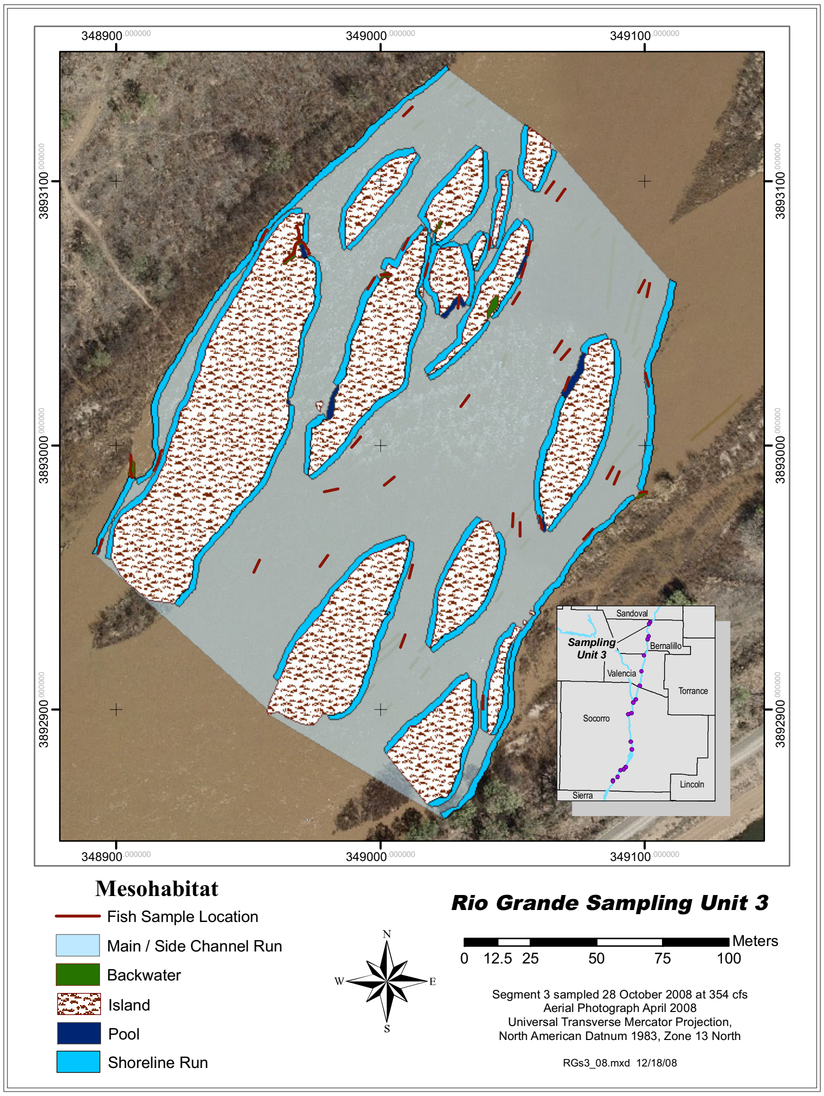
RIO GRANDE SILVERY MINNOW POPULATION ESTIMATION PROGRAM RESULTS FROM OCTOBER 2008

FINAL

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



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PREFACE

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

Given that the sampling and analytical aspects of this project were expected to evolve over time, the 2008 results presented in this report are preliminary and subject to revision as methodologies and analyses are refined in the future. While the statistical methods employed to generate the 2008 Rio Grande silvery minnow population numbers contained herein are statistically defensible, determination of the relationship between the number of fish taken through sampling efforts versus the number of fish present at any given site is the most difficult aspect of this project. However, the 2008 study does represent the culmination of three years of refinements and can be used as the foundation for future studies.

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 2008 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. Rio Grande silvery minnow was the most abundant native species collected (N = 1,576), followed by red shiner (N = 909), fathead minnow (N = 329), and flathead chub (N = 251). The highest densities of Rio Grande silvery minnow were recorded in the Isleta and San Acacia reaches. The most abundant introduced species were channel catfish (N = 666), western mosquitofish (N = 363), and common carp (N = 26).

The best model for the mesohabitat-specific depletion data (based on the lowest AIC_C value) was by mesohabitat only and was supported by a high model weight. The capture probability estimates (i.e., proportion of fish removed per seine haul) for the different mesohabitats ranged from 0.6827 (backwaters) to 0.7633 (shoreline runs). The associated standard errors for estimates were consistent between mesohabitats and ranged between 0.0188 and 0.0509.

Probability of detection and probability of site occupancy estimates during 2008 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 0.6670 while the estimate for age-0 individuals was 0.6673; probability of detection estimates were much lower for age-1 and age-2 individuals (<0.25). The probability of occupancy estimate for all Rio Grande silvery minnow was 0.8302 while the estimate for age-0 individuals was 0.8251. The occupancy estimate for age-1 individuals was 0.1509 but the occupancy estimate for age-2 individuals was quite low (0.0339). Probability of detection estimates for Rio Grande silvery minnow (all age-classes combined) in 2008 were similar to those recorded in 2005 and significantly higher than those recorded in 2006 or 2007.

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 2008. The site occupancy estimate was 1.0 for all age-classes combined and for age-0 individuals but was lower for age-1 (0.5726) and age-2 (0.5125) individuals. Estimates of the probability of extinction were relatively low for all age-classes (0.0172) and age-0 (0.0697) individuals. The probability of extinction was higher for both age-1 and age-2 individuals (0.2236 and 0.1242, respectively). Estimates of the probability of colonization were relatively high for age-0 (0.5877) and age-1 (0.7414) individuals.

The 2008 estimate of population was highest in the Isleta Reach (N = 1,027,489) and lowest in the San Acacia Reach (N = 404,864). The standard errors associated with population estimates for the three reaches were proportionally comparable for the Angostura and San Acacia reaches; standard error was notably higher in the Isleta Reach. The total population estimate for all reaches combined (N = 2,283,790) had a standard error [SE] of 740,860.73. 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 2008 sampling efforts. The population estimates for the study area varied among reaches with the highest numbers recorded in the San Acacia Reach (1,020,935) and the lowest numbers in the Angostura Reach (204,488). The overall population estimate using the Population Monitoring Program data (N = 2,066,354) had a standard error [SE] of 369,320.08. The overall population estimate ratio between the two data sets was 0.90 and there was no significant difference in the total population estimate between the two population estimation methods. While there were seemingly higher or lower estimates between the Population Monitoring and Population Estimate data sets (among reaches and ages), statistical analyses revealed no significant differences between reach-specific or age-specific estimates using the two population estimation methods.

The site occupancy data should be used in combination with population estimate data to provide a more complete understanding of the conservation status of Rio Grande silvery minnow. It is well known that simply having large numbers of a particular species in an area doesn't ensure its long-term survival. This is particularly true for short-lived species such as Rio Grande silvery minnow. The vast changes in populations of this species within short time periods underscore the need to ensure the presence of individuals over a broad geographical range. Changing environmental conditions within a particular region (either natural or manmade) can have rapid and severe impacts to local populations of Rio Grande silvery minnow. Large populations within these affected regions can be decimated within days because of river dewatering. Alternatively, the lack of spring runoff can inhibit spawning and limit recruitment to such a degree that populations decline several orders of magnitude within a year. The short life span of this species means that, following periods of low recruitment, total population size is not well buffered by surviving age-classes. For these reasons, it is imperative that populations of Rio Grande silvery minnow are established at multiple locations within its current range and at multiple locations within its historical range to ensure its long-term persistence in the wild.

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

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 (between months or years) or spatially (between sites or reaches). The current population monitoring protocol is not designed to provide an estimate of the total number of Rio Grande silvery minnow but rather an estimate of trends in abundance over time and space.

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

Techniques to estimate the presence and abundance of organisms, which do not require full site depletion or marking and recapture of individuals, have 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 (1993-2008) Population Monitoring Program for the Middle Rio Grande ichthyofaunal community (Angostura, NM to Elephant Butte Reservoir). In contrast to population monitoring that documents patterns of recruitment and survival at a regular time interval (i.e., monthly or bimonthly sampling) for the entire ichthyofaunal community, population estimation supplements the current Population Monitoring Program by providing a rigorous yearly estimate of the Rio Grande silvery minnow population during a single time-period (October). The objectives of this study were to 1) Develop and implement methods that provide statistically robust population estimates of Rio Grande silvery minnow, 2) Provide a population estimate of Rio Grande silvery minnow based on fish densities stratified by mesohabitat for 20 sampling units, 3) Develop site occupancy rates for Rio Grande silvery minnow populations over time, and 4) Calculate a population estimate of Rio Grande silvery minnow using Population Monitoring Program data, controlling for mesohabitat, and compare this value to that generated in Objective #2.

STUDY AREA

The headwaters of the Rio Grande are located in the San Juan Mountains of southern Colorado. The mainstem Rio Grande flows 750 km through New Mexico, draining an area of about 68,104 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).

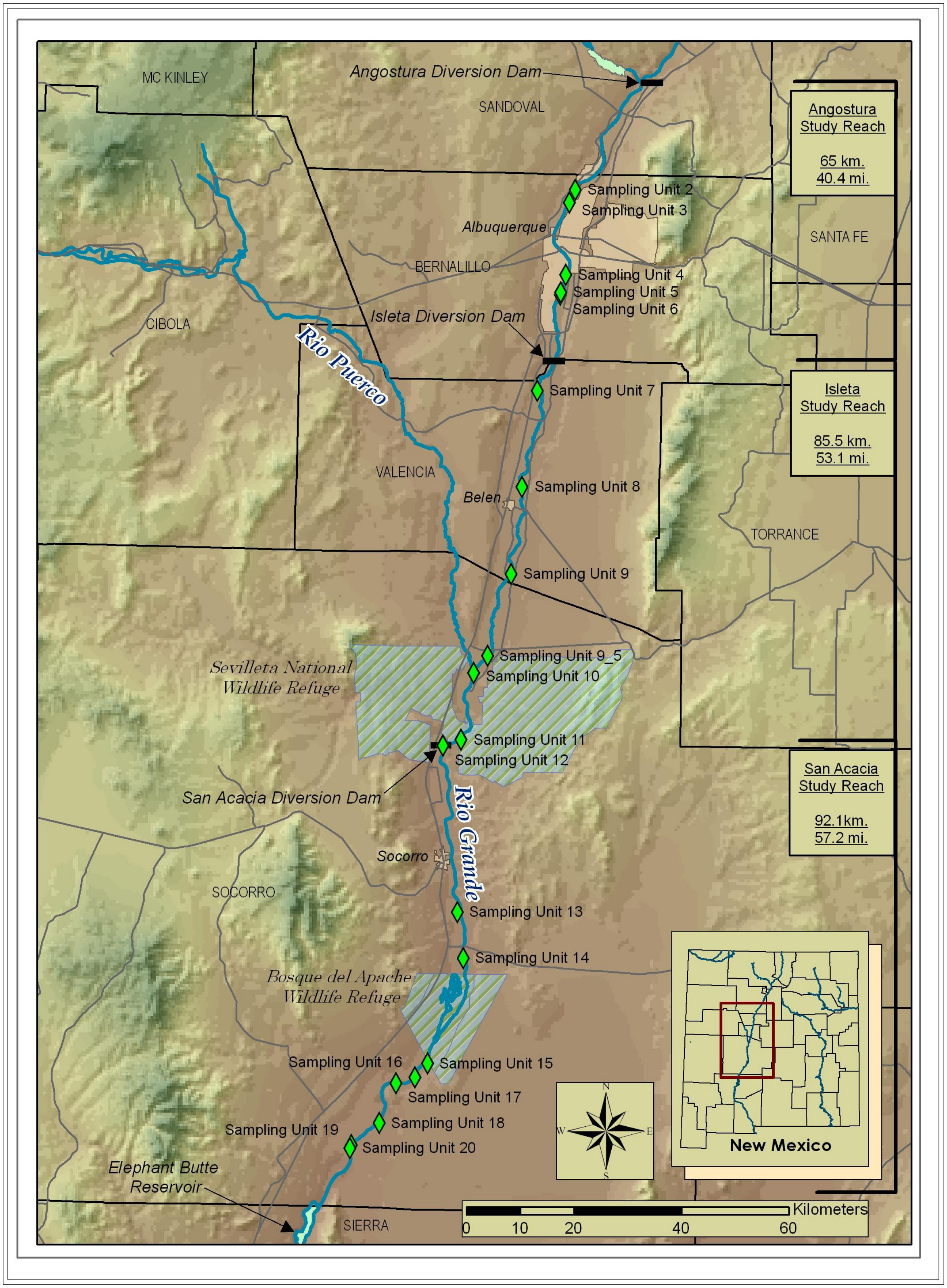

Figure 1. Map of the study area, reaches, and sampling units (numbered) for the Rio Grande silvery minnow Population Estimation Program. Sampling unit information is provided in Appendix A (Table A-1).

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 2007 and 2008, 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 2007. From mid-March 2007 until late June 2007, flows were elevated. Flow conditions in 2007 and 2008 included periodic intervals of very low discharge from July through October. Summer rains contributed little flow to the river in 2007 compared to 2008. Flows at the Albuquerque Gauge during October 2008 were relatively stable and slightly higher (mean = 509.7 cfs) than historical October flows (Mean of available data [1973-2007] = 467.8 cfs).

METHODS

Sampling and Mapping Methodology

Sampling unit location, selection, and timing

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

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

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

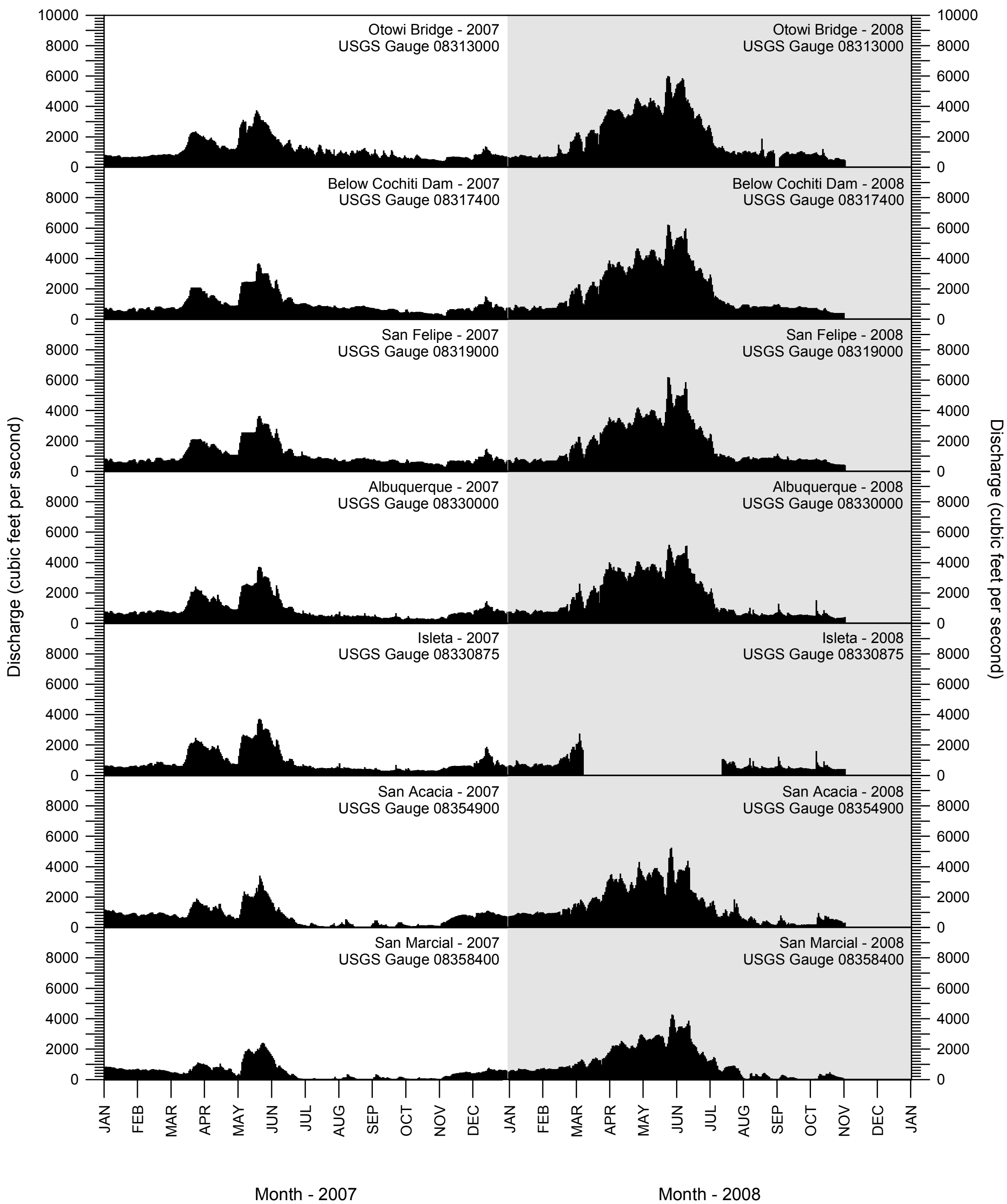

Figure 2. Discharge in the Rio Grande from January 2007 through October 2008 as recorded at seven U. S. Geological Survey (USGS) gauging stations. The Otowi Bridge gauge site is outside of the study area (ca. 25.5 river miles upstream of Cochiti Dam) but is provided for reference. USGS discharge data are provisional and subject to change.

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

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

The rationale for sampling at 20 units for the Population Estimation Program was also based on the statistical analyses and modeling techniques employed in this study. Power analysis of Rio Grande Population Monitoring Program data also supports using a sample size of about 20 to adequately detect population trends over time (MRGESACP, 2006). Rio Grande silvery minnow population estimates were generated from October 2008 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 2008 sampling effort was structured to acquire data about the relative proportion of mesohabitats at each sampling locality. Aquatic mesohabitats were segregated into seven broad categories: backwater, debris, pool, run, riffle, shoreline pool, and shoreline run (Table 1). The seven mesohabitats have been designated, based on past autumnal Middle Rio Grande fish population monitoring and habitat use/availability studies (e.g., Dudley and Platania, 1997, 2008), as high (backwater, shoreline pool, debris), medium (pool, shoreline run), or low density (run, riffle) Rio Grande silvery minnow mesohabitats.

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

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.

As part of the three-year Population Estimation Program pilot study, we used the final year (2008) to collect 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 useful point of reference to compare the costs and benefits 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 obtained at each sampling unit as well as digital photographs of physical river conditions.

Sampling was conducted within each 200-m unit, using a random stratified subset of the available non-run mesohabitats in 2008. This was in contrast to 2006 and 2007 when sampling efforts were extended to all available non-run mesohabitats. This change in protocol was necessary because of the greatly increased time required to complete closed mesohabitat samples at all selected locations in 2008. 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 on either side to minimize disturbance prior to sampling. At sampling units where there were five or fewer possible sample

Table 2. Scientific and common names and species codes of fish collected in the Middle Rio Grande from 1993 to 2008.

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 from 1993 to 2008 (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.

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 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 2.5 m intervals. A total of 20 sampling start points in runs were generated based on the X, Y coordinates (e.g., X = 5.0 m from left shore, Y = 40 m from top of unit) of all possibilities. Sampling 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 rare areas where samples could not be completed, alternate GRTS generated points 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 dipnet inside the enclosure and collect any remaining fish in the downstream seine, 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. 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) 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 then quickly dropped into place at the sampling location. Five personnel were required to operate the box under normal flow conditions (two to hold the box in place, two to operate the removable panel and collect the fish, and one to electrofish the inside of the box). The person with the electrofishing unit operated two wands (one on either side of the box) and moved slowly through the box until reaching the downstream end. The downstream panel of the box was removed immediately after electrofishing was complete. Fish from individual collecting efforts using the sampling box were handled briefly for identification and enumeration, placed in one of several fine nylon mesh holding cages (= live-well) present at the sampling unit (in the river), and released near their site of capture after sampling had concluded. 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 all mesohabitat types sampled. Multiple depletion efforts within the same 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 mesohabitat until ≤5% of the original number of fish captured on the first pass or ≤2 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 exception to this protocol was in non-shoreline areas (runs and pools) where densities of individuals were consistently very low; depletion sampling was conducted in these areas when ≥5 individuals were collected and continued until ≤5% of the original number of fish captured on the first pass or ≤2 individuals (whichever was higher) were captured on a subsequent pass. The Akaike Information Criterion (AIC; Akaike, 1973; Burnham and Anderson, 2002) using the Huggins removal estimator (Huggins, 1989, 1991) was used to generate the most parsimonious model based on the observed 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 meso-habitat 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 [2005-2008]) 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 (2005-2008). For the intensive sampling effort, units were sampled once per day for four days. A variety of mesohabitats were sampled on the first day and samples were taken at the same locations on subsequent days; in some cases the location of the sample had to be shifted to a different area with similar mesohabitat conditions if there was a change in flow. This study was conducted using the same sampling protocols established for regular population monitoring efforts. These repeated samples were taken at our 20 Population Monitoring Program sampling units (Appendix C, Table C-1). The data were organized into categories based on the presence/absence of Rio Grande silvery minnow over the four day sampling effort. The encounter history was based on the presence of Rio Grande silvery minnow at individual mesohabitat locations.

