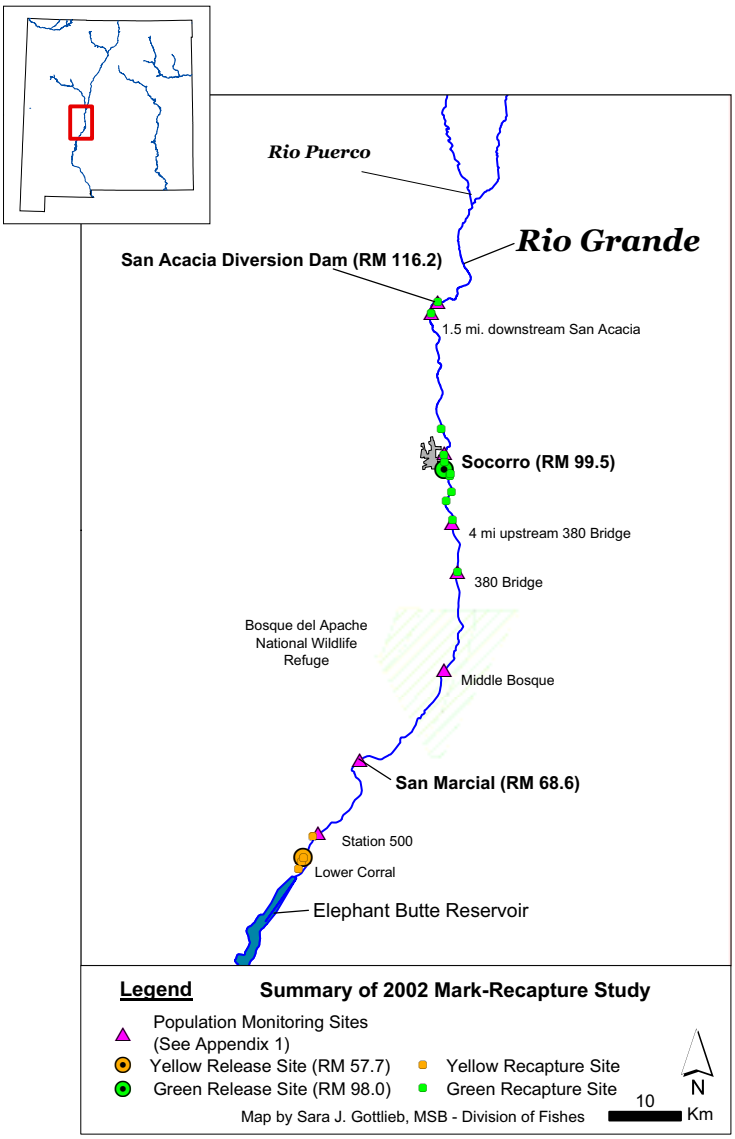
MOVEMENT PATTERNS OF RIO GRANDE SILVERY MINNOW *HYBOGNATHUS AMARUS*, IN THE SAN ACACIA REACH OF THE RIO GRANDE DURING 2002

Final Report



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EXECUTIVE SUMMARY

Rio Grande silvery minnow, *Hybognathus amarus*, was, historically, relatively widespread and abundant in the Rio Grande occurring from near Española, New Mexico, to the Gulf of Mexico. Recent studies in the Rio Grande basin documented the loss of this taxon upstream of Cochiti Dam and downstream of Elephant Butte Reservoir. The 90-95% reduction in the range of Rio Grande silvery minnow and threats to its continued persistence in the Middle Rio Grande resulted in the listing of this endemic cyprinid as a federal endangered species in 1994. The restriction of Rio Grande silvery minnow to a 279.8 km reach of river between Cochiti Dam and Elephant Butte Reservoir and fragmentation of that range into four segments (35.9, 65.2, 85.5, and 90.4 km long) due to diversion dam structures (Angostura, Isleta, and San Acacia) pose additional threats to the species. Among current proposals designed to aid in the recovery of Rio Grande silvery minnow is removal or redesign of the aforementioned three Middle Rio Grande diversion dams. Prior to any such modifications additional understanding of the autecology of silvery minnow are required. This includes information on home range, distance traveled, and schooling behavior of Rio Grande silvery minnow. In addition, data need to be generated regarding efficacy of marking techniques.

