	*Pimephales promelas*	21
76	*Platygobio gracilis*	4
81	*Carpiodes carpio*	22
81	*Catostomus commersoni*	1
93	*Ictalurus punctatus*	52
212	*Gambusia affinis*	147
283	*Morone chrysops*	3

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

age-0: 55
age-1: 7
age-2: 2

Rio Grande silvery minnow Population Estimation
October 2009

NEW MEXICO: VALENCIA Co., RIO GRANDE Drainage
Rio Grande, ca. 0.2 miles downstream of NM State Highway 346 Bridge crossing, Jarales.
Sampling Unit: 9
River Mile: 140.6
22 October 2009 **RKD09-054**
UTM Easting: 338117 UTM Northing: 3823765 Zone: 13 Quad: Veguita
R.K. Dudley, W.H. Brandenburg, S.P. Platania, R.C. Keller, A.L. Barkalow, J.L. Hester, M.A. Brandenburg
Effort: 491.5 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	1360
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	537
76	*Pimephales promelas*	96
76	*Platygobio gracilis*	14
81	*Carpiodes carpio*	2
81	*Catostomus commersoni*	1
93	*Ameiurus natalis*	2
93	*Ictalurus punctatus*	169
212	*Gambusia affinis*	386
294	*Lepomis macrochirus*	1

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

age-0: 530
age-1: 6
age-2: 1

Rio Grande silvery minnow Population Estimation
October 2009

NEW MEXICO: SOCORRO Co., RIO GRANDE Drainage
Rio Grande, ca. 1.0 miles downstream of U.S. Highway 60 bridge crossing, Bernardo. Sampling Unit: 10
20 October 2009 **RKD09-052** River Mile: 130.0
UTM Easting: 333822 UTM Northing: 3808533 Zone: 13 Quad: Abeytas
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 457.0 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	52
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	6
76	*Pimephales promelas*	17
76	*Platygobio gracilis*	1
81	*Carpiodes carpio*	4
93	*Ictalurus punctatus*	14
212	*Gambusia affinis*	4
295	*Sander vitreus*	1

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

age-0: 4
age-1: 1
age-2: 1

Rio Grande silvery minnow Population Estimation
October 2009

NEW MEXICO: SOCORRO Co., RIO GRANDE Drainage
Rio Grande, ca. 3.7 miles downstream of US Highway 60 Bridge crossing, Bernardo. Sampling Unit: 10
19 October 2009 **RKD09-051** River Mile: 126.9
UTM Easting: 330997 UTM Northing: 3805306 Zone: 13 Quad: Abeytas
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 381.9 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	194
76	*Hybognathus amarus**	126
76	*Pimephales promelas*	7
81	*Carpiodes carpio*	1
81	*Catostomus commersoni*	2
93	*Ameiurus natalis*	1
93	*Ictalurus punctatus*	10
212	*Gambusia affinis*	16
294	*Lepomis cyanellus*	2
294	*Pomoxis annularis*	2

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

age-0: 118
age-1: 8
age-2:

Rio Grande silvery minnow Population Estimation
October 2009

NEW MEXICO: SOCORRO Co., RIO GRANDE Drainage
Rio Grande, ca. 1.7 miles upstream of San Acacia Diversion Dam, San Acacia. Sampling Unit: 11
15 October 2009 **RKD09-049** River Mile: 117.9
UTM Easting: 328767 UTM Northing: 3792883 Zone: 13 Quad: La Joya
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 428.0 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	1
76	*Hybognathus amarus**	19
76	*Platygobio gracilis*	14
93	*Ictalurus punctatus*	4
212	*Gambusia affinis*	1

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

age-0: 19
age-1:
age-2:

NEW MEXICO: SOCORRO Co., RIO GRANDE Drainage
Rio Grande, ca. 0.8 miles downstream of San Acacia Diversion Dam, San Acacia. Sampling Unit: 12
16 October 2009 **RKD09-050** River Mile: 115.4
UTM Easting: 325363 UTM Northing: 3791796 Zone: 13 Quad: San Acacia
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 391.3 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	5
76	*Hybognathus amarus**	24
76	*Platygobio gracilis*	34
93	*Ictalurus punctatus*	8

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

age-0: 23
age-1: 1
age-2:

Rio Grande silvery minnow Population Estimation
October 2009

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
14 October 2009 **RKD09-048** River Mile: 91.6
UTM Easting: 328199 UTM Northing: 3760830 Zone: 13 Quad: San Antonio
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 468.9 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	2
76	*Hybognathus amarus**	326
76	*Platygobio gracilis*	11
93	*Ictalurus punctatus*	2
212	*Gambusia affinis*	5

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

age-0: 325
age-1: 1
age-2:

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
River Mile: 85.7
13 October 2009 **RKD09-047**
UTM Easting: 329256 UTM Northing: 3752209 Zone: 13 Quad: San Antonio
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 585.7 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	2
76	*Hybognathus amarus**	41
212	*Gambusia affinis*	8

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

age-0: 41
age-1:
age-2:

Rio Grande silvery minnow Population Estimation
October 2009

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
12 October 2009 **RKD09-046**
UTM Easting: 322489 UTM Northing: 3732572 Zone: 13 Quad: San Marcial
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus Effort: 391.3 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	16
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	6
76	*Platygobio gracilis*	1
93	*Ameiurus melas*	2
93	*Ictalurus punctatus*	4
212	*Gambusia affinis*	27
294	*Lepomis macrochirus*	1
294	*Micropterus salmoides*	1
294	*Pomoxis annularis*	1

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

age-0: 6
age-1:
age-2:

Rio Grande silvery minnow Population Estimation
October 2009

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
07 October 2009 **RKD09-043**
UTM Easting: 320044 UTM Northing: 3730043 Zone: 13 Quad: San Marcial
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus
Effort: 401.6 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	4
76	*Hybognathus amarus**	26
76	*Platygobio gracilis*	4
93	*Ictalurus punctatus*	2

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

age-0: 26
age-1:
age-2:

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
08 October 2009 **RKD09-044**
UTM Easting: 316840 UTM Northing: 3728978 Zone: 13 Quad: San Marcial
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus, J.L.Hester
Effort: 440.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	2
76	*Hybognathus amarus**	18
76	*Pimephales promelas*	1
81	*Carpiodes carpio*	1
93	*Ictalurus punctatus*	3

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

age-0: 17
age-1: 1
age-2:

Rio Grande silvery minnow Population Estimation
October 2009

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
09 October 2009 **RKD09-045**
UTM Easting: 313417 UTM Northing: 3721520 Zone: 13 Quad: Paraje Well
W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus
Effort: 314.5 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	2
76	*Hybognathus amarus**	28
76	*Pimephales promelas*	1
76	*Platygobio gracilis*	9

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

age-0: 28
age-1:
age-2:

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
05 October 2009 **RKD09-042**
UTM Easting: 308328 UTM Northing: 3717266 Zone: 13 Quad: Paraje Well
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus, J.L.Hester
Effort: 329.3 sq. m

FAMILY		N
69	*Dorosoma cepedianum*	1
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	55
93	*Ictalurus punctatus*	1
212	*Gambusia affinis*	1

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

age-0: 55
age-1:
age-2:

Rio Grande silvery minnow Population Estimation
October 2009

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

05 October 2009 **RKD09-041**

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

R.K. Dudley, W.H. Brandenburg, M.A. Farrington, A.L. Barkalow, R.L. Keller, K.M. Schaus, J.L.Hester

Effort: 327.3 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	2
76	*Hybognathus amarus**	18
93	*Ictalurus punctatus*	1

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

age-0: 18
age-1:
age-2:

Appendix F

Table F-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 (2005–2009).

Detection Probability Estimates from Minimum AIC$_c$ Model (A)

Label*	Estimate	SE	LCI	UCI
p 2005 All Day 1	0.9752	0.0174	0.9082	0.9972
p 2005 All Day 2	0.9751	0.0174	0.9049	0.9973
p 2005 All Day 3	0.9751	0.0174	0.9089	0.9972
p 2005 All Day 4	0.9749	0.0175	0.9106	0.9971
p 2005 Age-0 Day 1	0.9752	0.0174	0.9082	0.9972
p 2005 Age-0 Day 2	0.9751	0.0174	0.9049	0.9973
p 2005 Age-0 Day 3	0.9751	0.0174	0.9089	0.9972
p 2005 Age-0 Day 4	0.9749	0.0175	0.9106	0.9971
p 2005 Age-1 Day 1	0.3316	0.0995	0.1364	0.6592
p 2005 Age-1 Day 2	0.3313	0.0996	0.1316	0.6753
p 2005 Age-1 Day 3	0.3309	0.0997	0.1373	0.6559
p 2005 Age-1 Day 4	0.3294	0.1002	0.1399	0.6470
p 2005 Age-2 Day 1	0.0218	0.0246	0.0011	0.2801
p 2005 Age-2 Day 2	0.0218	0.0246	0.0011	0.2850
p 2005 Age-2 Day 3	0.0218	0.0246	0.0011	0.2791
p 2005 Age-2 Day 4	0.0216	0.0244	0.0011	0.2765
p 2006 All Day 1	0.9021	0.0334	0.8393	0.9633
p 2006 All Day 2	0.8851	0.0367	0.8431	0.9656
p 2006 All Day 3	0.8832	0.0372	0.8416	0.9647
p 2006 All Day 4	0.8790	0.0382	0.8416	0.9647
p 2006 Age-0 Day 1	0.8338	0.0538	0.7319	0.9311
p 2006 Age-0 Day 2	0.8076	0.0609	0.7397	0.9349
p 2006 Age-0 Day 3	0.8047	0.0618	0.7366	0.9333
p 2006 Age-0 Day 4	0.7983	0.0638	0.7366	0.9333
p 2006 Age-1 Day 1	0.7332	0.0551	0.6430	0.8624
p 2006 Age-1 Day 2	0.6969	0.0559	0.6490	0.8707
p 2006 Age-1 Day 3	0.6930	0.0562	0.6466	0.8674
p 2006 Age-1 Day 4	0.6843	0.0570	0.6466	0.8674
p 2006 Age-2 Day 1	0.0953	0.0553	0.0308	0.2891
p 2006 Age-2 Day 2	0.0810	0.0485	0.0322	0.2991
p 2006 Age-2 Day 3	0.0796	0.0479	0.0316	0.2951
p 2006 Age-2 Day 4	0.0767	0.0465	0.0316	0.2951
p 2007 All Day 1	0.9882	0.0119	0.9408	0.9997
p 2007 All Day 2	0.9881	0.0120	0.9403	0.9997
p 2007 All Day 3	0.9875	0.0125	0.9403	0.9997
p 2007 All Day 4	0.9850	0.0150	0.9480	0.9995
p 2007 Age-0 Day 1	0.9882	0.0119	0.9408	0.9997
p 2007 Age-0 Day 2	0.9881	0.0120	0.9403	0.9997
p 2007 Age-0 Day 3	0.9875	0.0125	0.9403	0.9997
p 2007 Age-0 Day 4	0.9850	0.0150	0.9480	0.9995
p 2007 Age-1 Day 1	0.1096	0.0413	0.0378	0.4729
p 2007 Age-1 Day 2	0.1090	0.0411	0.0373	0.4823
p 2007 Age-1 Day 3	0.1039	0.0400	0.0373	0.4835
p 2007 Age-1 Day 4	0.0881	0.0416	0.0479	0.3025
p 2007 Age-2 Day 1	0.0000	0.0000	0.0000	0.0000
p 2007 Age-2 Day 2	0.0000	0.0000	0.0000	0.0000
p 2007 Age-2 Day 3	0.0000	0.0000	0.0000	0.0000
p 2007 Age-2 Day 4	0.0000	0.0000	0.0000	0.0000