For example, an encounter history of 1101 meant that individuals were collected on days one, two, and four but not on day three. A higher proportion of presence encounters was interpreted as indicating that individuals were more consistently detected within the mesohabitat patch over time. The sampling unit was large enough (200 m) so that it was unlikely 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 2005-2008 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 2008. 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), with covariates of year (y = 2005 to 2008), and a discharge (d) covariate for measured flow (from the nearest USGS gauging station) during sampling. The Akaike Information Criterion corrected for small samples (AIC_c; Akaike, 1973; Burnham and Anderson, 2002) was used to select the most parsimonious site occupancy model based on the encounter history data. In addition to the basic parameter estimates ordered by the age-class variable, detailed estimates of the probability of occupancy were also generated by group and year. All parameter estimates are presented with their associated measure of sampling variance (SE = standard error) and confidence intervals (LCI = 95% lower confidence interval, UCI = 95% upper confidence interval).

Population Estimation of Rio Grande Silvery Minnow

Generating population estimates from October 2008 data

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

The final density calculation of individuals by mesohabitat was corrected using data generated from the depletion sampling model results (i.e., mesohabitat-specific capture probability estimate and the associated standard error). The number of sampled quadrats was determined for each mesohabitat category within a unit. The number of unsampled quadrats was calculated using the total unsampled area divided by the average area of the sampled quadrats. The total number of quadrats was the sum of the sampled and unsampled quadrats. Mesohabitat-specific calculations of density were made by multiplying the total number of quadrats by the average number of individuals collected per sampled quadrat and then dividing this product by the capture probability estimate. The associated standard errors for mesohabitat-specific calculations of density were made using detailed formulae outlined in Thompson (1992) and Skalski (1994). The total population estimate for each sampling unit was calculated as the sum of the population estimates for each mesohabitat. The standard error of the population estimate for each sampling unit was calculated by taking the sum of squares for all of the mesohabitat-specific standard errors (i.e., sampling variances) and then taking the square root of the resulting value. The upper and lower 95% confidence intervals were calculated around log-normal(N) and then converted back to linear scale; variance estimates were equivalent between scales (i.e., Var(log-normal($\hat{N}$)) = Var($\hat{N}$)/ $\hat{N}^2$)). The coefficient of variation (CV = ratio of the standard deviation to the mean) was calculated for the reach-specific average population estimates for all categories (i.e., marked vs. unmarked and age-classes).

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

Comparing RGSM estimates from Population Monitoring and Population Estimation data

In addition to population estimates of Rio Grande silvery minnow generated from data collected during this study, population size was also estimated using Population Monitoring Program data from October 2008. Estimates were generated for each of the three study reaches (Angostura, Isleta, and San Acacia). Fish densities were calculated as the number of individuals collected divided by the area sampled (#/m^2). Densities were grouped by mesohabitat for the purposes of estimating population size in a particular sampling reach. Density data from the Population Monitoring Program were corrected using the appropriate mesohabitat-specific value (from capture probability estimates) based on the observed depletion data obtained from the Population Estimation Program.

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

Mesohabitat availability was calculated from the October 2008 Population Monitoring Program data whenever possible. However, as the perimeter of each sampling unit was not mapped during population monitoring efforts, the area of the wetted channel was estimated by multiplying the width of the river channel by the length of the study unit. Nearly all non-run mesohabitats were measured and sampled in their entirety, with the exception of shoreline runs. The remaining shoreline run mesohabitat (unsampled) was calculated as the area of all shoreline mesohabitat minus the area of shoreline mesohabitat that was sampled. Similarly, run mesohabitat area was calculated as the area of all wetted mesohabitat minus the sum of the non-run mesohabitat and sampled run mesohabitat areas. Population estimates of Rio Grande silvery minnow (for different reaches, the total study area, different age-classes, and marked versus unmarked) were made using the same methods that were used for determining population size in the Population Estimation Program.

The undertaking of this computational exercise was recommended by MRGESACP peer-review statisticians and biologists. Those individuals, as well as the authors of this study, clearly recognize that the Population Monitoring Program generated population estimate is based on general estimates of mesohabitat area, relies on non-randomly selected sampling units, will violate numerous statistical assumptions, and thus must be viewed cautiously. The estimate generated from the population monitoring data was not designed to provide the same high level of rigor inherent in the statistical methodology used to address Objectives 1, 2, and 3 as presented in the Introduction. The primary reason for performing this exercise was to determine if additional investigation should be pursued regarding a potential statistical relationship between Rio Grande silvery minnow Population Monitoring Program data and the Rio Grande silvery minnow Population Estimation Program data.

RESULTS

Fish Community

Population status

The ichthyofaunal community in the Middle Rio Grande between Angostura Diversion Dam and Elephant Butte Reservoir was numerically dominated by cyprinids (Table 3; Appendix D, Report D-1). The native ichthyofauna consisted of seven species (red shiner, Rio Grande silvery minnow, fathead minnow, flathead chub, longnose dace, river carpsucker, and bluegill). Bluegill (N = 1) was the least abundant native fish while longnose dace and river carpsucker (both N = 9) were the next least abundant taxa. Rio Grande silvery minnow was the most abundant native species collected (N = 1,576), followed by red shiner (N = 909), fathead minnow (N = 329), and flathead chub (N = 251). The most abundant introduced species were channel catfish (N = 666), western mosquitofish (N = 363), and common carp (N = 26). The three remaining nonnative fish species were present at lower numbers (i.e., N < 15) than were the aforementioned nonnative species.

Abundance and distribution

The largest numbers of fish were collected in the Isleta Reach (N = 1,771; Table 4). Fish were distributed relatively evenly within this reach, with the exception of sampling unit #7 where a large number of individuals were collected and sampling units #9 and #10 where few individuals

Table 3. Summary of the Rio Grande silvery minnow Population Estimation Program fish collections from October 2008.

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT (%) OF TOTAL	FREQUENCY OF OCCURRENCE[2]	% FREQUENCY OCCURRENCE[2]
HERRINGS					
gizzard shad	I	--	0.00	--	--
CARPS AND MINNOWS					
red shiner	N	909	21.73	20	100
common carp	I	26	0.62	10	50
Rio Grande chub	N	--	0.00	--	--
Rio Grande silvery minnow	N	1,576	37.68	20	100
fathead minnow	N	329	7.87	12	60
bullhead minnow	I	--	0.00	--	--
flathead chub	N	251	6.00	18	90
longnose dace	N	9	0.22	3	15
SUCKERS					
river carpsucker	N	9	0.22	7	35
white sucker	I	13	0.31	5	25
smallmouth buffalo	N	--	0.00	--	--
BULLHEAD CATFISHES					
black bullhead	I	4	0.09	3	15
yellow bullhead	I	9	0.22	6	30
channel catfish	I	666	15.92	20	100
flathead catfish	I	13	0.31	3	15
TROUTS					
rainbow trout	I	--	0.00	--	--
brown trout	I	--	0.00	--	--
LIVEBEARERS					
western mosquitofish	I	363	8.68	17	85
TEMPERATE BASSES					
white bass	I	1	0.02	1	5
SUNFISHES					
green sunfish	I	--	0.00	--	--
bluegill	N	2	0.05	2	10
largemouth bass	I	--	0.00	--	--
white crappie	I	2	0.05	2	10
black crappie	I	--	0.00	--	--
PERCHES					
yellow perch	I	--	0.00	--	--
bigscale logperch	I	--	0.00	--	--
walleye	I	1	0.02	1	5
TOTAL		4,183			

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

Table 4. Summary of Rio Grande silvery minnow (including marked individuals) and total fish abundance and sampling effort, by sampling unit and reach, during the 2008 Rio Grande silvery minnow Population Estimation Program.

REACH Sampling Unit and Name	TOTAL NUMBER OF RGSM	TOTAL NUMBER OF MARKED RGSM	TOTAL NUMBER OF ALL FISH	SAMPLING EFFORT (m^2)
ANGOSTURA REACH				
2 Paseo del Norte upper	47	-	141	328.38
3 Paseo del Norte lower	175	-	427	317.08
4 Rio Bravo upper	3	-	93	288.95
5 Rio Bravo middle	20	-	147	448.43
6 Rio Bravo lower	34	-	297	323.94
Angostura Reach Total	279	0	1,105	1,706.78
ISLETA REACH				
7 Los Lunas	440	-	685	589.61
8 Belen	76	-	224	540.47
9 Jarales	27	-	162	441.40
9_5 Bernardo	41	-	302	407.33
10 S of Bernardo	2	-	154	316.52
11 Sevilleta	100	-	244	452.97
Isleta Reach Total	685	0	1,771	2,748.30
SAN ACACIA REACH				
12 S of San Acacia	18	-	132	325.43
13 Socorro	167	-	269	456.61
14 San Antonio	22	-	164	316.40
15 Bosque del Apache	10	-	132	291.50
16 S of Bosque del Apache	106	-	138	422.69
17 San Marcial	161	-	228	327.43
18 S of San Marcial	55	-	96	317.36
19 S of LFCC Return	36	-	76	156.17
20 S of Site 19	36	-	72	275.39
San Acacia Reach Total	611	0	1,307	2,888.99
MONTHLY TOTALS	1,576	0	4,183	7,344.08

were collected. The San Acacia Reach produced the second highest overall catch rate of fish (N = 1,307 in 2,888.99 m^2 sampled). The distribution of fish within the San Acacia Reach was uneven with higher densities in the upper portion of the reach. Sampling unit #20 yielded the fewest number of fish (N = 72) while unit #13 yielded the most fish (N = 269). Fish abundance in the Angostura Reach was uneven. The heavily channelized sampling unit #4 yielded the fewest number of fish (N = 93) of any sampling unit in the Angostura Reach. 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 San Acacia Reach and most abundant in the Angostura Reach. While flathead chub was most concentrated in the Angostura Reach, red shiner densities were highest in the Isleta Reach. Densities of Rio Grande silvery minnow and channel catfish did not vary as much among reaches as other common species. For all reaches combined, Rio Grande silvery minnow, red shiner, 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 upper portion of the Isleta Reach. The upper portion of the Angostura Reach yielded the most Rio Grande silvery minnow while there was a bimodal distribution in the San Acacia Reach.

Depletion Sampling

Multiple depletion passes within discrete mesohabitats were used to generate depletion model estimates using data collected in 2008 (Table 5). The best model for the mesohabitat-specific depletion data (based on the lowest AIC_C value) was by mesohabitat only and was supported by a high model weight. Riffles (RI) did not yield Rio Grande silvery minnow and so capture probability could not be estimated 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 was by mesohabitat and location combined, but the model weight was substantially lower (for SHPO and SHRU) than that for the mesohabitat-only model. Although the mesohabitat and location model for BW yielded a lower AICc value than the mesohabitat only model, it was excluded because one site had an estimate of $p = 1$ (a strong source of bias). The capture probability estimates (i.e., proportion of fish removed per depletion pass) for the different mesohabitats ranged from 0.6827 (backwaters) to 0.7633 (shoreline runs). The associated standard errors for estimates were consistent between mesohabitats and ranged between 0.0188 and 0.0509.

Occupancy Rates from Past Population Monitoring Data

The encounter history for Rio Grande silvery minnow (Table 6) during November 2008 was dominated by a single sampling category (1111 [27.5%]). 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 [18.0%]). The other sampling encounter categories had a relatively even probability distribution and there were not strong patterns in the combinations of encounters. The rarest combination (0110 [1.25%]) was where individuals were collected on days two and three but not on days one or four.

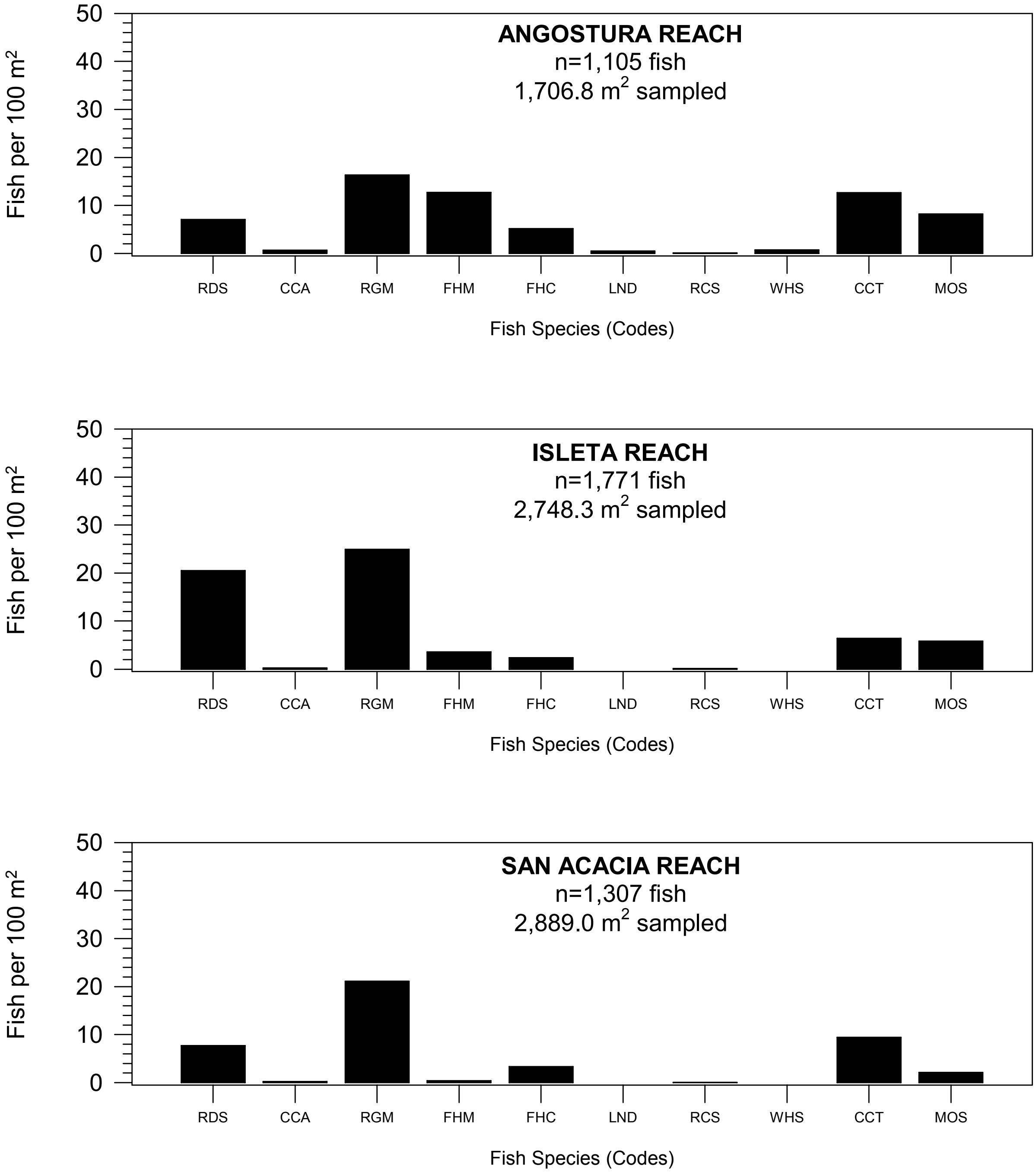

Figure 3. Catch rates, for the 10 focal species, by river reach during October 2008 at Rio Grande silvery minnow Population Estimation Program sampling units (see Table 2 for fish species codes).

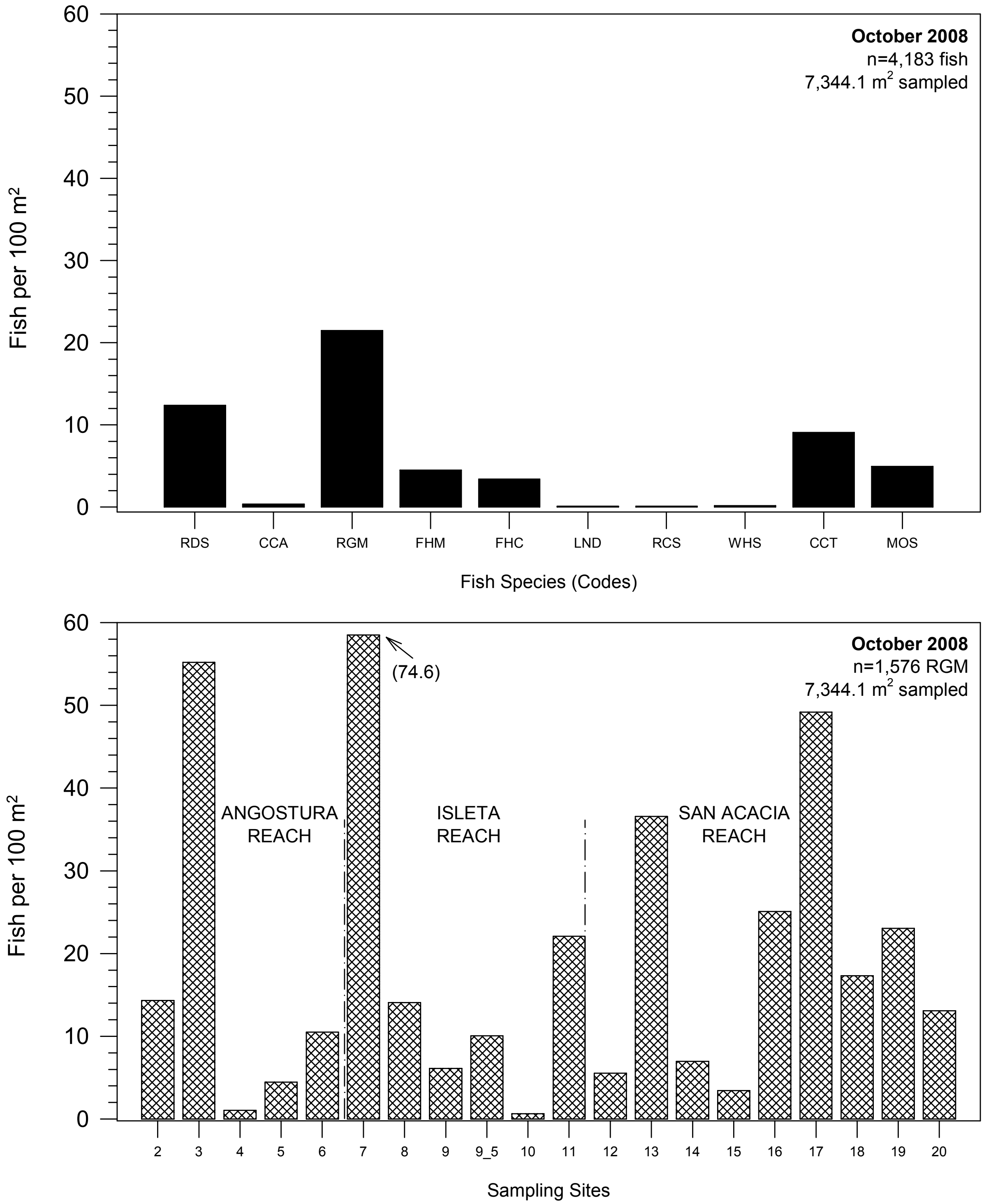

Figure 4. Catch rates for ten focal species (upper graph), including Rio Grande silvery minnow, (RGM; lower graph) during October 2008 at Rio Grande silvery minnow Population Estimation Program sampling units (see Table 2 for fish species codes).