In November and December 2001, approximately 12,000 captive reared Rio Grande silvery minnow ranging in length from 15 mm to 65 mm SL, were marked as part of a project that began as a pilot study designed to evaluate the utility of the Visible Implant fluorescent Elastomer (VIE) marking technique on a laboratory population of Rio Grande silvery minnow. An initial assessment of recapture ability and rate was also to be performed. A yellow tag (ca. 5-6 mm) was inserted on the left side (above the lateral line and immediately anterior to the dorsal fin) of 4,600 silvery minnow while a green tag was placed (same location) in 7,300 silvery minnow. The two different lots (yellow marked and green marked) were maintained separately and ultimately released separately at two localities in the San Acacia Reach of the Rio Grande on 9 January 2002.

The 2001-2002 mark-recapture study of hatchery reared wild-produced Rio Grande silvery minnow resulted in the acquisition of extremely valuable information in the fields of fish marking techniques and behavior, and archetypal data regarding movement of a small-bodied Great Plains stream fish. The study clearly demonstrated not only that a large number of Rio Grande silvery minnow can be marked in a relatively short time, but also that a substantial percentage of the marks are retained, that small fish can be successfully tagged, and that the combination of multiple colors and placement of VIE tags provides a system for hundreds of unique marks. A total of 66 tagged Rio Grande silvery minnow were collected during the tenure of this study. About half (47%) of the recaptured specimens were green-marked fish taken in samples in the upper portion of the San Acacia Reach. Slightly more (n=35) yellow-marked silvery minnow were recaptured, than green-marked, however 69% of the yellow-tagged silvery minnow were taken (collectively) in two samples and they were not nearly as equally distributed throughout the study area as green-tagged fish. Green-tagged fish were first recaptured 54 days after being released and last taken 133 days post-release.

This investigation also documented two very important facets of movement in Rio Grande silvery minnow. The study highlighted the propensity of hatchery reared silvery minnow to redistribute downstream and the ability of individuals to move extensive distances upstream in a relatively short time. Collectively, 67% of the marked fish moved downstream while 77% of the fish were collected either at or downstream of the release site. The distance traveled by recaptured fish ranged from 0.26 km (0.16 mi) to over 25 km (15.54 mi). The seven longest distances traveled were by Rio Grande silvery minnow containing a green VIE tag. In those seven samples, the distance of dispersal ranged from 3,360 m (2.09 mi) to 25,170 m (15.64 mi). In general, the recapture of marked fish was negatively correlated with distance from the respective release site.

Several interactions of released (marked) Rio Grande silvery minnow with wild conspecifics were also documented. Marked fish were usually collected with wild silvery minnow. At a minimum, collection of marked fish with conspecifics implies a repatriation of a least a portion of the hatchery fish population with the wild fish. The collection of the gravid marked Rio Grande silvery minnow in April 2002 and the subsequent collection of a reproductively spent female in May 2002 (post-spawn by wild population) demonstrated that those individuals had not only exhibited the normal life-history functions of the species but expressed them concurrently with members of the wild population.

The maximum distances traveled by Rio Grande silvery minnow documented in this study (25 km) far surpass those reported by other researchers studying small-bodied fishes. In those studies, the distance that fish moved were reported in terms of 10's or 100's of m while silvery minnow movements are best expressed in terms of km. These latter distances again serve to highlight the importance of a continuous river ecosystem to Great Plains stream fishes, especially those which are members of the reproductive guild characterized by pelagic broadcast spawning and semibuoyant eggs. Likewise, these data also punctuate the deleterious effects of river fragmentation on the continued existence of Rio Grande silvery minnow and indicated as paramount for recovery of Rio Grande silvery minnow in the Middle Rio Grande the need for a reconnected river.