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

Appendix F (continued)

Table F-1. (conintued) Rio Grande silvery minnow detection probability estimates among years for all sampling units combined (from Population Monitoring Program data) in the Middle Rio Grande based on repeated sampling efforts in November (2005–2009).

Detection Probability Estimates from Minimum AIC_c Model (A)

Label*	Estimate	SE	LCI	UCI
p 2008 All Day 1	1.0000	0.0000	1.0000	1.0000
p 2008 All Day 2	1.0000	0.0000	1.0000	1.0000
p 2008 All Day 3	1.0000	0.0000	1.0000	1.0000
p 2008 All Day 4	1.0000	0.0000	1.0000	1.0000
p 2008 Age-0 Day 1	1.0000	0.0000	1.0000	1.0000
p 2008 Age-0 Day 2	1.0000	0.0000	0.9999	1.0000
p 2008 Age-0 Day 3	1.0000	0.0000	1.0000	1.0000
p 2008 Age-0 Day 4	1.0000	0.0000	1.0000	1.0000
p 2008 Age-1 Day 1	0.5561	0.0998	0.5202	0.9064
p 2008 Age-1 Day 2	0.5775	0.0950	0.5177	0.9001
p 2008 Age-1 Day 3	0.5906	0.0927	0.5158	0.8954
p 2008 Age-1 Day 4	0.6073	0.0905	0.5154	0.8944
p 2008 Age-2 Day 1	0.2176	0.0928	0.1380	0.7738
p 2008 Age-2 Day 2	0.2328	0.0990	0.1371	0.7610
p 2008 Age-2 Day 3	0.2425	0.1033	0.1364	0.7517
p 2008 Age-2 Day 4	0.2556	0.1094	0.1363	0.7498
p 2009 All Day 1	1.0000	0.0000	1.0000	1.0000
p 2009 All Day 2	1.0000	0.0000	1.0000	1.0000
p 2009 All Day 3	1.0000	0.0000	1.0000	1.0000
p 2009 All Day 4	1.0000	0.0000	1.0000	1.0000
p 2009 Age-0 Day 1	1.0000	0.0000	1.0000	1.0000
p 2009 Age-0 Day 2	1.0000	0.0000	1.0000	1.0000
p 2009 Age-0 Day 3	1.0000	0.0000	1.0000	1.0000
p 2009 Age-0 Day 4	1.0000	0.0000	1.0000	1.0000
p 2009 Age-1 Day 1	0.7181	0.0605	0.6802	0.8902
p 2009 Age-1 Day 2	0.7336	0.0585	0.6864	0.8958
p 2009 Age-1 Day 3	0.7301	0.0590	0.6767	0.8871
p 2009 Age-1 Day 4	0.7350	0.0584	0.6795	0.8896
p 2009 Age-2 Day 1	0.3307	0.0992	0.2491	0.6415
p 2009 Age-2 Day 2	0.3482	0.0998	0.2565	0.6514
p 2009 Age-2 Day 3	0.3441	0.0997	0.2450	0.6361
p 2009 Age-2 Day 4	0.3497	0.0999	0.2483	0.6404