Table 5. Rio Grande silvery minnow multiple depletion removal analysis and modeling results for data collected from multiple mesohabitat types and locations in the Middle Rio Grande (2008).

RGSM depletion data

Models*	AICc	Delta AICc	AICc Weights	Model Likelihood	Number of Parameters	Deviance
BW - {Mesohabitat+Location}	-2453.9292	0.0000	1.0000	1.0000	24.0000	36.7097
BW - {Mesohabitat}*	-2386.4235	67.5057	0.0000	0.0000	13.0000	127.4126
PO - {Mesohabitat}*	-27.3761	0.0000	1.0000	1.0000	1.0000	1.3972
SHPO - {Mesohabitat}*	-1070.8501	0.0000	0.9804	1.0000	13.0000	44.3363
SHPO - {Mesohabitat+Location}	-1063.0294	7.8207	0.0196	0.0200	26.0000	23.2246
SHRU - {Mesohabitat}*	-1126.8076	0.0000	0.9783	1.0000	20.0000	67.7668
SHRU - {Mesohabitat+Location}	-1119.1896	7.6180	0.0217	0.0222	38.0000	34.1569

*Top models were selected for all mesohabitat models except BW; this was because the mesohabitat+location model included one site with an estimate of $p = 1$, which biases the AICc value. There was only one model for PO because of limited depletion opportunities in this mesohabitat.

{Mesohabitat}	Capture Probability Estimate	Standard Error of Estimate	Lower 95% CI of Estimate	Upper 95% CI of Estimate
BW	0.6827	0.0188	0.6459	0.7196
PO	0.6878	0.0509	0.5880	0.7875
SHPO	0.7278	0.0235	0.6817	0.7738
SHRU	0.7633	0.0200	0.7241	0.8025

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 2008.

RGSM encounter history (all age-classes)

Encounters*	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0000	72	18.00	72	18.00
0001	13	3.25	85	21.25
0010	9	2.25	94	23.50
0011	11	2.75	105	26.25
0100	13	3.25	118	29.50
0101	7	1.75	125	31.25
0110	5	1.25	130	32.50
0111	11	2.75	141	35.25
1000	31	7.75	172	43.00
1001	8	2.00	180	45.00
1010	12	3.00	192	48.00
1011	23	5.75	215	53.75
1100	33	8.25	248	62.00
1101	17	4.25	265	66.25
1110	25	6.25	290	72.50
1111	110	27.50	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	0.6670	0.0136	0.6398	0.6932
p: Age-0 RGSM	0.6673	0.0137	0.6400	0.6936
p: Age-1 RGSM	0.2112	0.0462	0.1346	0.3155
p: Age-2 RGSM	0.1657	0.1002	0.0458	0.4513
ψ: All RGSM	0.8302	0.0195	0.7885	0.8651
ψ: Age-0 RGSM	0.8251	0.0198	0.7830	0.8605
ψ: Age-1 RGSM	0.1509	0.0325	0.0976	0.2262
ψ: Age-2 RGSM	0.0339	0.0199	0.0106	0.1036

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

Probability of detection and probability of occupancy estimates during 2008 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 0.6670 while the estimate for age-0 individuals was 0.6673; probability of detection estimates were much lower for age-1 and age-2 individuals (<0.25). The probability of occupancy estimate for all Rio Grande silvery minnow was 0.8302 while the estimate for age-0 individuals was 0.8251. The occupancy estimate for age-1 individuals was 0.1509 but the occupancy estimate for age-2 individuals was quite low (0.0339).

The availability of data from 2005 to 2008 allowed for a preliminary 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 (0.5726) and age-2 (0.5125) individuals. Estimates of the probability of extinction were relatively low for all age-classes (0.0172) and age-0 (0.0697) individuals. The probability of extinction was higher for both age-1 and age-2 individuals (0.2236 and 0.1242, respectively). Estimates of the probability of colonization were relatively high for age-0 (0.5877) and age-1 (0.7414) individuals. However, because a site for all age-classes never went from unoccupied to occupied, the colonization estimate for this group was zero. Estimates of the probability of occupancy varied among years and age-classes but were most variable for groups with fewer data (i.e., age-1 and age-2 individuals). Detailed Rio Grande silvery minnow detection probability estimates among years and for individual sampling occasions (for all sampling units combined) are provided in Appendix E.

Population Estimation of Rio Grande Silvery Minnow

Population estimates from October 2008 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 (854.14) while the highest was recorded in the Angostura Reach (3,341.66). The average population estimate per sampled segment for all reaches was 1,951.96. The lowest coefficient of variation (CV) was recorded in the San Acacia Reach (1.06) while the highest CV was in the Isleta Reach (1.52). The number of sampling units used to calculate total population size was similar between the Isleta (N = 421) and San Acacia (N = 474) reaches; the shortest reach was Angostura (N = 275). The total population estimate was highest in the Isleta Reach (N = 1,027,489) and lowest in the San Acacia Reach (N = 404,864). The standard errors associated with population estimates for the three reaches were proportionally comparable for the Angostura and San Acacia reaches; standard error was notably higher in the Isleta Reach. The overall population estimate (N = 2,283,790) had a standard error [SE] of 740,860.73. The upper 95% confidence intervals (CI), especially in the Angostura and Isleta Reach, 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 2008 (unlike in 2006 or 2007). All of the population estimates are therefore the same for the marked-unmarked vs. unmarked-only categories in 2008.

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 (2005-2008).

RGSM Site Occupancy Models

Models*	AIC_c	Delta AIC_c	AIC_c Weights	Model Likelihood	Number of Parameters	Deviance
A: {$\psi(g)$ $\varepsilon(g)$ $\gamma(g)$ $p(g*y+d)$}	684.0304	0.0000	0.64043	1.0000	29	620.0304
B: {$\psi(g)$ $\varepsilon(g)$ $\gamma(g)$ $p(g*y)$}	686.2819	2.2515	0.20776	0.3244	28	624.7011
C: {$\psi(g)$ $\varepsilon(g*y)$ $\gamma(g)$ $p(g*y)$}	687.2178	3.1874	0.13012	0.2032	36	605.8043
D: {$\psi(g)$ $\varepsilon(g)$ $\gamma(g)$ $p(g*y+y*d)$}	691.2336	7.2032	0.01747	0.0273	32	619.8747
E: {$\psi(g)$ $\varepsilon(g*y)$ $\gamma(g*y)$ $p(g*y)$}	694.1516	10.1212	0.00406	0.0063	40	602.3953

Parameter Estimates from Minimum AIC_c Model (A)**

Label*	Estimate	SE	LCI	UCI
ψ All Fish	1.0000	0.0000	1.0000	1.0000
ψ Age-0	1.0000	0.0000	1.0000	1.0000
ψ Age-1	0.5726	0.1712	0.2538	0.8407
ψ Age-2	0.5125	0.2651	0.1161	0.8938
ε All Fish	0.0172	0.0171	0.0024	0.1125
ε Age-0	0.0697	0.0353	0.0251	0.1790
ε Age-1	0.2236	0.0926	0.0919	0.4504
ε Age-2	0.1242	0.2093	0.0033	0.8603
γ All Fish	0.0000	0.0000	0.0000	0.0000
γ Age-0	0.5877	0.2270	0.1852	0.8994
γ Age-1	0.7414	0.1993	0.2721	0.9565
γ Age-2	1.0000	1.0000	0.0000	1.0000

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

Group	Year	Estimate	SE	LCI	UCI
All Fish	2005	1.0000	0.0000	1.0000	1.0000
All Fish	2006	0.9828	0.0171	0.9493	1.0163
All Fish	2007	0.9658	0.0336	0.9000	1.0317
All Fish	2008	0.9492	0.0495	0.8521	1.0462
Age-0	2005	1.0000	0.0000	1.0000	1.0000
Age-0	2006	0.9303	0.0353	0.8610	0.9996
Age-0	2007	0.9064	0.0471	0.8141	0.9987
Age-0	2008	0.8982	0.0535	0.7934	1.0031
Age-1	2005	0.5726	0.1712	0.2371	0.9081
Age-1	2006	0.7614	0.0810	0.6028	0.9201
Age-1	2007	0.7681	0.0708	0.6292	0.9069
Age-1	2008	0.7683	0.0711	0.6290	0.9076
Age-2	2005	0.5125	0.2651	-0.0071	1.0322
Age-2	2006	0.4489	0.1663	0.1228	0.7749
Age-2	2007	0.3931	0.1369	0.1248	0.6614
Age-2	2008	0.3443	0.1613	0.0282	0.6604

*Where ψ(psi)=probability of occupancy, ε(epsilon)=probability of extinction, γ(gamma)=probability of colonization, *p*=detection probability, *y*=year, *d*=discharge, and *g*(group)=age-class: group 1 = All Fish, group 2 = Age-0, group 3 = Age-1, and group 4 = Age-2.
**Detailed estimates of *p* by year and sampling occasion are provided in Appendix E.

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 for only unmarked individuals).

Rio Grande silvery minnow (both marked and unmarked)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	3,341.66	3,802.96	275	918,956.76	463,548.46	361,416.76	2,336,586.53
Isleta	2,440.59	3,704.11	421	1,027,489.45	632,107.28	338,474.54	3,119,095.94
San Acacia	854.14	906.92	474	404,863.97	142,000.29	207,669.66	789,305.66
All Reaches	1,951.96	2,855.91	1,170	2,283,790.30	740,860.73	1,228,568.97	4,245,344.18

Rio Grande silvery minnow (unmarked only)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	3,341.66	3,802.96	275	918,956.76	463,548.46	361,416.76	2,336,586.53
Isleta	2,440.59	3,704.11	421	1,027,489.45	632,107.28	338,474.54	3,119,095.94
San Acacia	854.14	906.92	474	404,863.97	142,000.29	207,669.66	789,305.66
All Reaches	1,951.96	2,855.91	1,170	2,283,790.3	740,860.73	1,228,568.97	4,245,344.18

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). This was primarily caused by the large numbers of age-0 Rio Grande silvery minnow in all reaches. The coefficient of variation for age-0 individuals was highest in the Isleta Reach (1.42) and lowest in the Angostura Reach (1.07). Values of CV for age-1 individuals were similar between the Angostura and Isleta reaches (1.89 and 1.84, respectively); the low numbers of age-1 individuals in the San Acacia Reach resulted in an elevated CV value (2.79). The overall population estimate for age-0 (N = 1,856,409) Rio Grande silvery minnow was not significantly higher than for age-1 (N = 395,829) individuals. 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).

Comparison of RGSM estimates from Population Monitoring and Population Estimation data

Population estimates were also generated using data from the Population Monitoring Program October 2008 sampling efforts. For all Rio Grande silvery minnow and only unmarked individuals, the average population estimates per sampling unit were slightly higher than those generated using the Population Estimation Program data (Table 10). The highest average population estimates per sampling unit were recorded in the Isleta and San Acacia Reaches (2,036.58 and 2,153.87, respectively) while the lowest was in the Angostura Reach (743.59). Values of CV ranged from 0.55 in the San Acacia Reach to 1.25 in the Angostura 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 2008 during the Population Monitoring Program.

The population estimates for the study area varied among reaches with the highest numbers recorded in the San Acacia Reach (1,020,935) and the lowest numbers in the Angostura Reach (204,488). The overall population estimate using the Population Monitoring Program data (N = 2,066,354) had a standard error [SE] of 369,320.08. The overall population estimate ratio between the two data sets was 0.90 and there was no significant difference in the total population estimate between the two population estimation methods. The reach-specific estimates were most divergent for the Angostura Reach where the Population Monitoring value (N = 204,488) was lower than the Population Estimate value (N = 918,957). However, there were no significant differences between reach-specific estimates using the Population Monitoring and Population Estimate data sets.

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 1,897,757 for age-0 individuals and 168,340 for age-1 individuals. There were no significant differences between age-specific estimates using the Population Monitoring and Population Estimate data sets. No age-1 Rio Grande silvery minnow were collected in the San Acacia Reach during the Population Monitoring efforts.

DISCUSSION

In contrast to population monitoring that provides year-round documentation of trends (i.e., monthly or bimonthly sampling) for the entire ichthyofaunal community, the Population Estimation Program supplements the current Population Monitoring Program by providing a robust yearly estimate of the Rio Grande silvery minnow population during a single time-period (e.g., October). Systematic population monitoring activities provide an assessment of recruitment success over

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)

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	2,828.84	3,025.28	275	777,929.89	368,783.67	321,872.42	1,880,170.16
Isleta	1,680.80	2,384.03	421	707,616.58	406,855.77	248,243.89	2,017,053.58
San Acacia	833.83	918.63	474	395,237.59	143,832.09	198,001.81	788,946.08
All Reaches	1,586.67	2,110.71	1,170	1,856,409.04	547,596.06	1,053,910.31	3,269,969.46

Rio Grande silvery minnow (age-1)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	440.42	830.41	275	121,116.26	101,244.21	29,077.84	504,478.57
Isleta	730.24	1,345.37	421	307,429.30	229,578.45	83,381.70	1,133,495.38
San Acacia	20.31	56.64	474	9,626.38	8,864.00	2,072.26	44,717.94
All Reaches	338.32	849.704	1,170	395,829.04	220,416.19	142,932.48	1,096,186.36

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 for only unmarked individuals).

Rio Grande silvery minnow (both marked and unmarked)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	743.59	927.97	275	204,488.19	113,083.40	74,296.44	562,818.59
Isleta	2,036.58	1,834.87	421	857,401.14	313,108.44	428,558.44	1,715,370.96
San Acacia	2,153.87	1,184.43	474	1,020,934.69	185,359.80	717,303.98	1,453,090.55
All Reaches	1,766.11	1,423.88	1,170	2,066,354.35	369,320.08	1,459,691.00	2,925,153.54

Rio Grande silvery minnow (unmarked only)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	743.59	927.97	275	204,488.19	113,083.40	74,296.44	562,818.59
Isleta	2,036.58	1,834.87	421	857,401.14	313,108.44	428,558.44	1,715,370.96
San Acacia	2,153.87	1,184.43	474	1,020,934.69	185,359.80	717,303.98	1,453,090.55
All Reaches	1,766.11	1,423.88	1,170	2,066,354.35	369,320.08	1,459,691.00	2,925,153.54

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)

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	290.23	282.13	275	79,813.54	34,381.18	35,553.90	179,170.29
Isleta	1,934.05	1,842.11	421	814,235.49	314,344.46	392,169.52	1,690,543.00
San Acacia	2,153.87	1,184.43	474	1,020,934.69	185,359.80	717,303.98	1,453,090.55
All Reaches	1,622.01	1,460.11	1,170	1,897,757.40	378,718.06	1,288,329.03	2,795,468.46

Rio Grande silvery minnow (age-1)

Reach	Average Pop. Est. per sampled segment	Standard Dev. of Pop. Est. per sampled segment	Total number of segments	Total Pop. Est	Standard Error of Pop. Est.	Lower 95% CI	Upper 95% CI
Angostura	453.07	993.66	275	124,594.09	121,088.55	25,196.65	616,101.14
Isleta	102.04	153.76	421	42,960.10	26,238.97	14,248.93	129,523.39
San Acacia	0.00	0.00	474	0.00	0.00	.	.
All Reaches	143.88	499.61	1,170	168,339.89	129,584.73	44,209.92	640,994.56

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 managing populations of rare organisms (i.e., federally threatened or endangered). Monitoring changes in populations requires estimating species-specific abundance over time, usually from multiple sites.

The use of catch-per-unit-effort (CPUE) to monitor the status of fish populations is well established in fisheries science. Some of the first important theoretical contributions were provided by the mid-1900s (Ricker 1940, 1944; Zippin 1956, 1958). Constant effort on each pass simplifies the CPUE estimator to the standard removal estimator (Otis et al. 1978). The relationship between CPUE and abundance has received considerable attention in the literature (see reviews by Otis et al. 1978, Bannerot and Austin 1983). Experimental and statistical treatment of the issue has demonstrated that CPUE is a valid estimator of abundance and that the relationship is one of strict proportionality for single species (Richards and Schnute, 1986). The work of Richards and Schnute (1986, 1992) and other researchers using CPUE in fisheries applications has appeared in international reviews on the general topic of estimating animal abundance (Seber 1992). Extensive reviews of the various methods for estimating animal abundance identify CPUE as one of the most widely used and well-researched techniques in fisheries science (e.g., Seber 1992, Schwarz and Seber 1999). CPUE provides a metric by which to gauge the relative increases or decreases (trends) in populations over time and space.

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

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

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 2008 (based on November sampling efforts). There are numerous benefits in being able to document the estimated site occupancy rate of species over time. Probability of detection estimates can provide insight to patterns of site occupancy of Rio Grande silvery minnow both within and among sampling units. Site occupancy models can be developed over time to incorporate changes in the probability of detection and the presence/absence patterns at a particular site.

Site occupancy rates at the mesohabitat level were generated using techniques developed by MacKenzie et al. (2002, 2003, and 2006). The large decline in the abundance of Rio Grande silvery minnow from 2005 to 2006 was reflected in changes in the site occupancy rates at the established Population Monitoring Program sampling units. There was a noticeable decline in the percentage of sites occupied by age-0 Rio Grande silvery minnow between 2005 and 2006 (Dudley et al. 2007). Probability of detection estimates for Rio Grande silvery minnow (all age-classes combined) in 2008 were similar to those recorded in 2005 and significantly higher than those recorded in 2006 or 2007. Site occupancy estimates for 2008 reflected consistency in the encounter histories and were significantly higher than those recorded in 2006 or 2007.

More detailed site occupancy models at the sampling unit level were generated based on the availability of extensive data spanning four years (2005-2008). 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, 2007-2008). 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 (0.0172) based on data collected over the past four years. Estimates of site occupancy suggest a minor decline from 2005 to 2008 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).

The population estimate of Rio Grande silvery minnow for 2008 was based on an intensive sampling regime. A high degree of precision was obtained in mapping mesohabitats and determining the areas and densities of silvery minnow in specific mesohabitats. Data were collected from a relatively large number of sampling units over a one-month period. Subsequent powerful statistical and modeling analytical techniques were used to examine the data and calculate population estimates. The methodology employed allowed for calculations of population size of Rio Grande silvery minnow among reaches, for marked and unmarked fish, and between age-classes. The sampling variances associated with population estimates were reasonable, especially given the widely variable observed densities of Rio Grande silvery minnow among sampling units.

While large numbers of Rio Grande silvery minnow have been annually stocked into the river for at least the past seven years (including 2008), there was no significant positive correlation between recent stocking numbers and population estimates from 2006-2008 (unpubl. data). However, this is not surprising considering that while populations of Rio Grande silvery minnow have increased or decreased over several orders of magnitude in the past few years, this variation could be explained almost entirely from critical aspects of the annually dynamic hydraulic regime (Dudley and Platania, 2008) as opposed to the steady input of hatchery fish. In addition, the Rio Grande silvery minnow stocked in 2008 appear not to have dispersed widely throughout the system and/or had relatively high mortality rates (Dudley and Platania, 2008). None of the sampling units of this study yielded marked individuals. Mortality rate of Rio Grande silvery minnow stocked in the spring would be expected to be high, especially if those individuals had spawned. However, the young of those marked fish would be included in our population estimate as wild fish. Also, marked individuals stocked in the fall would not have had an adequate time to disperse throughout the system, and would likely be proportionally underrepresented in the population estimate. Increased sampling in the areas where stocked fish were spot released would result in higher population estimates of marked fish. However, the purpose of this study was to estimate the population of wild Rio Grande silvery minnow (i.e., marked fish were noted so that they could be removed from the estimate of population size). Further, only wild individuals (unmarked) are counted toward recovery of the Rio Grande silvery minnow (U. S. Department of the Interior, 2007).