INTRODUCTION

The Rio Grande basin (Rio Grande and Pecos River) in New Mexico historically contained an ichthyofaunal community comprised of seven Great Plains stream cyprinids. The phantom shiner, *Notropis orca*, and Rio Grande bluntnose shiner, *Notropis simus simus*, are extinct (Bestgen and Platania, 1990) and the speckled chub, *Macrhybopsis aestivalis*, and Rio Grande shiner, *Notropis jemezanus*, have been extirpated from the Rio Grande, New Mexico (Bestgen and Platania, 1991; Platania, 1991). The only extant Great Plains stream cyprinid remaining in the Rio Grande, New Mexico is the federally endangered Rio Grande silvery minnow, *Hybognathus amarus* (U. S. Department of the Interior, 1994).

Rio Grande silvery minnow was, historically, relatively widespread and abundant in the Rio Grande drainage. In the Rio Grande, this species formerly occurred from near Española, NM, to the Gulf of Mexico (Bestgen and Platania, 1991). Rio Grande silvery minnow was extirpated from the Pecos River and replaced by a congener, plains minnow, *Hybognathus placitus*. This taxon was lost from the majority of its other occupied river reaches due, in part, to changes in river operations (e.g., alteration of the historic flow regime and increased levels of stream drying) and population fragmentation due to construction of dams that serve as instream barriers to upstream movement.

Population information on Rio Grande silvery minnow and the associated Middle Rio Grande (Rio Grande between Velarde, New Mexico and Elephant Butte Reservoir) fish community has been regularly gathered since 1987. The first studies were conducted by Platania (1993) from 1987-1992 to determine spacial and temporal changes in the ichthyofaunal community and to better understand species-specific habitat use patterns. An additional purpose of those studies was to provide information on the conservation status and population dynamics of Rio Grande silvery minnow.

Recent studies in the Rio Grande basin documented the loss of this taxon upstream of Cochiti Dam and downstream of Elephant Butte Reservoir. Quarterly sampling efforts during the summer and autumn of 1989 and 1990 revealed that densities of Rio Grande silvery minnow in all remaining river reaches were extremely low. The 90-95% reduction in the range of Rio Grande silvery minnow and threats to its continued persistence in the Middle Rio Grande resulted in the listing of this endemic cyprinid as a federal endangered species (U. S. Department of the Interior, 1994). The restriction of Rio Grande silvery minnow to a 279.8 km reach of river between Cochiti Dam and Elephant Butte Reservoir and fragmentation of that range into four segments (35.9, 65.2, 85.5, and 90.4 km long) due to diversion dam structures (Angostura, Isleta, and San Acacia) pose additional threats to the species. Middle Rio Grande dam and diversion structures do not prohibit downstream transport of eggs and larvae but do prevent upstream movement of fishes. The inability to rejuvenate upstream populations could be detrimental to Rio Grande silvery minnow since it produces semibuoyant eggs that drift with the current for 24-48 hours prior to hatching (Platania, 1995). Laboratory and field studies have demonstrated that upon hatching, larval Rio Grande silvery minnow remain a component of the drift at least until their air bladder develops. This physiological event usually occurs three days after hatching. Downstream transport distance of the progeny of Rio Grande silvery minnow is dependent on a variety of factors including flow magnitude and duration, water temperature, and channel morphology.

The reproductive strategy, in combination with the diversion dams, suggest that there is movement of Rio Grande silvery minnow from upstream to downstream segments. An important factor determining the rate of downstream movement is the length of the home reach. The shorter a reach, the greater the likelihood of extirpation within that reach. Four mainstem cyprinid species which had similar life-history strategies as Rio Grande silvery minnow and were historically sympatric, were extirpated by 1964 (Bestgen and Platania, 1991). Given the loss of four of the five members of this ecological guild, it is not unreasonable to presume that Rio Grande silvery minnow would likely be the next fish to be extirpated from the Middle Rio Grande.

Among current proposals that are designed to aid in the recovery of Rio Grande silvery minnow is removal or redesign of the three Middle Rio Grande diversion dams (Angostura, Isleta, San Acacia). Research proposals designed to evaluate behavior and swimming ability of Rio Grande silvery minnow in reference to fish passage device have also been solicited. The principal goals of the proposed project are to assess information that can be obtained from batch marked groups of Rio Grande silvery minnow. This includes but is not limited to information on home range, distance traveled, and schooling behavior of Rio Grande silvery minnow. In addition, data will be generated regarding efficacy of marking technique. Development of a cost effective and efficient mark-recapture procedure is required for many of the research studies delineated in the Rio Grande silvery minnow recovery plan (U. S. Department of the Interior, 1999).

The products of this study would comply with goals specified in the Rio Grande silvery minnow recovery plan (U. S. Fish and Wildlife Service, 1999). The portions of the recovery plan covered, in part, by the objectives in this study are action items 1.5 (Physical modification of habitat and irrigation works), 2.3.3 (Investigate upstream migration and recruitment rates of larval Rio Grande silvery minnow), 2.8.2 (Determine the efficacy of various methods for marking larval Rio Grande silvery minnow), and 2.8.3.7 (Establish and maintain standardized monitoring efforts to detect establishment of stocked populations).

STUDY AREA

The reach of the Rio Grande that extends from Velarde, New Mexico and Elephant Butte Reservoir is defined as the Middle Rio Grande and exhibits considerable change through its 364 km length. At high elevations, the Middle Rio Grande is a narrow, canyon-bound cold river with large substrata and a salmonid-dominated fish community. In contrast, downstream areas are 50-250 m wide, sand-bottomed, and supported a warmwater fish community. The area of interest for this study was the downstream-most portion of the Middle Rio Grande (San Acacia Reach). Upstream and downstream movements of fishes in the San Acacia Reach are constrained by San Acacia Diversion Dam to the north and Elephant Butte Reservoir to the south. This isolated reach supports one of the last remaining populations of Rio Grande silvery minnow in the Rio Grande basin.

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

The San Acacia Reach of the Rio Grande is about 60 river miles long and relatively wide with a predominantly sand substrata. The river can transport a high suspended silt load through a broad variety of mesohabitats when flow is sufficient. The mainstem channel (versus wetted channel) is 100-200 m wide. Under high flow conditions, depths in the San Acacia Reach can be >1 m and water velocity in excess of >1 m/s. From approximately the middle of Bosque del Apache National Wildlife Refuge downstream to Elephant Butte Reservoir, the river channel is <50 m wide and mesohabitats more homogenous than upstream. This is also true of the river several kilometers immediately downstream of San Acacia Diversion Dam and near bridge crossings.

Diel and seasonal discharge varied somewhat during 2002 but was consistently low during this study (Figure 1). There was a general trend of lower flow at U. S. Geological Survey (USGS) San Marcial Gauge (#08358400) compared to USGS San Acacia Gauge (#08354900). There was also a period typified by episodes of extremely low flow and occasional river drying that persisted in portions of the San Acacia Reach from mid March until late October. Summer rains supplemented low base flows and resulted in elevated instream turbidity levels.