A large number of Rio Grande silvery minnow are salvaged from drying portions of the river each year but the number of individuals released into upstream reaches appears to have had little effect on inter- or intra-annual population fluctuations, based on results from population monitoring (Dudley and Platania, 2008). It is possible that the stresses inflicted on fish during the capture, handling, and transport activities could result in high rates of initial mortality (C. Caldwell, NMSU, pers. comm.). In addition, many of the salvaged individuals are collected earlier in the year than this study was conducted. These smaller life stages are expected to have higher rates of mortality and it is likely many of these fish perished before recruiting into the population. Additionally, the point stocking of fish does not allow adequate time to ensure full mixing within the population. This will result in a similar effect as that described for stocked Rio Grande silvery minnow.

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

The population estimates from October 2008 data were generated following a period of improved Rio Grande silvery minnow spawning and recruitment as compared with 2006 (Dudley and Platania, 2008). There have been multiple massive changes in the abundance of Rio Grande silvery minnow within a relatively short period (1999-2008). Recent changes (i.e., within the past four years) have been some of the most dramatic during the period of record; populations have changed by about an order of magnitude (10X) every year since 2003 (Dudley and Platania, 2008). October population monitoring samples illustrate that there was a substantial decline from 2005 to 2006 following by a substantial increase from 2006 to 2007. The mean CPUE (catch per unit effort) of Rio Grande silvery minnow dropped from 36.99 in 2005 to 1.38 in 2006 but rebounded to 10.85 in 2007 and 7.96 in 2008. 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, 2007, and 2008 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 2008, 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.

There was a modest difference between the total population size estimates when using Population Estimation Program data vs. Population Monitoring Program data. There was a slightly higher estimate obtained by using the Population Estimate data compared with the Population Monitoring data. This was in contrast to 2006 and 2007 when the Population Monitoring data resulted in higher estimates than the Population Estimate data. It is possible that the change in methodology between 2007 and 2008 (i.e., only enclosed mesohabitat depletion samples in 2008) resulted in higher estimates during 2008. However, there were no significant differences in estimates of total population size using the Population Monitoring or Population Estimate data in either 2007 or 2008.

While there were seemingly higher or lower estimates between the two the Population Monitoring and Population Estimate data sets (among reaches and ages), statistical analyses revealed no significant differences between reach-specific or age-specific estimates using the two population estimation methods. When comparing individual reaches or age-classes, there is a higher likelihood of observing a larger spread in population estimates simply because there are fewer data points used to make these subset estimates. The variance that also accompanies these subset estimates is also usually elevated because of the same reason (i.e., fewer data points). 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 comparison between the two population estimation methods over time.

There were also a number of differences in how the data were gathered and compiled during the Population Estimation Program vs. Population Monitoring Program studies. While the Population Estimation Program relied on actual mapping and precise calculation of the areas of mesohabitats for each unit, the Population Monitoring Program simply utilized stream width approximations and much less refined estimates of mesohabitat area. These areas were used to generate density estimates of fish in both studies but a much higher degree of confidence should be ascribed to data collected as part of the Population Estimation Program. Also, there was a nonrandom selection of mesohabitats for sampling during the Population Monitoring Program. Thus, the population size estimates generated as part of the Population Estimation Program are more statistically valid and realistic compared to the estimates generated using Population Monitoring Program data.

The 2006-2008 estimates of Rio Grande silvery minnow population size should be viewed cautiously as they are only a few data points and are preceded by the rigorous long-term Population Monitoring Program that was initiated in 1993. There have been numerous periods of rapidly expanding and contracting population size that have occurred over the past 15 years. While estimates from a few years provide a useful starting point for long-term monitoring, its importance (both statistically and from a resource management standpoint) will only be realized after multiple years of population estimation data are collected and analyzed.

The site occupancy data should be used in combination with population estimate data to provide a more complete understanding of the conservation status of Rio Grande silvery minnow. It is well known that simply having large numbers of a particular species in an area doesn't ensure its long-term survival. This is particularly true for short-lived species such as Rio Grande silvery minnow. The vast changes in populations of this species within short time periods underscore the need to ensure the presence of individuals over a broad geographical range. Changing environmental conditions within a particular region (either natural or manmade) can have rapid and severe impacts to local populations of Rio Grande silvery minnow. Large populations within these affected regions can be decimated within days because of river dewatering. Alternatively, the lack of spring runoff can inhibit spawning and limit recruitment to such a degree that populations decline several orders of magnitude within a year. The short life span of this species means that, following periods of low recruitment, total population size is not well buffered by surviving age-classes. For these reasons, it is imperative that populations of Rio Grande silvery minnow are established at multiple locations within its current range and at multiple locations within its historical range to ensure its long-term persistence in the wild.

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

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Appendix A.

Middle Rio Grande sampling units for the Population Estimation Program

Table A-1. Sampling unit localities for the October 2008 Rio Grande silvery minnow Population Estimation Program.

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

Table A-1. Sampling unit localities for the October 2008 Rio Grande silvery minnow Population Estimation Program (continued).

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

Table A-1. Sampling unit localities for the October 2008 Rio Grande silvery minnow Population Estimation Program (continued).

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

Appendix B.

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

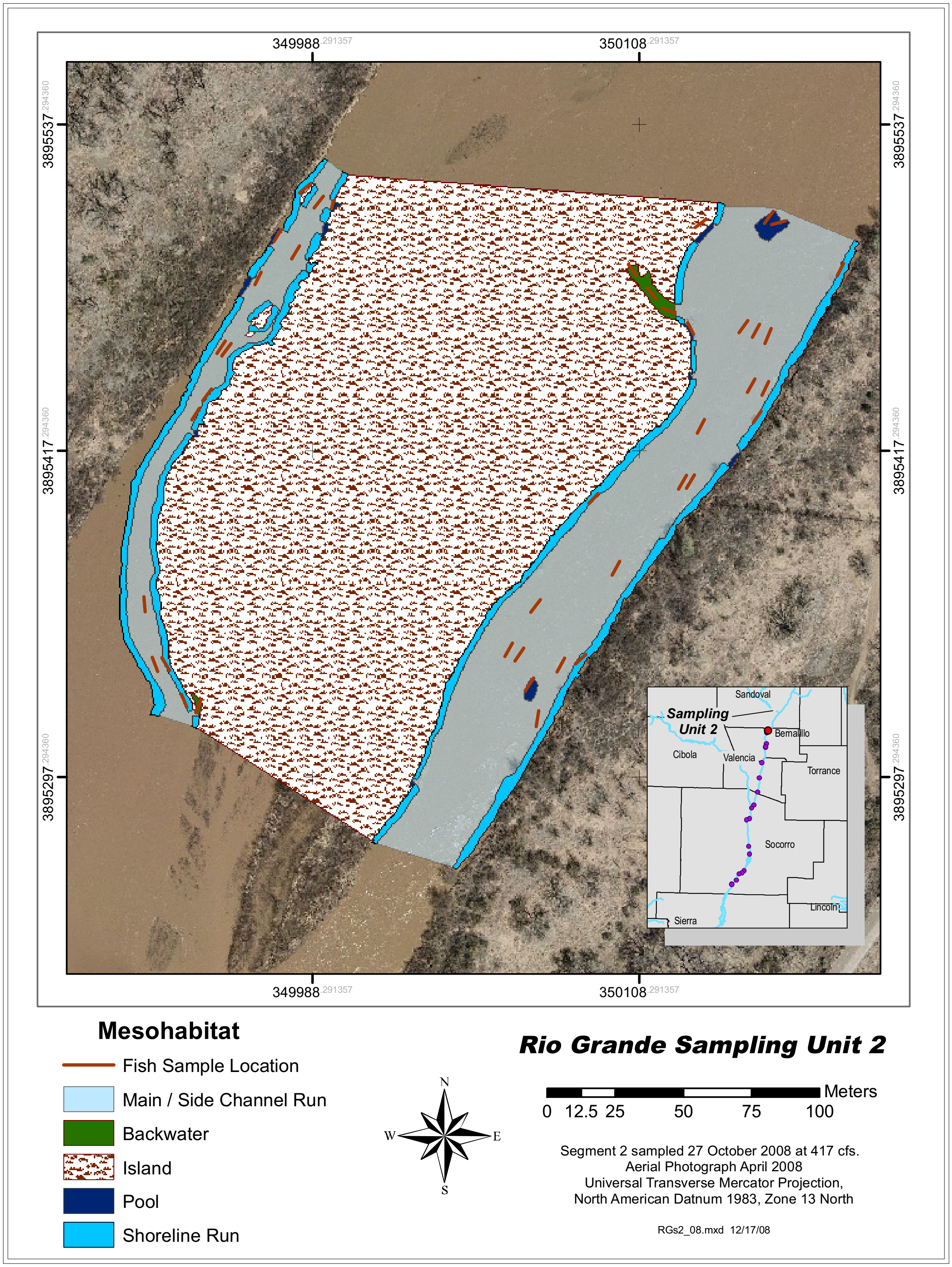

Figure B-1. Map of sampling unit #2 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

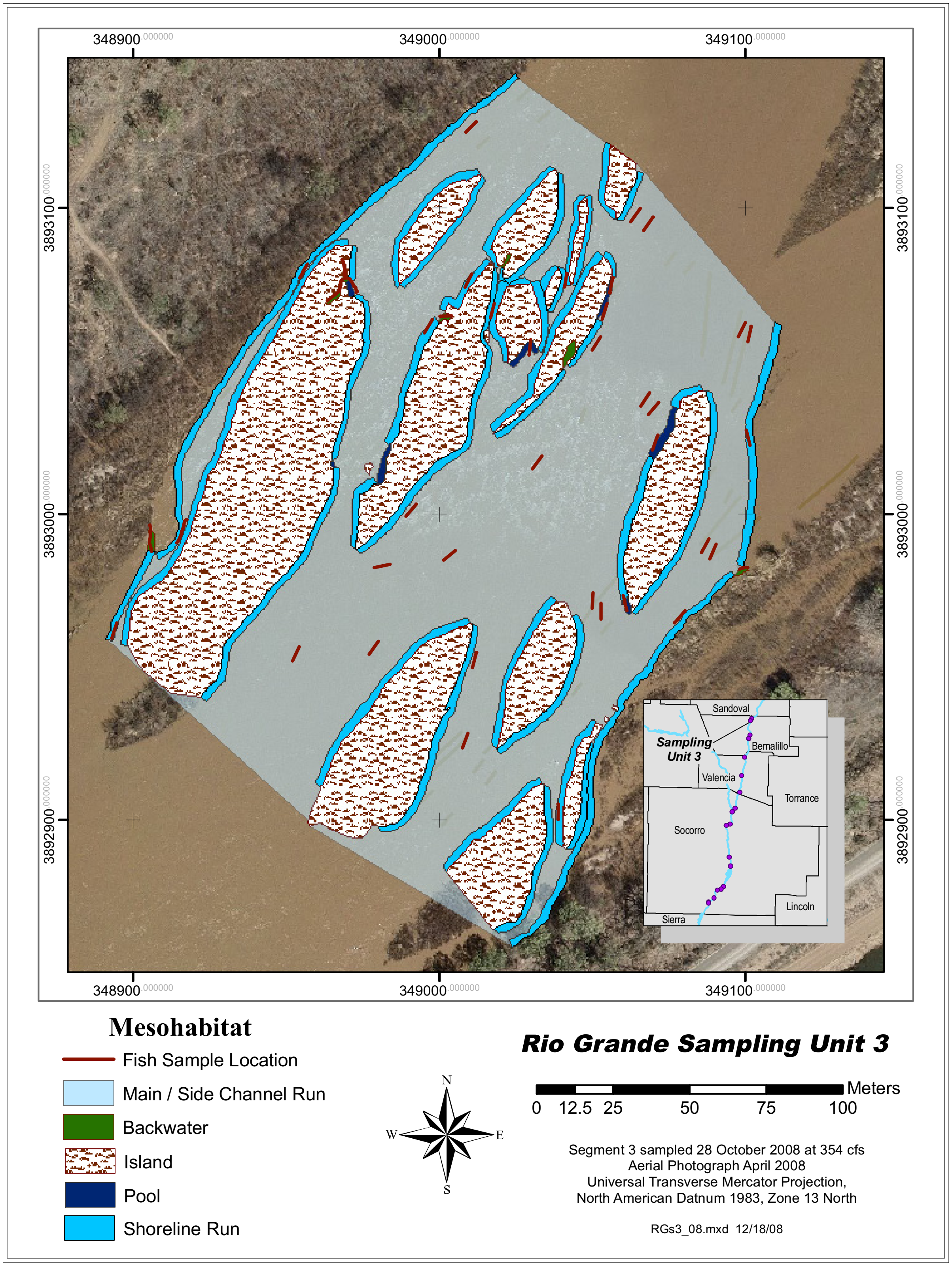

Figure B-2. Map of sampling unit #3 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

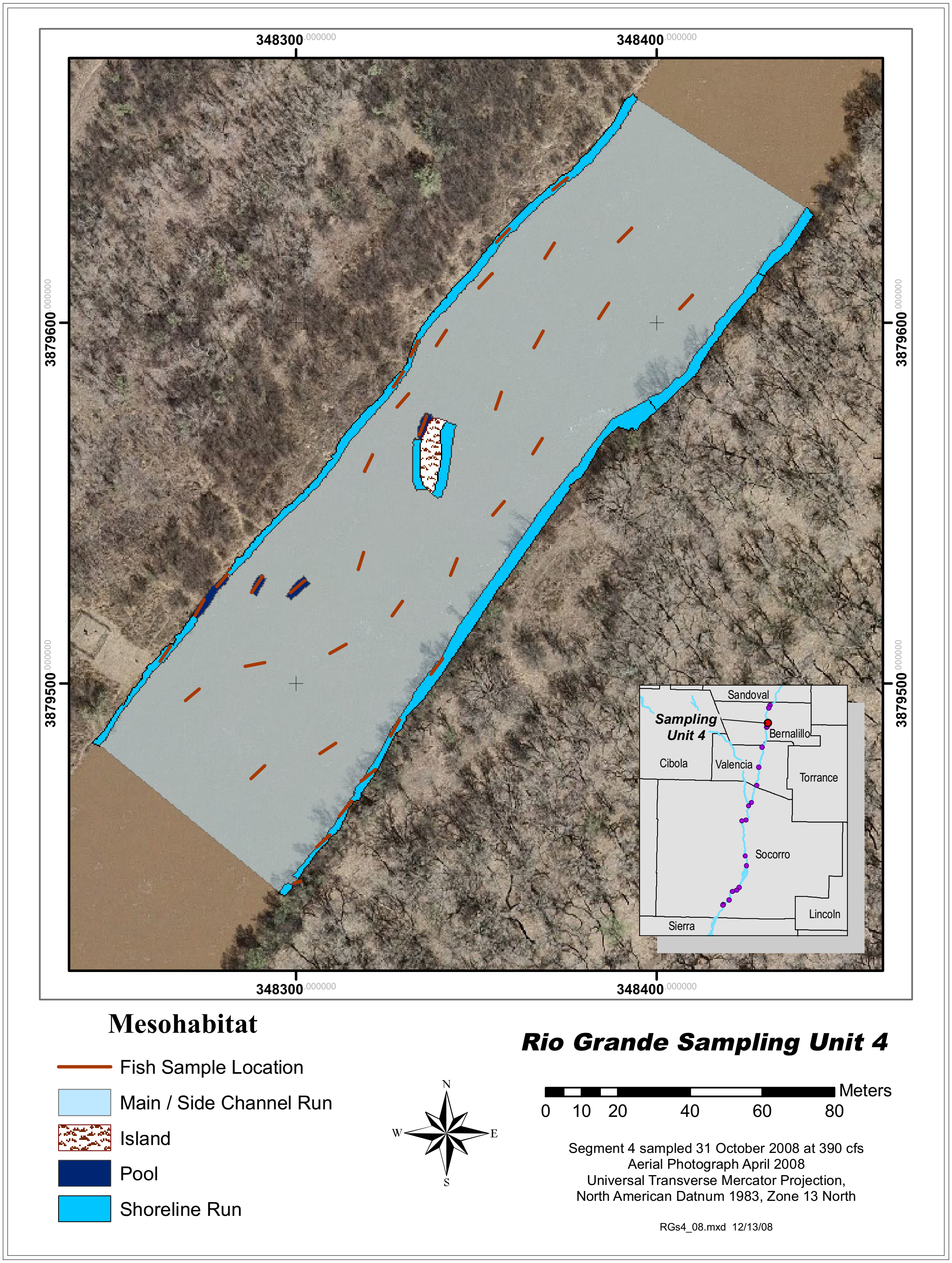

Figure B-3. Map of sampling unit #4 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

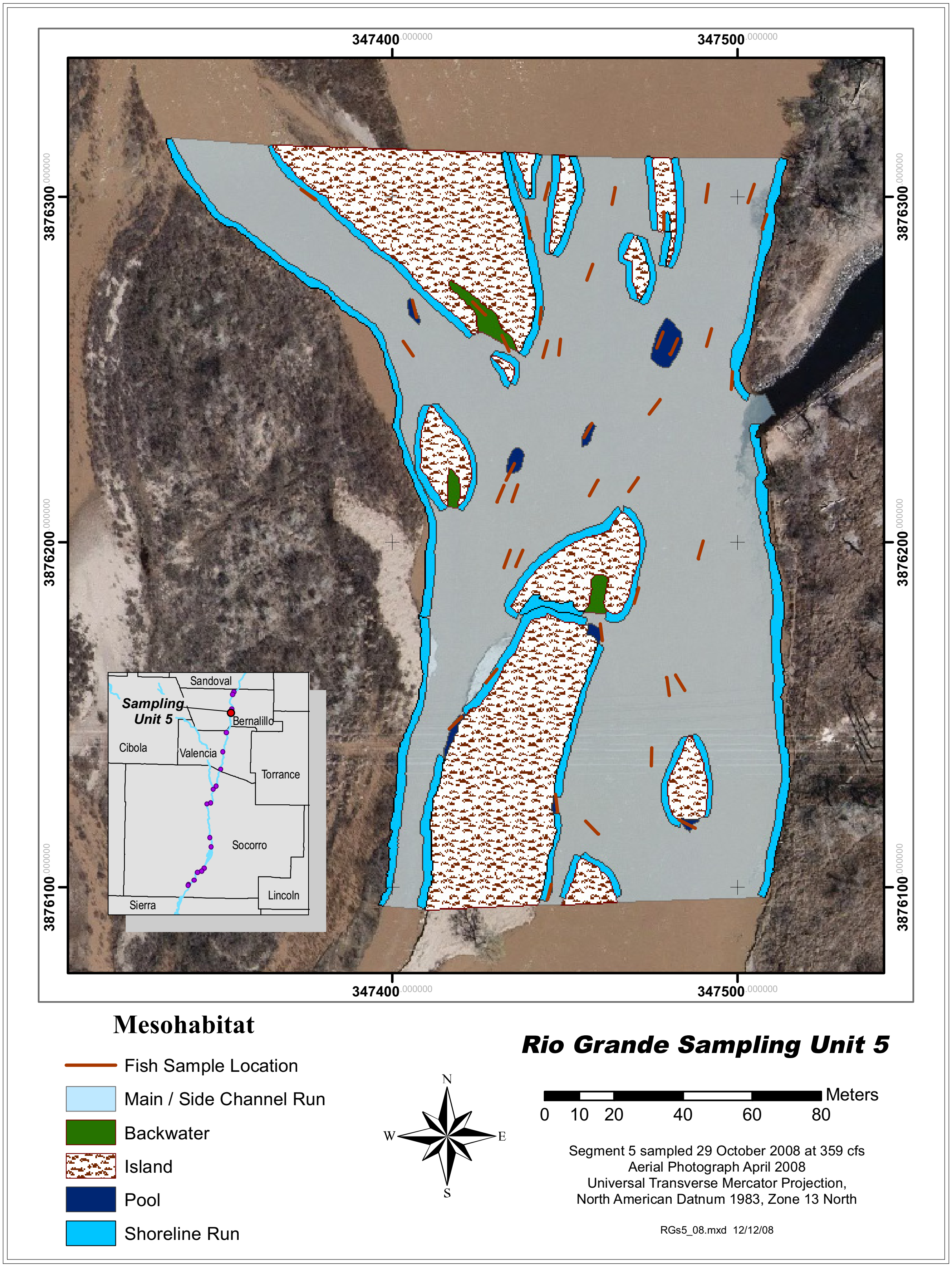

Figure B-4. Map of sampling unit #5 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