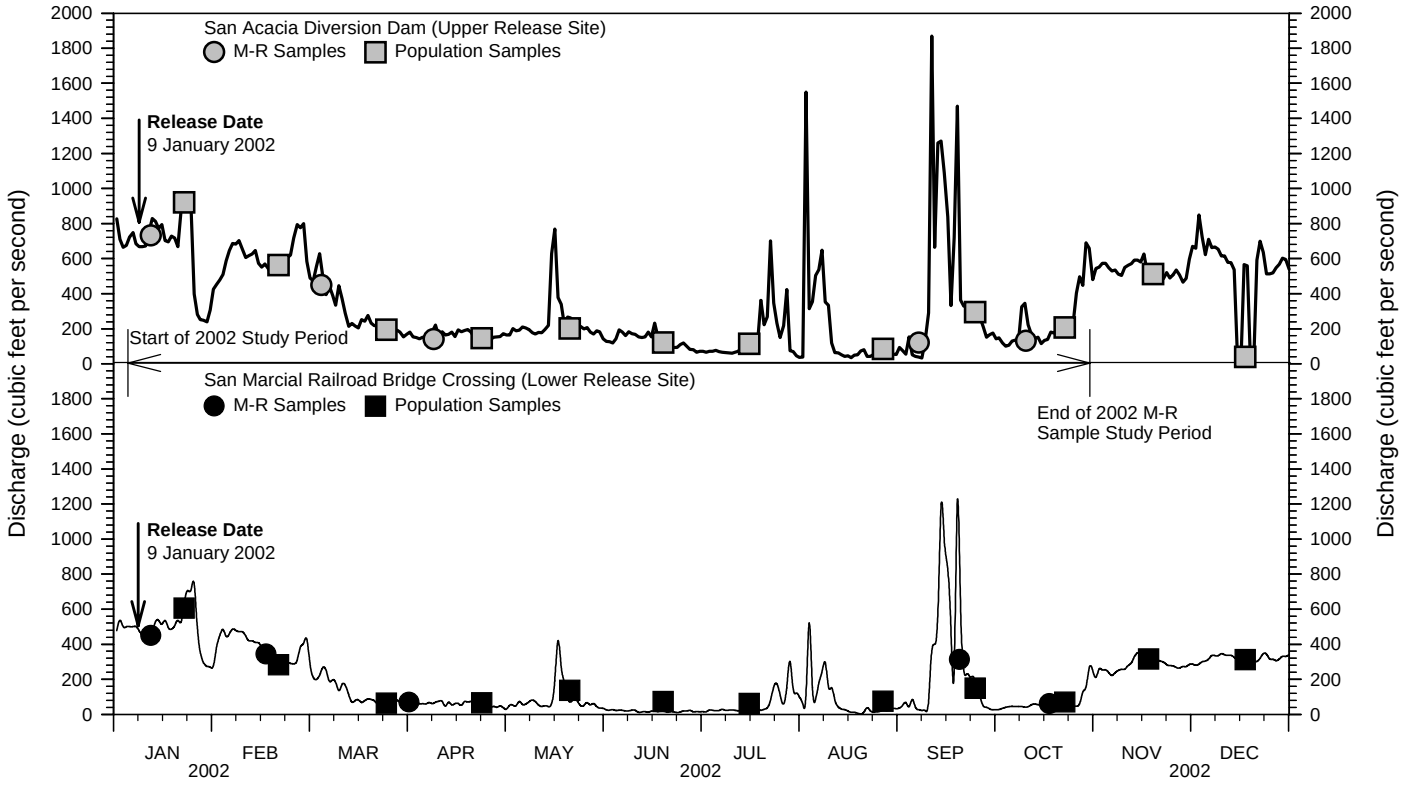

Figure 1. Hydrograph of the Rio Grande, New Mexico, at San Acacia Diversion Dam (upper graph) and San Marcial Railroad Bridge Crossing (lower graph) during 2002. Circles and squares indicate dates of sampling.

The upstream release site for marked (green) Rio Grande silvery minnow was located about 18 river miles downstream of San Acacia Diversion Dam. The locality descriptor for the release site was: New Mexico: Socorro County, Rio Grande, 0.5 miles downstream of Socorro Low Flow Conveyance Channel bridge, east and downstream of Socorro Wastewater Treatment Plant, Socorro, NM (River Mile 98.5; 3768692 N, 327079 E; Zone 13). Flow at this site generally increased in spring (March-May) followed by an annual decrease in summer/autumn (July-October). While flow during 2002 was low throughout the year at this site, there were no known river drying events.

The channel width of the Rio Grande during 2002 in the vicinity of the release site was generally <50 m with the majority of the flow carried along the west side of the channel. Water velocities <0.5 m/s and depths <0.5 m characterized the site with main channel runs being the numerically dominant mesohabitat. Sand and silt were the primary substrata with gravel only rarely present. There was a high degree of habitat heterogeneity with lower velocity mesohabitats represented even at high flow. Riparian vegetation at this site was a mixture of salt cedar and cottonwood trees.

The lower (downstream most) release site for marked Rio Grande silvery minnow (yellow) was located about 59 river miles downstream of San Acacia Diversion Dam. The locality descriptor for the lowermost release site was: New Mexico: Socorro County, Rio Grande, 19 miles downstream of the southern boundary of Bosque del Apache National Wildlife Refuge, NM (River Mile 57.7; 3714740 N, 307380 E; Zone 13). Flow during 2002 was low at this site and extremely diminished during summer when most water was supplemented by extensive pumping of the Low Flow Conveyance Channel. River drying was not known to occur at this site during 2002 but did take place at areas upstream (e.g., near Bosque del Apache National Wildlife Refuge).