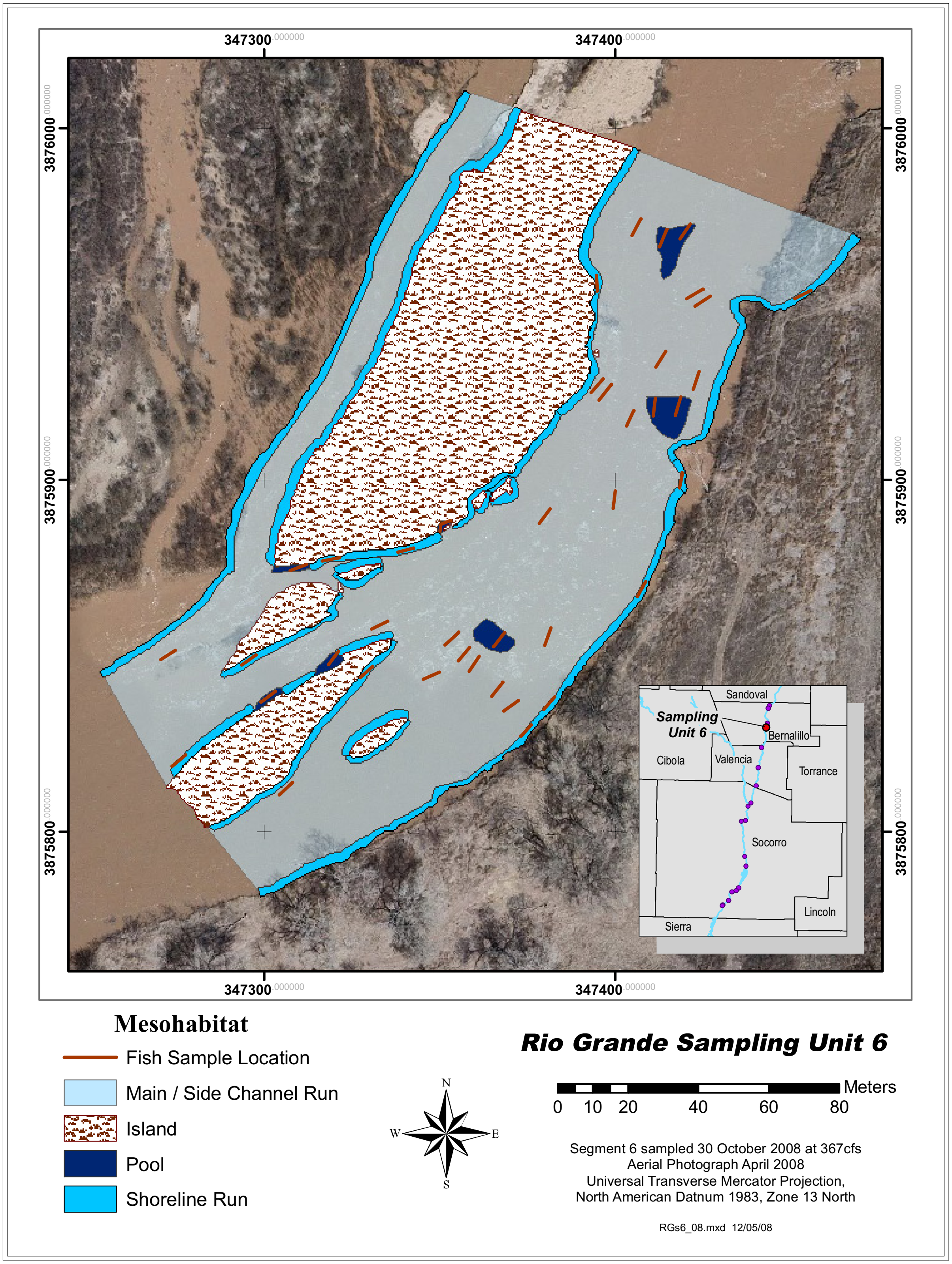

Figure B-5. Map of sampling unit #6 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

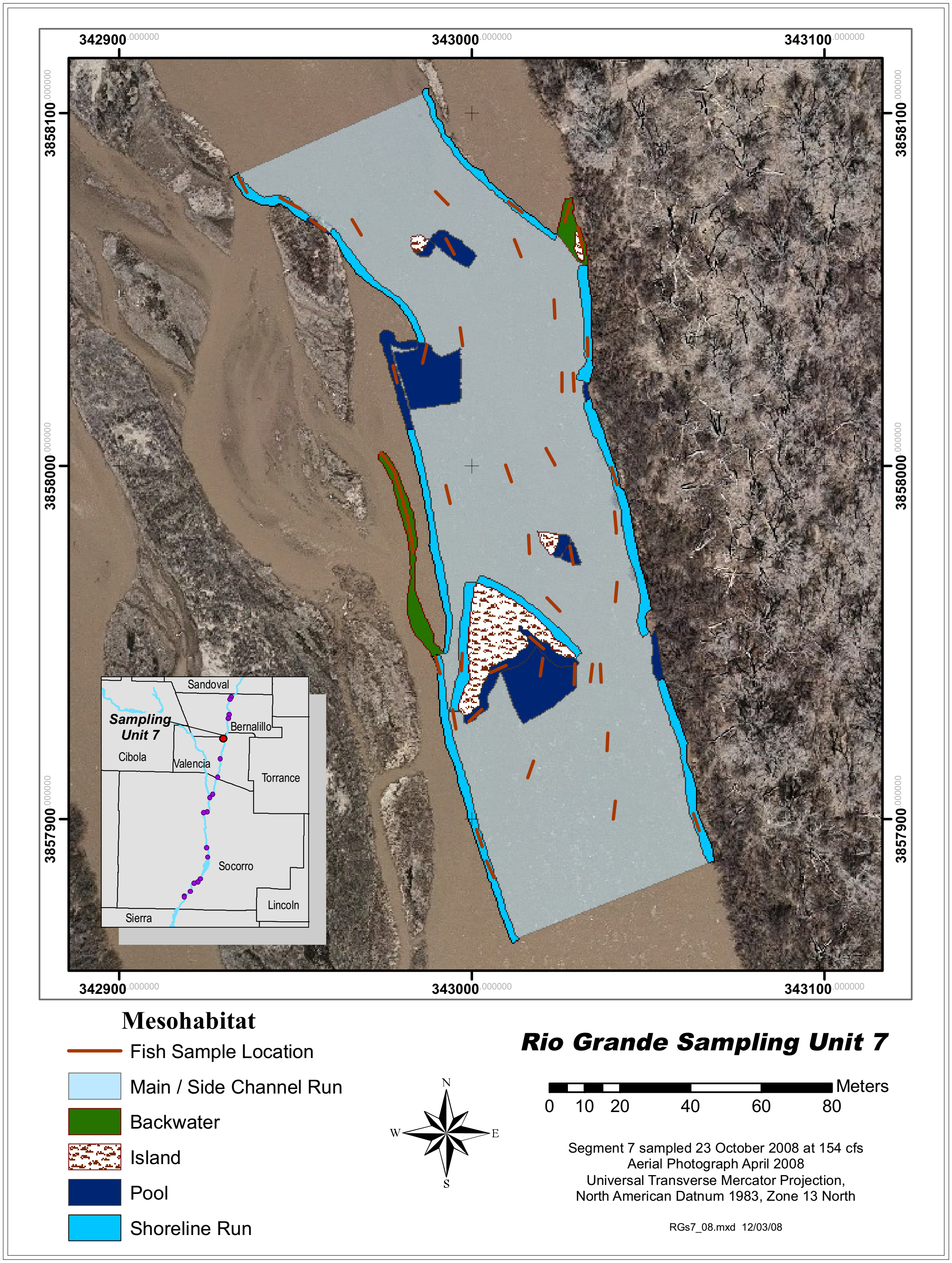

Figure B-6. Map of sampling unit #7 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

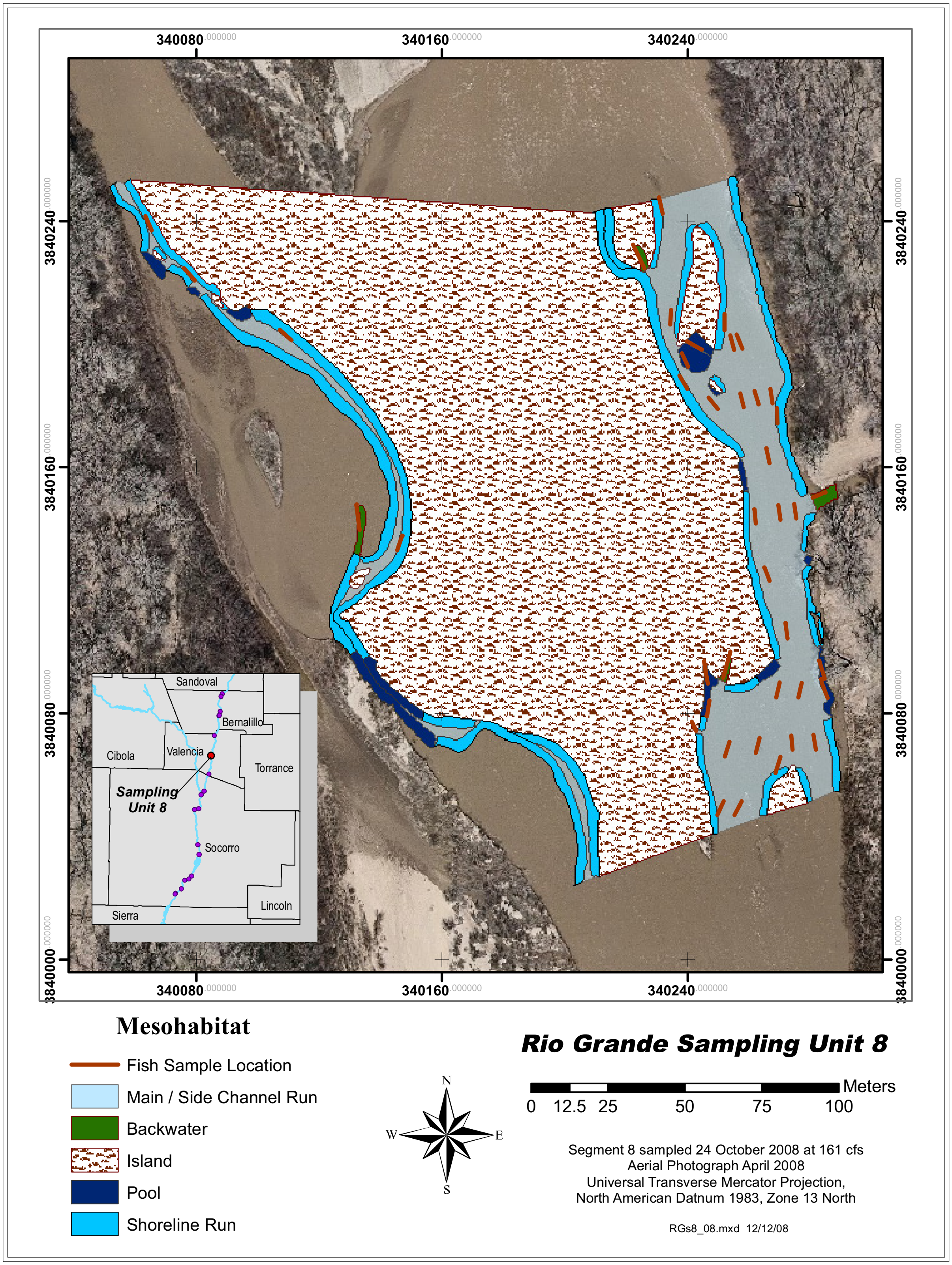

Figure B-7. Map of sampling unit #8 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

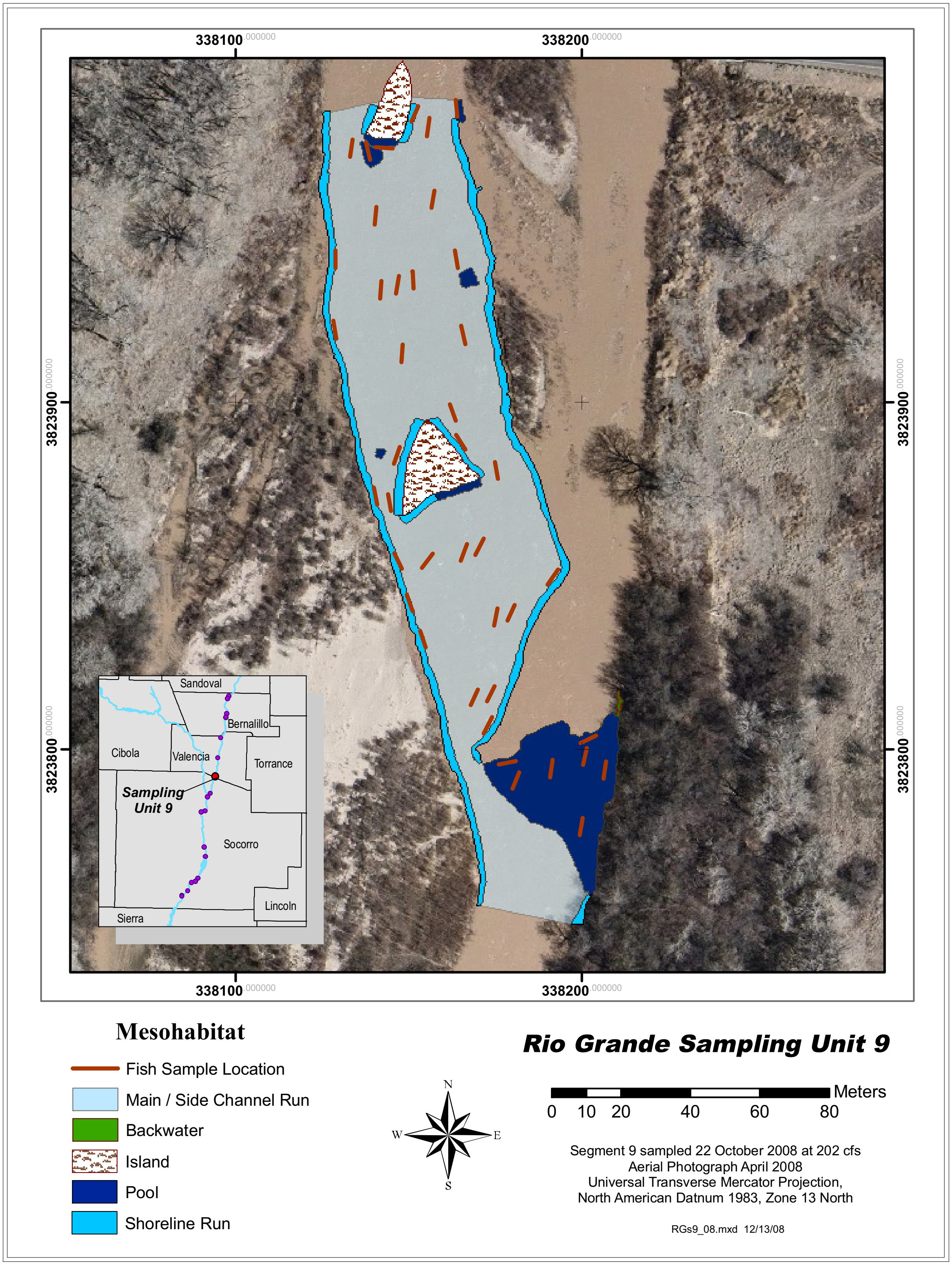

Figure B-8. Map of sampling unit #9 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

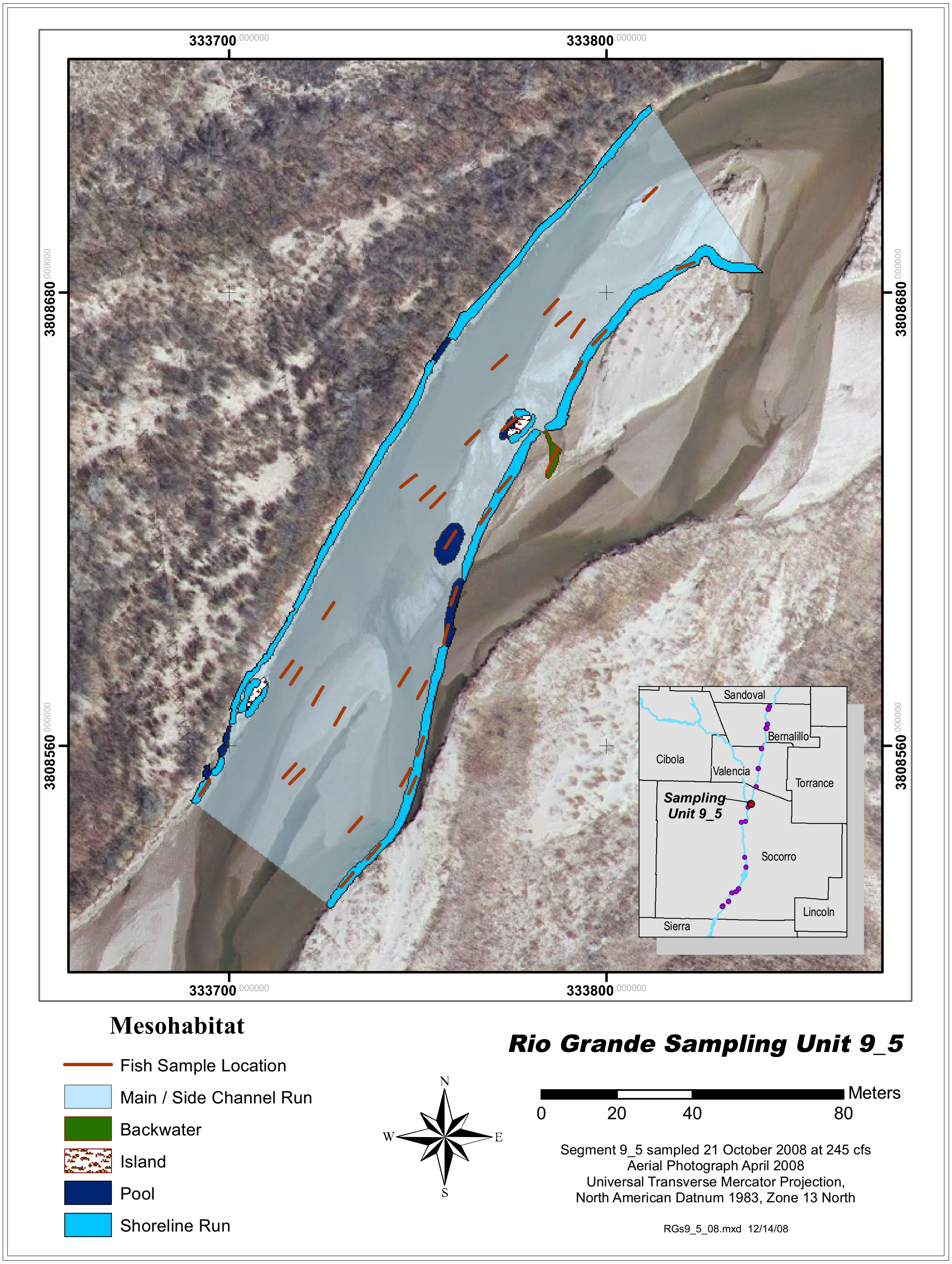

Figure B-9. Map of sampling unit #9_5 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

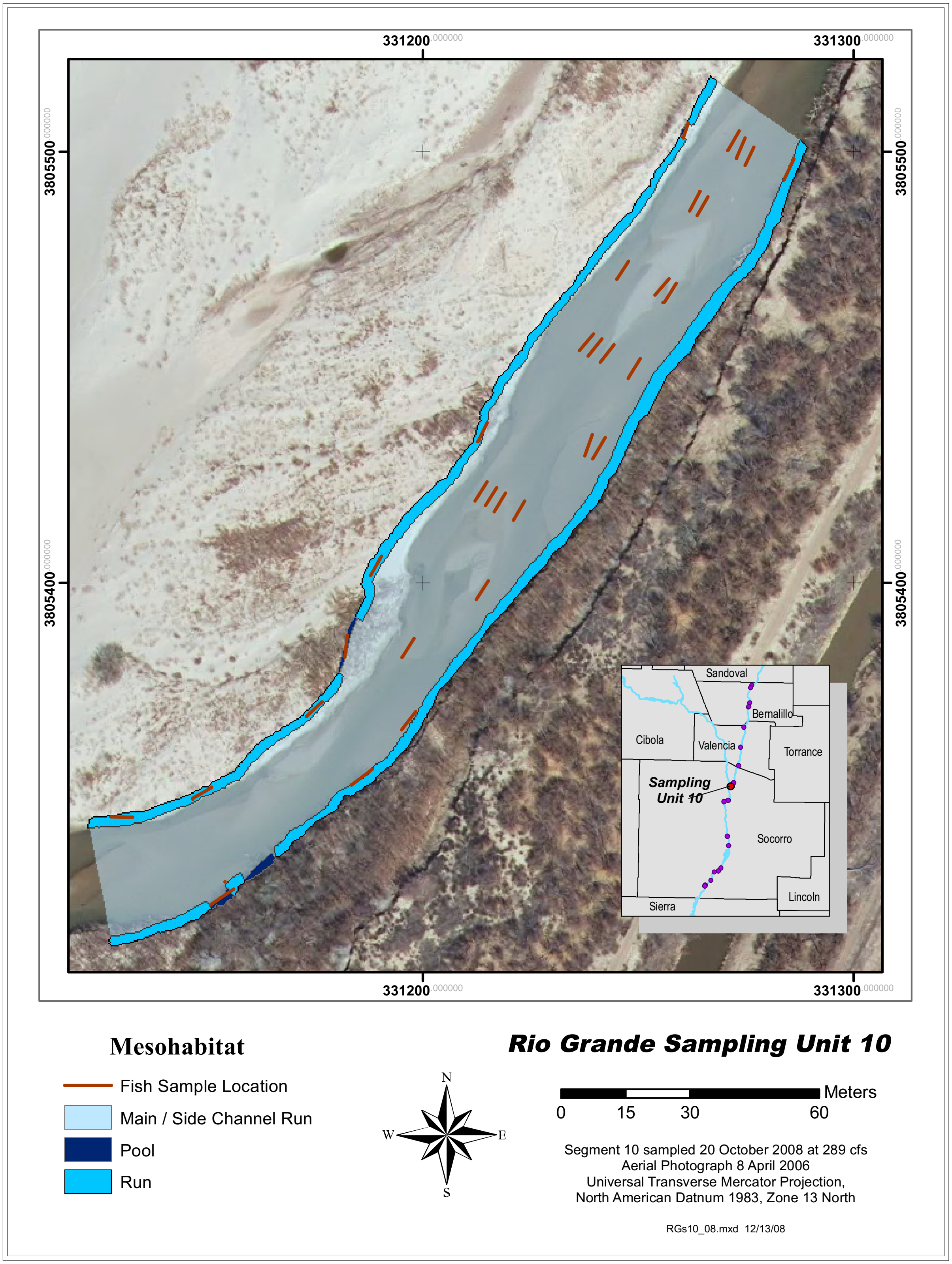

Figure B-10. Map of sampling unit #10 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

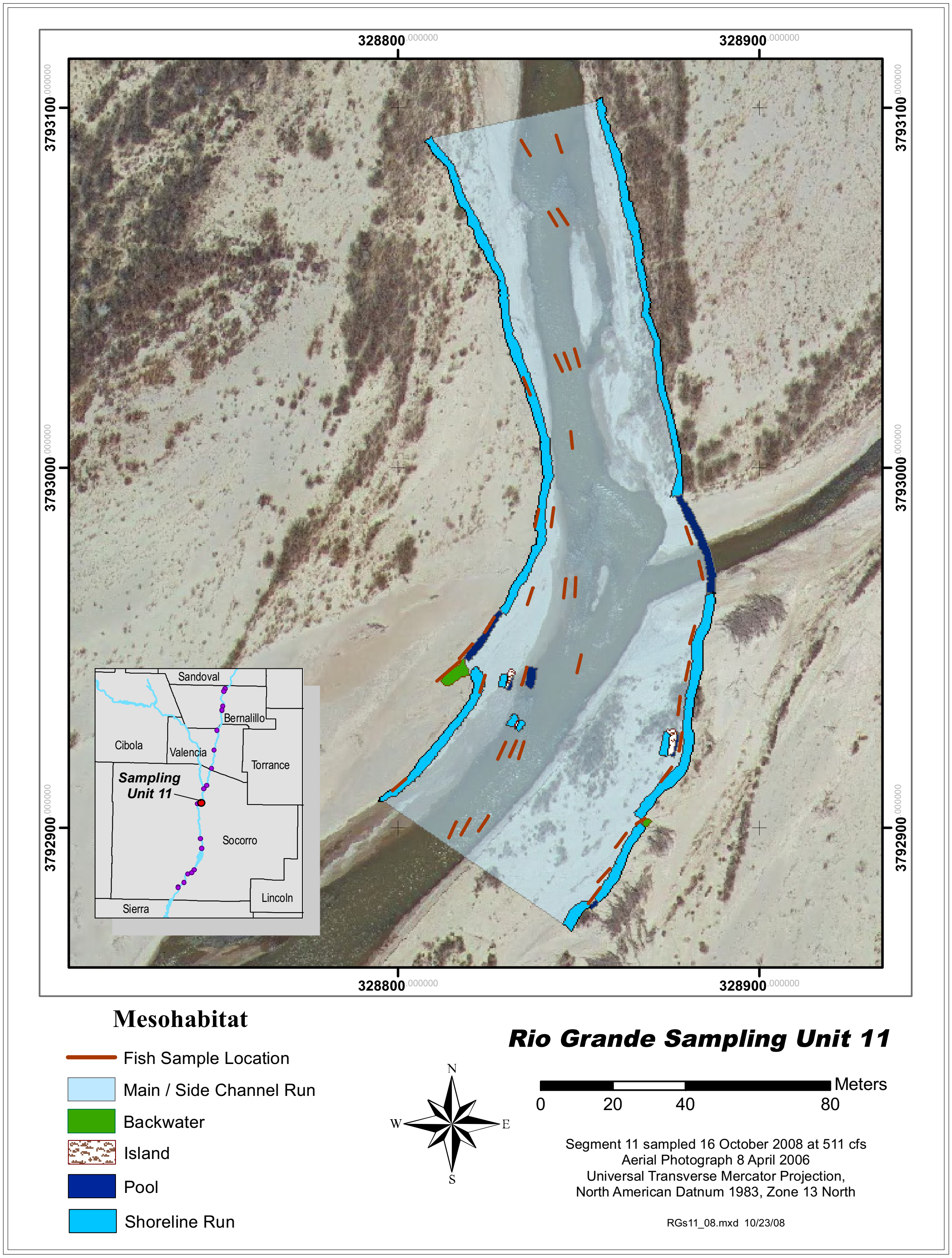

Figure B-11. Map of sampling unit #11 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

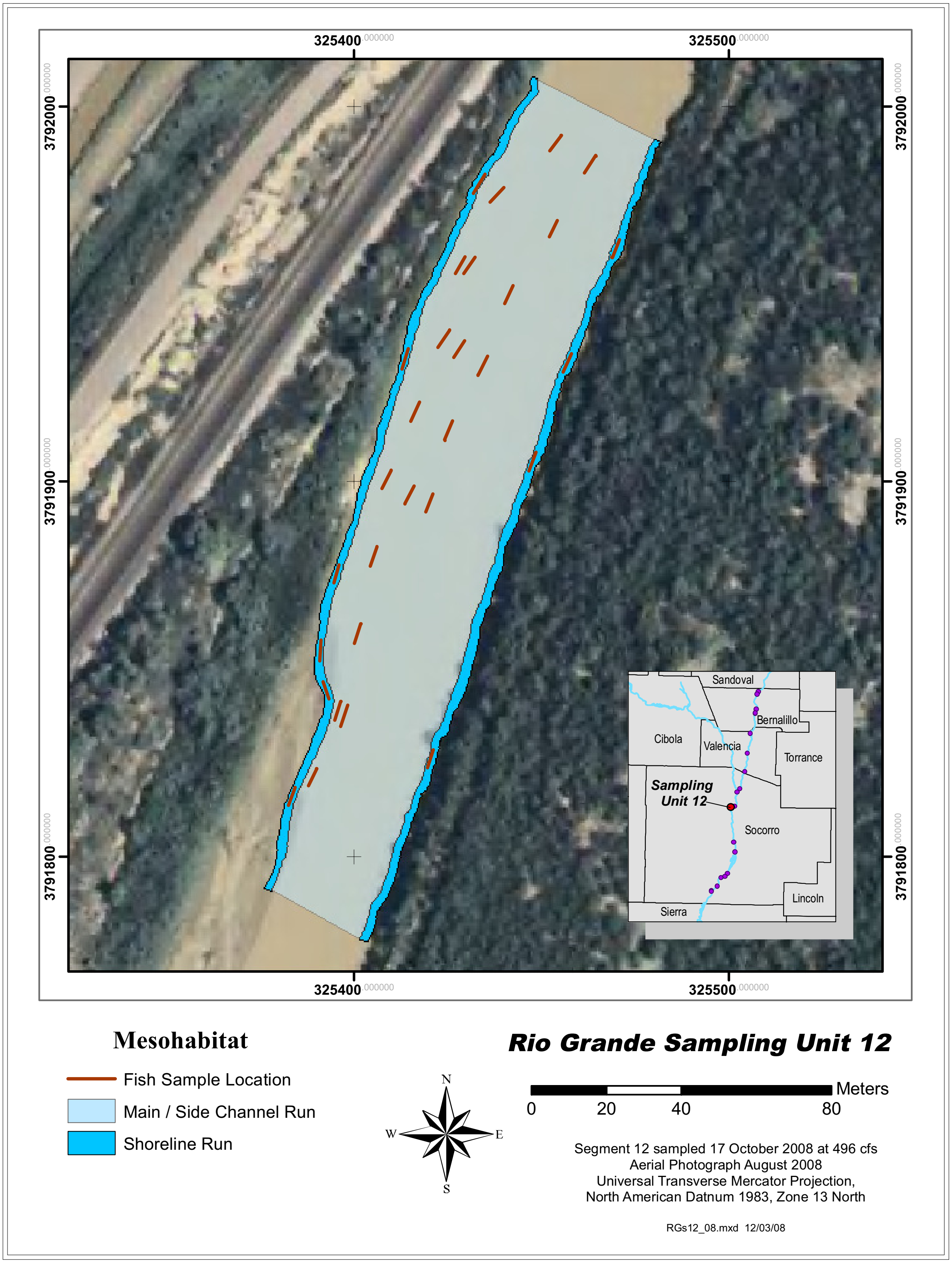

Figure B-12. Map of sampling unit #12 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

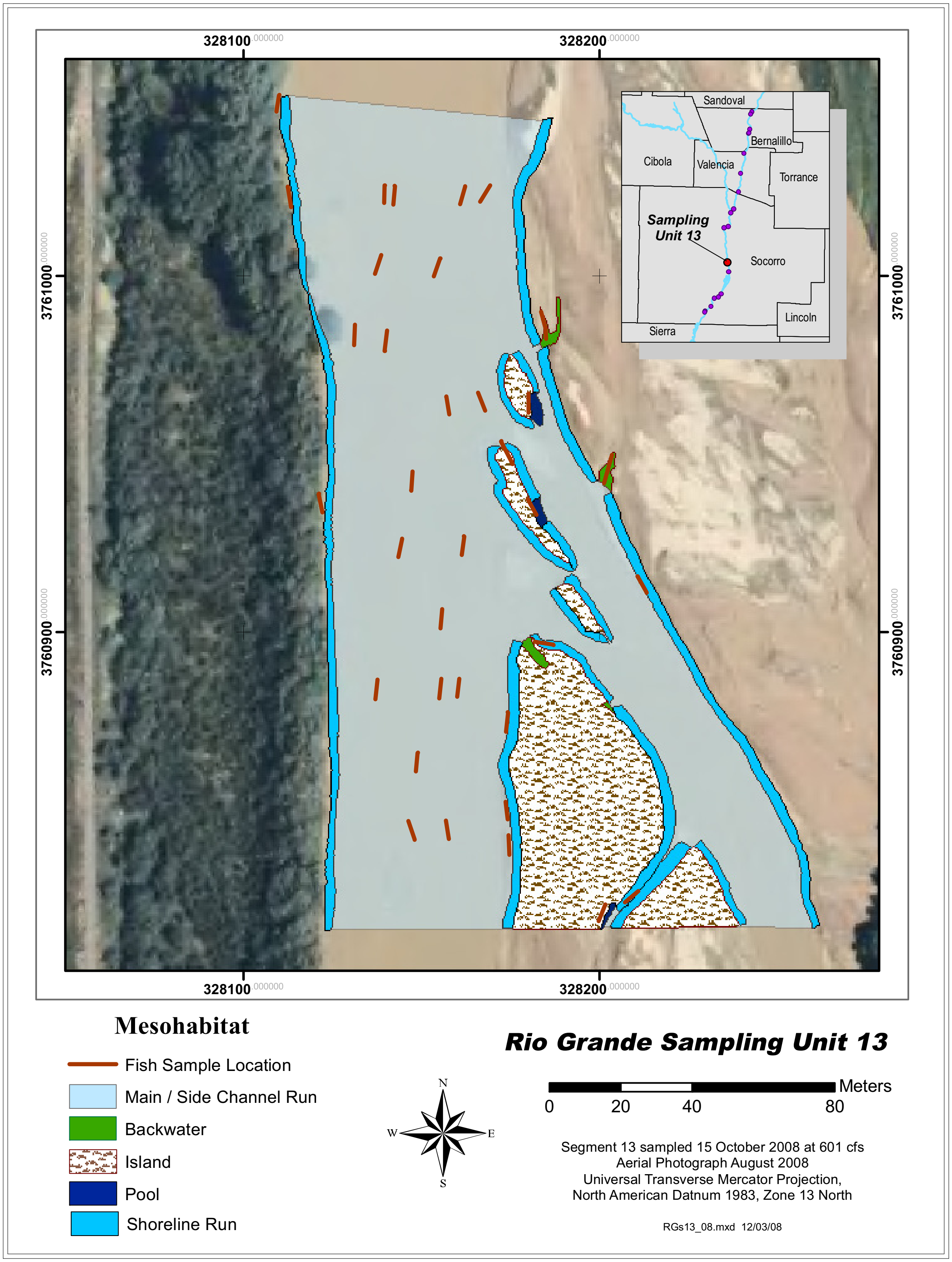

Figure B-13. Map of sampling unit #13 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

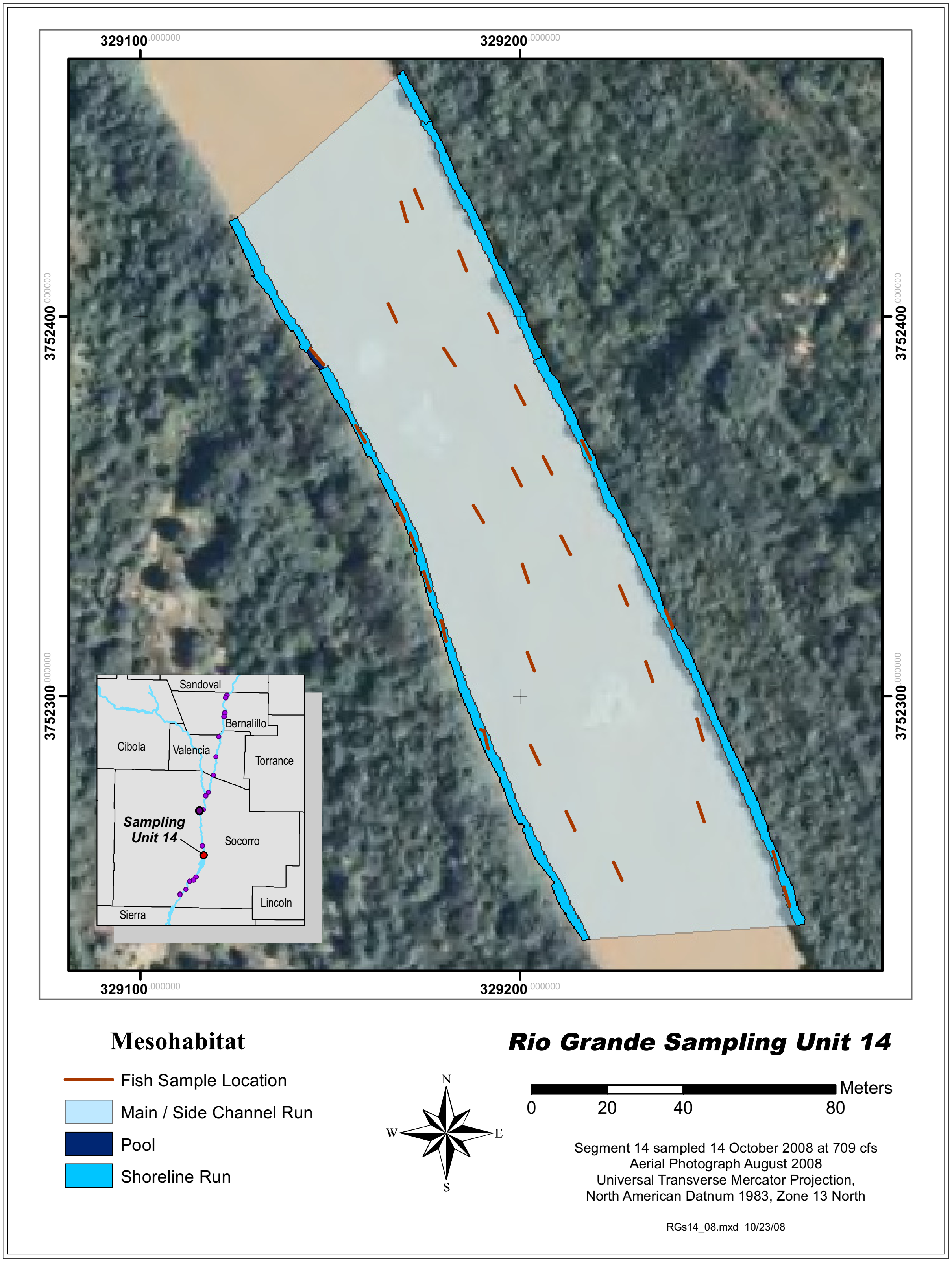

Figure B-14. Map of sampling unit #14 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