The Rio Grande at the downstream release site was ephemeral, narrow, and channelized with a predominantly silt-sand substrata. There were often large deposits of silt at this site that formed stable underwater substrata waves. Riparian vegetation consisted of a mixture of willow and cottonwood trees. Channel width was <25 m with the majority of flow along the west side of the channel. Main channel runs were abundant and water velocities <0.2 m/s and depths <0.5 m common throughout the year. Several secondary channels carried flow along portions of the east side of the river during periods of low flow (i.e., <100 cfs). Secondary channels, when present, were characterized by moderate habitat heterogeneity (i.e., some backwaters and occasional debris piles).

MATERIALS AND METHODS

Marking Methodology

The method selected for marking Rio Grande silvery minnow during this study was the Visible Implant fluorescent Elastomer (VIE) system distributed by Northwest Marine Technology, Inc. This system was developed to provide externally visible marks for fish that are too small for most other marking techniques. The elastomer is a bio-compatible material that is injected as a liquid into tissue through a hypodermic needle. The elastomer cures rapidly into a pliable solid which serves as a cohesive and well-defined mark encased in healthy tissue. Transparent or translucent tissue, such as that between fin rays, are primary sites for marking. The use of different colors in combination with different body locations offers the potential for developing an extensive range of unique identification marks. Elastomers were available in four fluorescent (red, orange, yellow, and green) and three non-fluorescent colors (blue, purple, and black).

A lot of approximately 4,600 captive reared Rio Grande silvery minnow ranging in length from 15 mm to 65 mm SL, was the first to receive marks as part of the U. S. Bureau of Reclamation funded mark-recapture study. Those fish were collected from outdoor holding ponds at the Dexter National Fish Hatchery and Technology Center (DNFHTC) by hatchery personnel using minnow traps

set on 5-7 November 2001 and seines on 8 November 2001. The fish were subsequently transferred to and held at an indoor 2,271-liter raceway at DNFHTC until marked with a fluorescent yellow tag on 8-9 November 2001. Detailed description of marking protocol and procedures follow.

Rio Grande silvery minnow were collected from the indoor raceway at a rate of about 10-15 fish at a time with small dip nets. Once captured, the fish were placed in a holding tank/water bath containing tricaine methanesulfonate (MS-222) in a concentration of about 200 mg/liter. Ice packs were placed underneath the holding tank to maintain a water temperature close to that of the raceway (18^{o}C). Once anesthetized, Rio Grande silvery minnow were implanted with a yellow VIE tag following the protocol designated by Northwest Marine Technology (supplier of the tag). The tag (ca. 5-6 mm) was inserted on the left side of the fish (orientation: both fish and handler facing forward), above the lateral line, and immediately anterior to the dorsal fin. After insertion of the VIE tag, Rio Grande silvery minnow were transferred to a "recovery tank" that contained a commercial solution of stresscoat (concentration of 5 ml stresscoat per 38 liters of water) and a 0.25% NaCl concentration. Ice packs were also used to regulate the water temperature of the recovery tank. Silvery minnow were transferred back to a raceway once they were deemed to have recovered from the effects of the anesthesia. Fish that failed to recover from the anesthesia as well as those that did not appear to be in good condition after tagging were preserved in a solution of 10% buffered formalin and deposited in the Division of Fishes at the Museum of Southwestern Biology (MSB).

About 3,400 fish (40-65 mm SL) were tagged on 8 November 2001, of which 22 were retained (preserved). Five people (four people marking and one person shuttling fish to and from raceways) participated in the 8 November 2001 marking efforts. The rate of marking was estimated to be about one fish every six to nine seconds. In addition to receiving the VIE tag, the first 192 fish processed were also fin clipped to provide genetic information on the stock for Dr. Thomas F. Turner, Division of Fishes, MSB, at the University of New Mexico (UNM). A small fin clip was taken from the lower lobe of the caudal fin, and each tissue sample was individually preserved in a 1.5 ml NUNC tubes containing 95% EtOH. Rio Grande silvery minnow that were fin clipped were kept separate from other tagged fish so that mortality rates for each group could be assessed independently.

On 9 November 2001, an additional 1,200 Rio Grande silvery minnow received a fluorescent yellow VIE tag following the aforementioned procedure. Fish marked on 9 November 2001 (n = 1,200) were generally smaller (15-40 mm SL) than those tagged during the previous day (40-65 mm SL). The 9 November 2001 Rio Grande silvery minnow were maintained separate from those tagged on 8 November 2001 so that size dependent mortality rates could be assessed. No fin clips were taken from Rio Grande silvery minnow tagged on 9 November 2001 and a total of 57 fish from that sample were preserved. Again a crew of five people participated in this effort except that on this day all five people were marking fish. When additional fish were needed, one of the individuals marking fish assumed responsibility of collecting and transferring specimens.

Rio Grande silvery minnow marked on 9 November 2001 were collected by seining since, according to DNFHTC staff, fish were no longer being captured in minnow traps. The added stress on fish captured by seine, in addition to the smaller length of individuals collected, likely resulted in a higher mortality rate observed on 9 November 2001 compared to that recorded in fish marked on 8 November 2001.

At the end of each day of marking, all VIE tagged fish were treated in the raceways with an antibiotic (nitrofurazone: 250 mg per liter of water) and a small amount of commercial stresscoat. Because the raceways at DNFHTC are flow-through systems, inflow was discontinued and water in the tank allowed to settle to maximize medication of the fish. Aerators were placed in the raceways, while inflow was off, to maintain dissolved oxygen levels. As of 28 November 2001, no additional post-marking (8-9 November 2001) Rio Grande silvery minnow mortalities had occurred indicating the effectiveness of the procedure and handling techniques employed.

Between 30 November and 3 December 2001 approximately 7,300 captive reared Rio Grande silvery minnow were collected from a holding pond at DNFHTC using minnow traps and prepared to be the second lot of fish to receive a VIE tag. As before, captured fish were transferred to two 2,271-liter raceways at DNFHTC. A green VIE tag was used to mark this second lot of Rio Grande silvery minnow on 6 -7 December 2001. Tag location remained the same as the first lot, which was on the left side of the fish, above the lateral line and just anterior to the insertion of the dorsal fin. Likewise, marking procedures remained the same as during the November 2001 marking trip.

On 6 December 2001 green VIE tags were placed in 5,806 Rio Grande silvery minnow (36-64 mm SL). Three separate stations were established, each consisting of a waterbath (containing MS-222) and a recovery tank. At any given time during this effort, there were about seven people marking fish. One individual at each of the stations was responsible for shuttling Rio Grande silvery minnow between raceways and marking stations.

As before, the first 192 Rio Grande silvery minnows to receive a green VIE tag had a small portion of their caudal fin (lower lobe) clipped to provide genetic information on the stock to Dr. Turner (UNM). Each tissue sample was individually preserved in a 1.5 ml NUNC tube containing 95% EtOH. Rio Grande silvery minnow that were fin clipped were kept in a raceway separate from the other marked fish so that mortality rates for each group could be assessed independently.

As of 7 December 2001, only one Rio Grande silvery minnow mortality had been recorded (and preserved) from the fin clipped lot. Of the remaining 5,614 Rio Grande silvery minnow marked on 6 December 2001, 52 moralities (37-59 mm SL) were recorded. Those individuals were preserved in 10% buffered formalin. On 7 December 2001 the final 1,447 Rio Grande silvery minnow were marked (same location) with a green VIE tag. No moralities were noted from the 7 December 2001 lot. Marked fish occupied two raceways which, at the end of each day, were treated with the nitrofurazone (20 ppm) and a small amount of stresscoat. Large aerators were placed in each raceway to maintain dissolved oxygen levels while the in-flows to each system were shut off to allow the nitrofurazone to medicate marked Rio Grande silvery minnow.

Release of marked fish

A total of about 12,000-marked Rio Grande silvery minnow were held at DNFHTC indoor facilities in mid-December 2002. After marking of this second batch (of 7,300) plans were formalized for release of these two lots (yellow and green) in the San Acacia Reach of the Rio Grande.