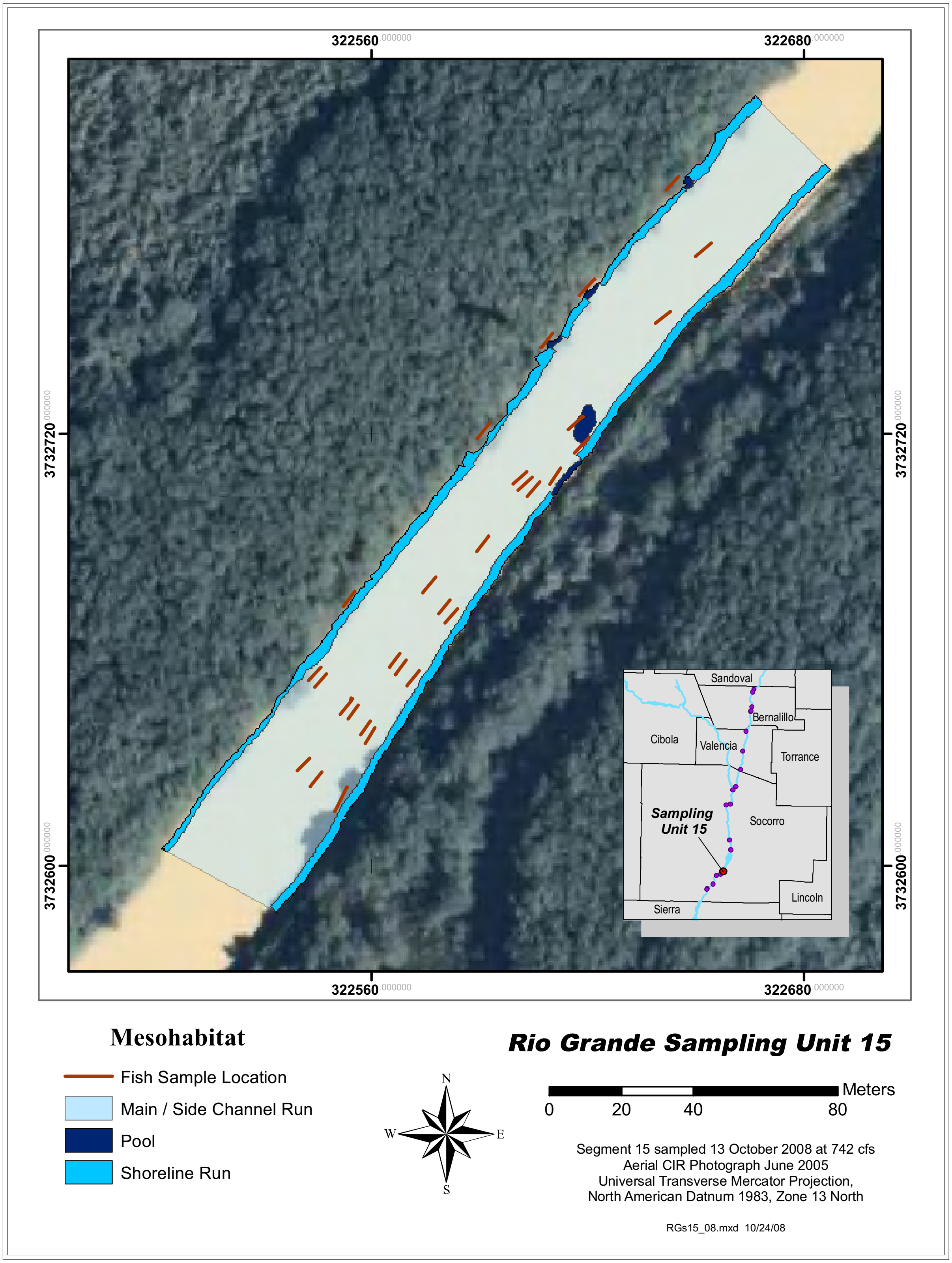

Figure B-15. Map of sampling unit #15 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

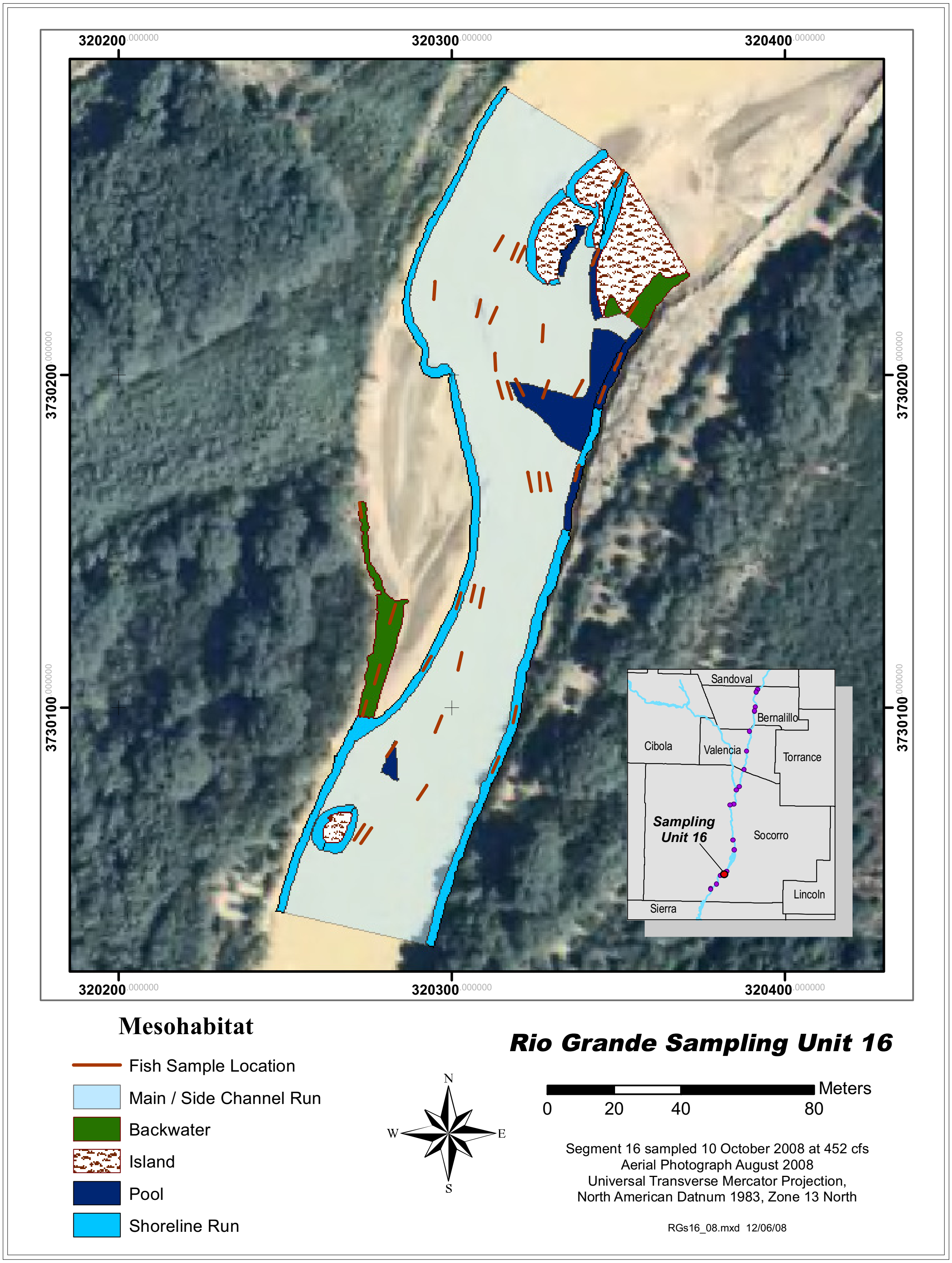

Figure B-16. Map of sampling unit #16 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

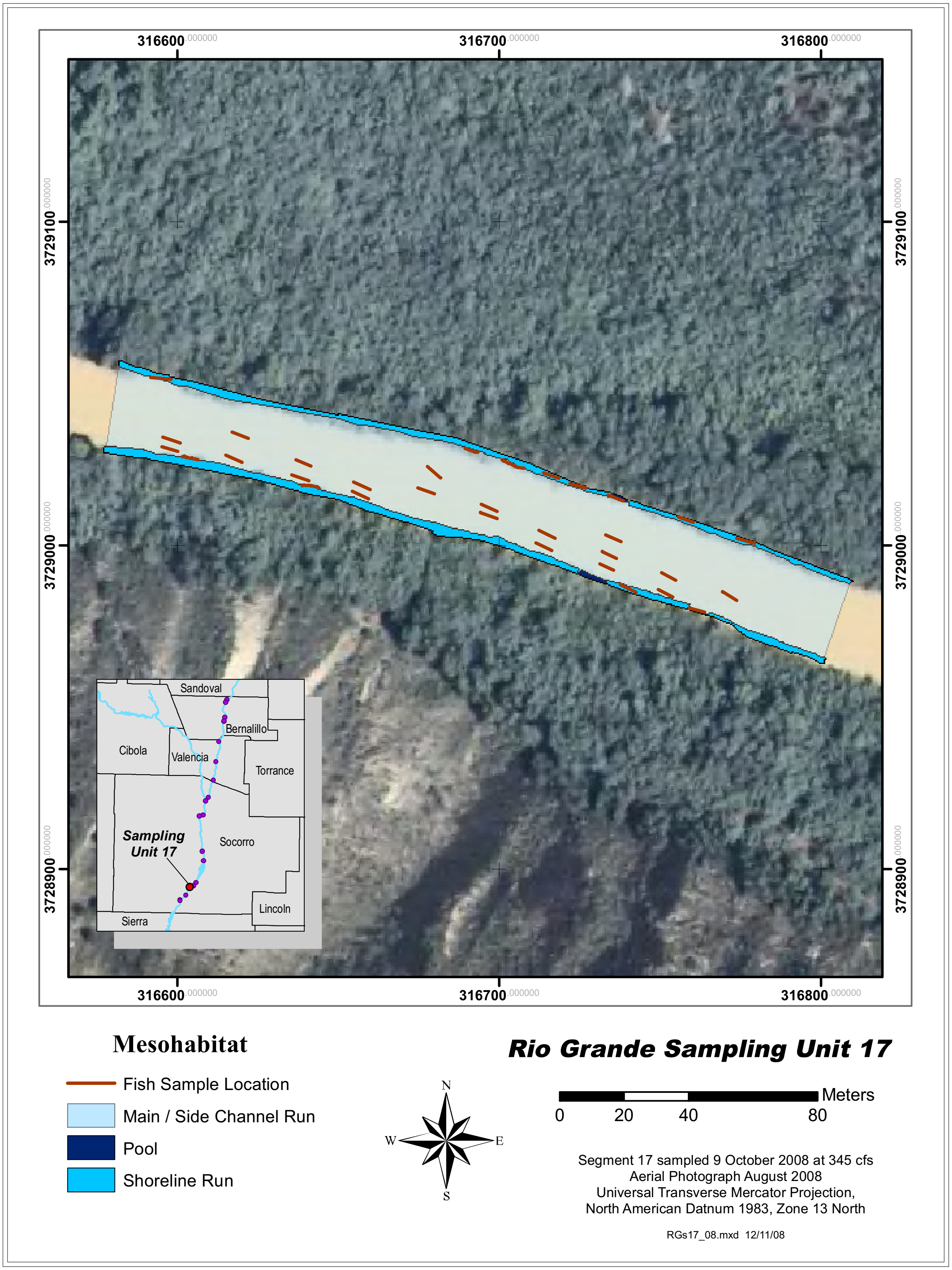

Figure B-17. Map of sampling unit #17 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

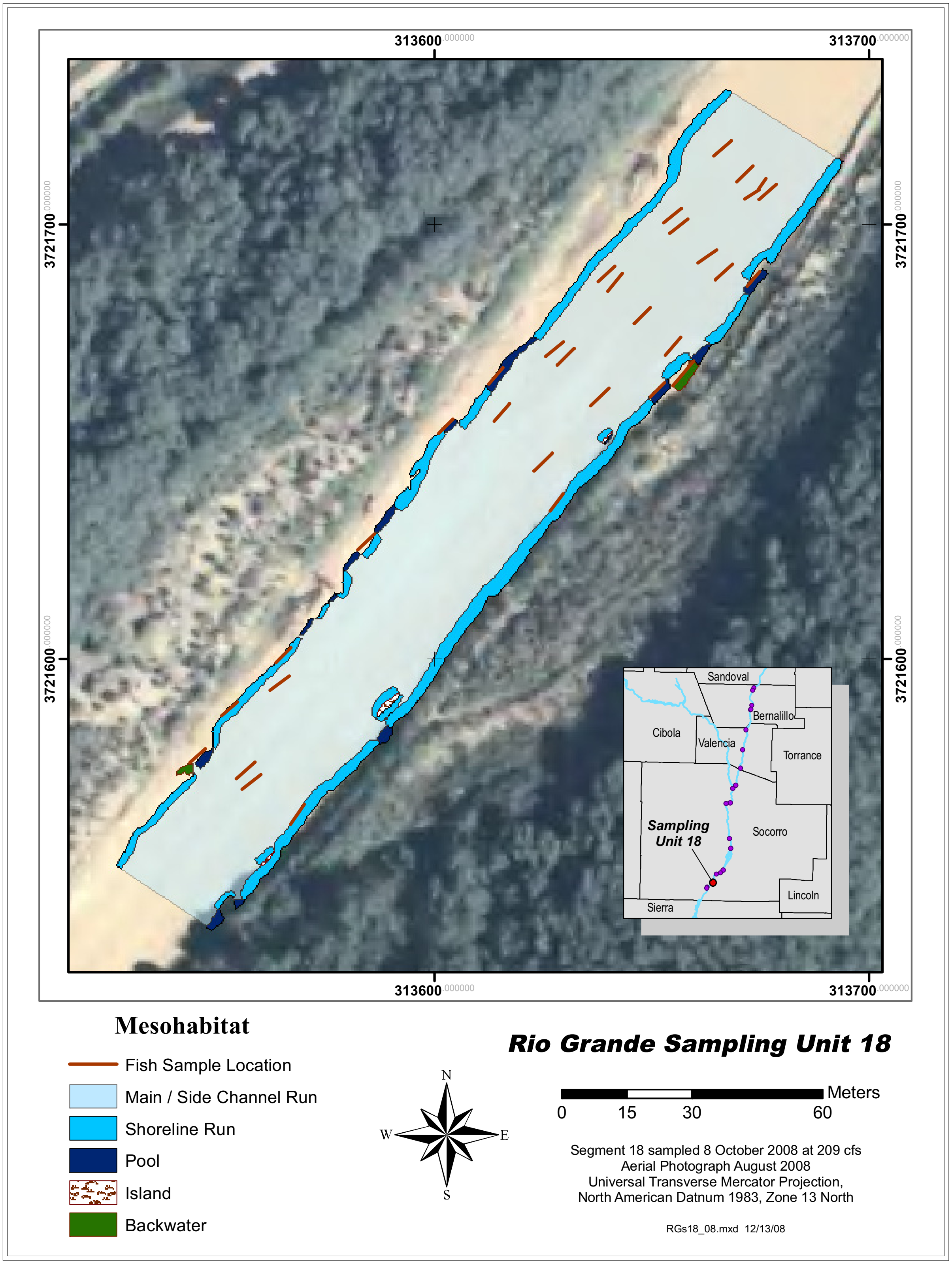

Figure B-18. Map of sampling unit #18 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

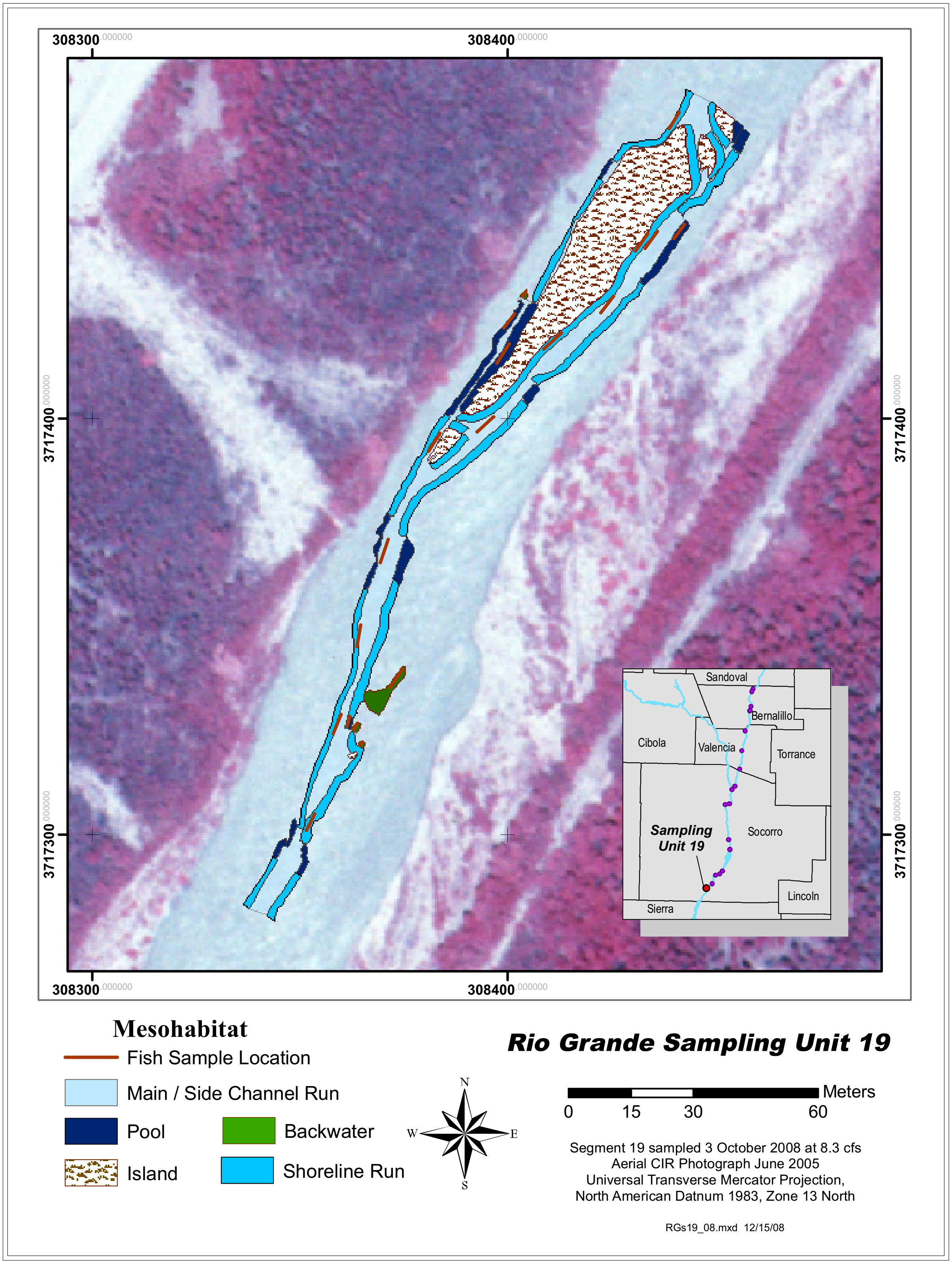

Figure B-19. Map of sampling unit #19 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

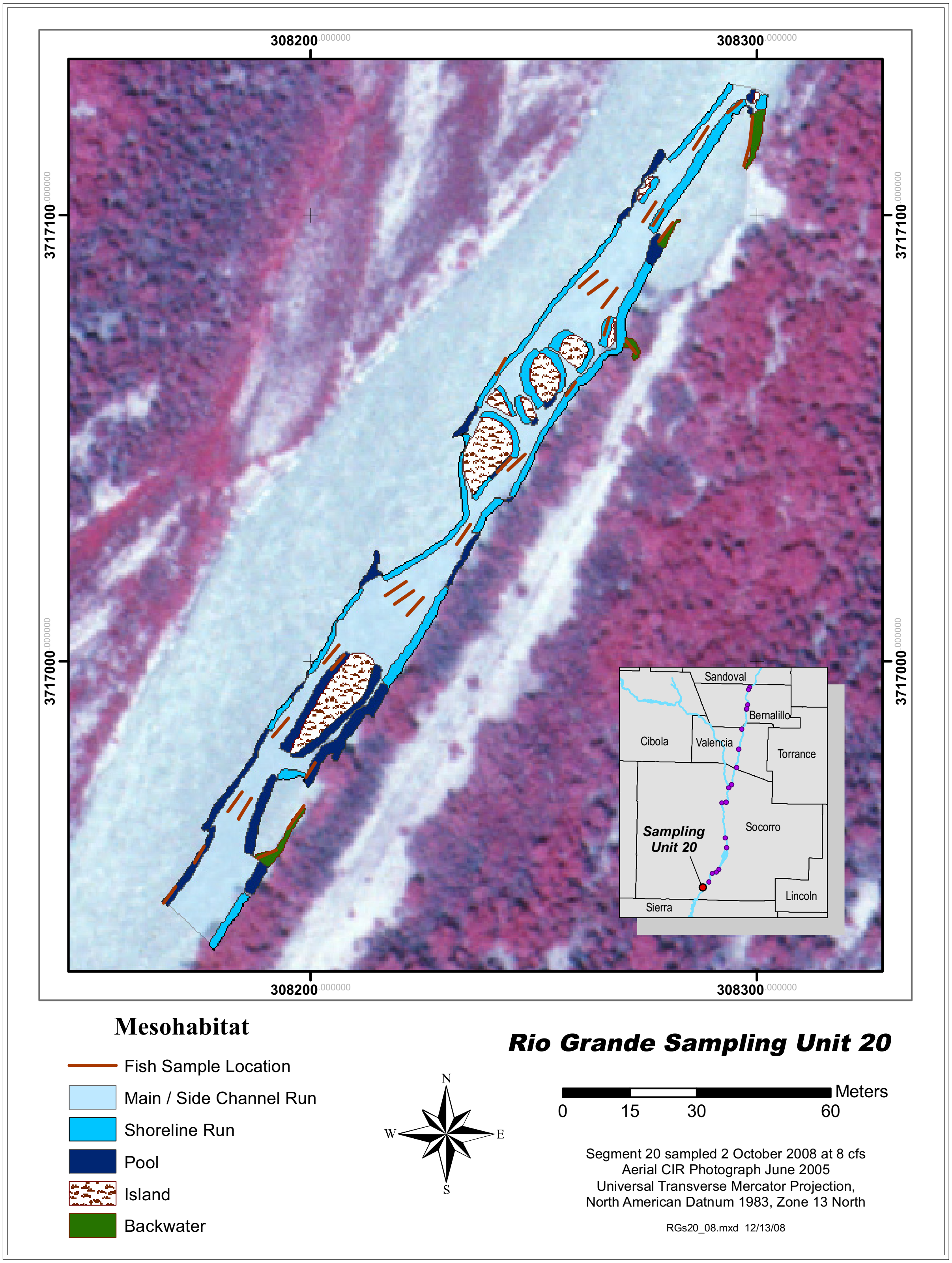

Figure B-20. Map of sampling unit #20 in the Middle Rio Grande, including all fish samples in run habitats and all available mesohabitats.

Appendix C.

Middle Rio Grande sampling units for the Population Monitoring Program

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

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

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

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

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

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

Appendix D.

Report D-1. Ichthyofaunal composition of the October 2008 Rio Grande silvery minnow Population Estimation Program sampling efforts

Rio Grande silvery minnow Population Estimation
October 2008

New Mexico: Bernalillo Co., Rio Grande Drainage

Rio Grande, ca. 0.4 miles upstream of Paseo del Norte Bridge crossing, Albuquerque. Sampling Unit: 2

27 October 2008 **RKD08-184** River Mile: 191.6

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

R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman, A.L. Barkalow, J.A. Bachus Effort: 328.4 sq. m

FAMILY		**N**
76	*Cyprinella lutrensis*	15
76	*Cyprinus carpio*	5
76	*Hybognathus amarus**	47
76	*Pimephales promelas*	6
76	*Platygobio gracilis*	7
76	*Rhinichthys cataractae*	1
81	*Catostomus commersoni*	9
93	*Ameiurus melas*	1
93	*Ictalurus punctatus*	39
212	*Gambusia affinis*	9
294	*Pomoxis annularis*	1
295	*Sander vitreus*	1

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

age-0: 26

age-1: 20

age-2: 1

Rio Grande silvery minnow Population Estimation
October 2008

New Mexico: Bernalillo Co., Rio Grande Drainage
Rio Grande, ca. 1.2 miles downstream of Paseo del Norte Bridge crossing, Albuquerque.
Sampling Unit: 3
River Mile: 189.9
28 October 2008 **RKD08-185**
UTM Easting: 348954 UTM Northing: 3892935 Zone: 13 Quad: Los Griegos
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman
Effort: 317.1 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	43
76	*Cyprinus carpio*	5
76	*Hybognathus amarus**	175
76	*Pimephales promelas*	24
76	*Platygobio gracilis*	45
76	*Rhinichthys cataractae*	5
81	*Catostomus commersoni*	1
93	*Ameiurus melas*	1
93	*Ictalurus punctatus*	40
212	*Gambusia affinis*	88

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

age-0: 157
age-1: 18
age-2:

Rio Grande silvery minnow Population Estimation
October 2008

New Mexico: Bernalillo Co., Rio Grande Drainage

Rio Grande, ca. 1.6 miles upstream of Rio Bravo Blvd. Bridge crossing, Albuquerque. Sampling Unit: 4

31 October 2008 **RKD08-188** River Mile: 179.9

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

R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, A.L. Barkalow Effort: 289.0 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	25
76	*Hybognathus amarus**	3
76	*Pimephales promelas*	11
76	*Platygobio gracilis*	2
81	*Carpiodes carpio*	1
81	*Catostomus commersoni*	1
93	*Ictalurus punctatus*	45
212	*Gambusia affinis*	5

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

age-0: 3

age-1:

age-2:

Rio Grande silvery minnow Population Estimation
October 2008

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
29 October 2008 **RKD08-186**
UTM Easting: 347381 UTM Northing: 3876106 Zone: 13 Quad: Albuquerque West
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman, A.L. Barkalow
Effort: 448.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	19
76	*Hybognathus amarus**	20
76	*Pimephales promelas*	24
76	*Platygobio gracilis*	17
76	*Rhinichthys cataractae*	3
81	*Catostomus commersoni*	1
93	*Ictalurus punctatus*	56
212	*Gambusia affinis*	7

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

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

Rio Grande silvery minnow Population Estimation
October 2008

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
30 October 2008 **RKD08-187**
UTM Easting: 347155 UTM Northing: 3875786 Zone: 13 Quad: Albuquerque West
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman Effort: 323.9 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	19
76	*Cyprinus carpio*	2
76	*Hybognathus amarus**	34
76	*Pimephales promelas*	153
76	*Platygobio gracilis*	18
81	*Carpiodes carpio*	1
81	*Catostomus commersoni*	1
93	*Ictalurus punctatus*	36
212	*Gambusia affinis*	32
294	*Lepomis macrochirus*	1

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

age-0: 32
age-1: 2
age-2:

Rio Grande silvery minnow Population Estimation
October 2008

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
23 October 2008 **RKD08-182**
UTM Easting: 342969 UTM Northing: 3857901 Zone: 13 Quad: Los Lunas
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman
Effort: 589.6 sq. m

FAMILY		**N**
76	*Cyprinella lutrensis*	135
76	*Cyprinus carpio*	5
76	*Hybognathus amarus**	440
76	*Pimephales promelas*	32
76	*Platygobio gracilis*	4
81	*Carpiodes carpio*	1
93	*Ameiurus natalis*	3
93	*Ictalurus punctatus*	26
212	*Gambusia affinis*	38
294	*Lepomis macrochirus*	1

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

age-0: 415
age-1: 25
age-2:

Rio Grande silvery minnow Population Estimation
October 2008

New Mexico: Valencia Co., Rio Grande Drainage
Rio Grande, ca. 2.9 miles upstream of NM 6 bridge crossing, Belen. Sampling Unit: 8
24 October 2008 **RKD08-183** River Mile: 152.4
UTM Easting: 340193 UTM Northing: 3840028 Zone: 13 Quad: Tome
W.H. Brandenburg, C.C. McBride, B.L. Christman, A.L. Barkalow Effort: 540.5 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	57
76	*Hybognathus amarus**	76
76	*Pimephales promelas*	28
76	*Platygobio gracilis*	1
81	*Carpiodes carpio*	3
93	*Ictalurus punctatus*	11
212	*Gambusia affinis*	47
294	*Pomoxis annularis*	1

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

age-0: 65
age-1: 10
age-2: 1

New Mexico: Valencia Co., Rio Grande Drainage
Rio Grande, ca. 0.1 miles downstream of NM State Highway 346 Bridge crossing, Jarales. Sampling Unit: 9
River Mile: 140.6
22 October 2008 **RKD08-181**
UTM Easting: 338117 UTM Northing: 3823765 Zone: 13 Quad: Veguita
M.A. Farrington, W.H. Brandenburg, C.C. McBride, B.L. Christman, A.L. Barkalow Effort: 436.9 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	66
76	*Hybognathus amarus**	26
76	*Pimephales promelas*	4
81	*Carpiodes carpio*	1
93	*Ameiurus melas*	2
93	*Ictalurus punctatus*	9
212	*Gambusia affinis*	15

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

age-0: 21
age-1: 3
age-2: 2

Rio Grande silvery minnow Population Estimation
October 2008

New Mexico: Socorro Co., Rio Grande Drainage
Rio Grande, ca. 1.0 miles downstream of U.S. Highway 60 bridge crossing, Bernardo. Sampling Unit: 9.5
21 October 2008 **RKD08-180** River Mile: 130.0
UTM Easting: 333822 UTM Northing: 3808533 Zone: 13 Quad: Abeytas
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman Effort: 407.3 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	178
76	*Hybognathus amarus**	41
76	*Pimephales promelas*	19
76	*Platygobio gracilis*	4
93	*Ameiurus natalis*	1
93	*Ictalurus punctatus*	49
212	*Gambusia affinis*	10

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

age-0: 40
age-1: 1
age-2:

New Mexico: Socorro Co., Rio Grande Drainage
Rio Grande, ca. 3.7 miles downstream of US Highway 60 Bridge crossing, Bernardo. Sampling Unit: 10
20 October 2008 **RKD08-179** River Mile: 126.9
UTM Easting: 330997 UTM Northing: 3805306 Zone: 13 Quad: Abeytas
R.K. Dudley, M.A. Farrington, C.C. Mcbride, B.L. Christman, A.L. Barkalow Effort: 316.5 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	102
76	*Cyprinus carpio*	2
76	*Hybognathus amarus**	2
76	*Platygobio gracilis*	1
93	*Ameiurus natalis*	1
93	*Ictalurus punctatus*	40
212	*Gambusia affinis*	6

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

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

Rio Grande silvery minnow Population Estimation
October 2008

New Mexico: Socorro Co., Rio Grande Drainage
Rio Grande, ca. 1.7 miles upstream of San Acacia Diversion Dam, San Acacia. Sampling Unit: 11
16 October 2008 **RKD08-177** River Mile: 117.9
UTM Easting: 328767 UTM Northing: 3792883 Zone: 13 Quad: La Joya
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman, A.L. Barkalow Effort: 453.0 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	8
76	*Hybognathus amarus**	100
76	*Pimephales promelas*	15
76	*Platygobio gracilis*	55
93	*Ictalurus punctatus*	41
212	*Gambusia affinis*	25

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

age-0: 97
age-1: 2
age-2: 1

New Mexico: Socorro Co., Rio Grande Drainage
Rio Grande, ca. 0.8 miles downstream of San Acacia Diversion Dam, San Acacia. Sampling Unit: 12
17 October 2008 **RKD08-178** River Mile: 115.4
UTM Easting: 325363 UTM Northing: 3791796 Zone: 13 Quad: San Acacia
M.A. Farrington, W.H. Brandenburg, C.C. McBride, B.L. Christman, A.L. Barkalow Effort: 325.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	11
76	*Hybognathus amarus**	18
76	*Pimephales promelas*	8
76	*Platygobio gracilis*	41
93	*Ameiurus natalis*	1
93	*Ictalurus punctatus*	43
212	*Gambusia affinis*	10

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

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

Rio Grande silvery minnow Population Estimation
October 2008

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
15 October 2008 **RKD08-176** River Mile: 91.6
UTM Easting: 328199 UTM Northing: 3760830 Zone: 13 Quad: San Antonio
R.K. Dudley, M.A. Farrington, C.C. Mcbride, B.L. Christman, A.L. Barkalow Effort: 456.6 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	25
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	167
76	*Pimephales promelas*	4
76	*Platygobio gracilis*	23
93	*Ameiurus natalis*	1
93	*Ictalurus punctatus*	17
212	*Gambusia affinis*	31

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

age-0: 167
age-1:
age-2:

Rio Grande silvery minnow Population Estimation
October 2008

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
14 October 2008 **RKD08-175**
UTM Easting: 329256 UTM Northing: 3752209 Zone: 13 Quad: San Antonio
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman
Effort: 316.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	1
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	22
76	*Platygobio gracilis*	15
81	*Carpiodes carpio*	1
93	*Ameiurus natalis*	2
93	*Ictalurus punctatus*	121
212	*Gambusia affinis*	1

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

age-0: 21
age-1: 1
age-2:

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
13 October 2008 **RKD08-174**
UTM Easting: 322489 UTM Northing: 3732572 Zone: 13 Quad: San Marcial
R.K.Dudley, W.H. Brandenburg, C.C. McBride, B.L. Christman, A.L. Barkalow
Effort: 291.5 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	70
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	10
93	*Ictalurus punctatus*	38
212	*Gambusia affinis*	13

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

age-0: 10
age-1:
age-2:

Rio Grande silvery minnow Population Estimation
October 2008

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
10 October 2008 **RKD08-173**
UTM Easting: 320044 UTM Northing: 3730043 Zone: 13 Quad: San Marcial
R.K. Dudley, M.A. Farrington, C.C. Mcbride, B.L. Christman, A.L. Barkalow Effort: 422.7 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	20
76	*Cyprinus carpio*	3
76	*Hybognathus amarus**	106
76	*Platygobio gracilis*	2
93	*Ictalurus punctatus*	7

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

age-0: 106
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
09 October 2008 **RKD08-172**
UTM Easting: 316840 UTM Northing: 3728978 Zone: 13 Quad: San Marcial
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride, B.L. Christman Effort: 327.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	48
76	*Hybognathus amarus**	161
76	*Platygobio gracilis*	3
93	*Ictalurus punctatus*	15
93	*Pylodictis olivaris*	1

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

age-0: 161
age-1:
age-2:

Rio Grande silvery minnow Population Estimation
October 2008

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
08 October 2008 **RKD08-171**
UTM Easting: 313417 UTM Northing: 3721520 Zone: 13 Quad: Paraje Well
R.K.Dudley, W.H. Brandenburg, C.C. McBride, B.L. Christman, A.L. Barkalow Effort: 317.4 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	8
76	*Hybognathus amarus**	55
76	*Platygobio gracilis*	5
81	*Carpiodes carpio*	1
93	*Ictalurus punctatus*	27

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

age-0: 55
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
03 October 2008 **RKD08-170**
UTM Easting: 308328 UTM Northing: 3717266 Zone: 13 Quad: Paraje Well
R.K.Dudley, W.H. Brandenburg, M.A. Farrington, C.C. McBride Effort: 156.2 sq. m

FAMILY		N
76	*Cyprinella lutrensis*	24
76	*Hybognathus amarus**	36
76	*Platygobio gracilis*	7
93	*Ictalurus punctatus*	2
93	*Pylodictis olivaris*	6
212	*Gambusia affinis*	1

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

age-0: 36
age-1:
age-2:

Rio Grande silvery minnow Population Estimation
October 2008

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
02 October 2008 **RKD08-169**
UTM Easting: 308118 UTM Northing: 3716920 Zone: 13 Quad: Paraje Well
R.K. Dudley, W.H. Brandenburg, M.A. Farrington, C.C. Mcbride, B.L. Christman
Effort: 275.4 sq. m

FAMILY		N
69	*Dorosoma cepedianum*	8
76	*Cyprinella lutrensis*	17
76	*Cyprinus carpio*	1
76	*Hybognathus amarus**	36
76	*Platygobio gracilis*	1
93	*Ictalurus punctatus*	4
93	*Pylodictis olivaris*	6
212	*Gambusia affinis*	6
283	*Morone chrysops*	1

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

age-0: 36
age-1:
age-2:

Appendix E

Table E-1. Rio Grande silvery minnow detection probability estimates among years for all sampling segments combined (from Population Monitoring Program data) in the Middle Rio Grande based on repeated sampling efforts in November (2005-2008).

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

Label*	Estimate	SE	LCI	UCI
p 2005 All Fish Day 1	0.9753	0.0172	0.9067	0.9938
p 2005 All Fish Day 2	0.9753	0.0173	0.9065	0.9938
p 2005 All Fish Day 3	0.9752	0.0173	0.9062	0.9938
p 2005 All Fish Day 4	0.9750	0.0175	0.9053	0.9937
p 2005 Age-0 Day 1	0.9792	0.0150	0.9177	0.9950
p 2005 Age-0 Day 2	0.9759	0.0169	0.9082	0.9940
p 2005 Age-0 Day 3	0.9756	0.0171	0.9070	0.9939
p 2005 Age-0 Day 4	0.9747	0.0177	0.9043	0.9937
p 2005 Age-1 Day 1	0.3335	0.1023	0.1688	0.5521
p 2005 Age-1 Day 2	0.3327	0.1021	0.1683	0.5513
p 2005 Age-1 Day 3	0.3267	0.1013	0.1644	0.5447
p 2005 Age-1 Day 4	0.3066	0.0992	0.1505	0.5246
p 2005 Age-2 Day 1	0.0243	0.0268	0.0027	0.1851
p 2005 Age-2 Day 2	0.0246	0.0271	0.0028	0.1872
p 2005 Age-2 Day 3	0.0248	0.0273	0.0028	0.1885
p 2005 Age-2 Day 4	0.0251	0.0276	0.0028	0.1901
p 2006 All Fish Day 1	0.8829	0.0368	0.7897	0.9380
p 2006 All Fish Day 2	0.8827	0.0368	0.7893	0.9379
p 2006 All Fish Day 3	0.8823	0.0369	0.7888	0.9377
p 2006 All Fish Day 4	0.8812	0.0372	0.7871	0.9371
p 2006 Age-0 Day 1	0.8388	0.0491	0.7187	0.9137
p 2006 Age-0 Day 2	0.8174	0.0532	0.6900	0.9000
p 2006 Age-0 Day 3	0.8150	0.0538	0.6863	0.8987
p 2006 Age-0 Day 4	0.8098	0.0554	0.6778	0.8961
p 2006 Age-1 Day 1	0.6996	0.0547	0.5829	0.7951
p 2006 Age-1 Day 2	0.6989	0.0548	0.5822	0.7945
p 2006 Age-1 Day 3	0.6931	0.0552	0.5759	0.7897
p 2006 Age-1 Day 4	0.6730	0.0584	0.5503	0.7759
p 2006 Age-2 Day 1	0.1101	0.0613	0.0350	0.2967
p 2006 Age-2 Day 2	0.1113	0.0620	0.0354	0.2996
p 2006 Age-2 Day 3	0.1121	0.0624	0.0356	0.3014
p 2006 Age-2 Day 4	0.1132	0.0630	0.0360	0.3038
p 2007 All Fish Day 1	0.9870	0.0129	0.9136	0.9982
p 2007 All Fish Day 2	0.9870	0.0129	0.9134	0.9982
p 2007 All Fish Day 3	0.9870	0.0130	0.9132	0.9982
p 2007 All Fish Day 4	0.9868	0.0131	0.9124	0.9981
p 2007 Age-0 Day 1	0.9890	0.0111	0.9243	0.9985
p 2007 Age-0 Day 2	0.9873	0.0127	0.9148	0.9982
p 2007 Age-0 Day 3	0.9871	0.0129	0.9136	0.9982
p 2007 Age-0 Day 4	0.9866	0.0133	0.9111	0.9981
p 2007 Age-1 Day 1	0.1154	0.0441	0.0530	0.2331
p 2007 Age-1 Day 2	0.1150	0.0439	0.0528	0.2325
p 2007 Age-1 Day 3	0.1123	0.0430	0.0515	0.2277
p 2007 Age-1 Day 4	0.1034	0.0406	0.0466	0.2138
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 E (continued)

Table E-1. (conintued) 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 (2005-2008).

Detection Probability Estimates from Minimum AIC_c Model (A)

Label*	Estimate	SE	LCI	UCI
p 2008 All Fish Day 1	1.0000	0.0000	1.0000	1.0000
p 2008 All Fish Day 2	1.0000	0.0000	1.0000	1.0000
p 2008 All Fish Day 3	1.0000	0.0000	1.0000	1.0000
p 2008 All Fish 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	1.0000	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	0.6294	0.0800	0.4644	0.7689
p 2008 Age-1 Day 2	0.6286	0.0800	0.4636	0.7682
p 2008 Age-1 Day 3	0.6222	0.0804	0.4573	0.7629
p 2008 Age-1 Day 4	0.6001	0.0829	0.4327	0.7470
p 2008 Age-2 Day 1	0.2918	0.1363	0.1016	0.6002
p 2008 Age-2 Day 2	0.2945	0.1370	0.1028	0.6033
p 2008 Age-2 Day 3	0.2962	0.1375	0.1036	0.6052
p 2008 Age-2 Day 4	0.2984	0.1381	0.1045	0.6077

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