During the evening of 8 January 2002, the approximately 12,000 marked Rio Grande silvery minnow were transferred from indoor raceways to the DNFHTC live-fish transport truck. The two different lots (yellow marked and green marked) were kept separate in the hatchery truck by means of a fine mesh internal barrier. Early on the morning of 9 January 2002, DNFHTC personnel drove for about three hours before arriving at the first release (downstream) site on the Rio Grande. Water temperature in the river at the first release site was lower than that in the holding tank, so river water was added to the holding tank until temperatures equalized. Soon after, about 4,600 yellow marked Rio Grande silvery minnow were released at the lower study site. No mortalities were noted in the yellow tagged fish during transport and release.

Upon completion of the first release, the hatchery truck drove north for about one hour before arriving at the second release site which was near Socorro. River water was again added to the holding tank to equalize water temperature prior to the release of green tagged fish. About 7,300 green VIE tagged Rio Grande silvery minnow were released at this site on 9 January 2002. No mortalities were noted in the green tagged fish during transport and release.

Field Collections

Directed sampling efforts

Sampling for marked Rio Grande silvery minnow needed to be structured so as not to encumber our ability to survey extensive reaches in a relatively reasonable period of time. This required modifying some segments of the field protocol employed in other research programs and associated sampling methodologies (i.e., Rio Grande silvery minnow population monitoring). Fish were sampled with a seine (2.1 m x 1.8 m, 0.5 cm mesh) and the number of seine hauls recorded. There was no attempt to quantify the area sampled as this would have required the expenditure of considerably more effort and resulted in a reduction of area sampled. All available mesohabitats at a given collection station were sampled but the majority of effort was directed towards habitats most commonly occupied by Rio Grande silvery minnow. Fish were processed following the field handling protocols described below.

The first sampling effort directed toward recapture of marked silvery minnow occurred on 11 January 2002. This somewhat cursory sampling effort was unique compared to the remainder the directed sampling efforts as the sole purpose of the former survey was to determine if the marked fish had survived stocking. An additional goal was to minimize the disturbance to the recently released fish as opposed to assess retention rates or distances moved. This sampling effort was conducted at both of the release sites which were vacated soon after the presence of marked fish was confirmed.

Directed sampling for yellow marked Rio Grande silvery minnow occurred during February, April, September, and October 2002 in the lower portion of the San Acacia Reach. Sampling directed towards the capture of green tagged Rio Grande silvery minnow occurred in March, April, September, and October 2002. Collecting efforts from May through August 2002 was conducted in coordination with population monitoring activities.

Population monitoring samples

Monthly population monitoring samples were taken at nine sites in the San Acacia Reach (Appendix 1) between San Acacia Diversion Dam (RM 116.2) and the downstream most station (RM 57.5). During these efforts, fish were collected by rapidly drawing a two-person 2.1 m x 1.8 m small mesh (0.5 cm) seine through discrete mesohabitats. Fish from each seine sample were sorted, identified to species in the field, enumerated, released near the site of capture. All Rio Grande silvery minnow collected during the population monitoring study were examined for the presence of a VIE mark. If a mark was present, the color was noted, length of the fish determined, and location of capture within the sampling station noted.

Fish handling protocol

Upon arrival at the sampling site, numerous (ca. four) nylon mesh live wells were placed in the river at intervals of about 150 m. Sampling generally began at the farthest downstream point at the site and continued upstream. Rio Grande silvery minnow collected during the directed sampling effort were temporarily held in 19-liter plastic buckets. Once the live well was reached, fish were transferred from the bucket to the live well and the process repeated until the last live well was reached at the farthest upstream point.

After sampling at the site was completed, Rio Grande silvery minnow were gathered from the live wells using dip nets, transferred to 19- liter buckets, and carried to the processing station on shore. Fish were next transferred to a 95-liter ice chest containing 57 liters of water drawn from the river. Water in the ice chest was treated with 5 ml of stress coat, 150 gms of NaCl, and 3 gms of MS-222. The latter chemical was infused at a low concentration so as to slow but not sedate the fish.

Rio Grande silvery minnow were then removed from the ice chest and carefully examined, using bright visible blue light and sunglasses equipped with special filters, for the presence of a VIE

tag. If a mark was present, the color was noted, specimen examined for external parasites, general condition, and other pertinent indicators of health, and placed in a bucket of untreated river water.

If a mark was not present, the fish was placed in a clear plastic tub containing 5 liters of water, stresscoat and NaCl at the aforementioned concentrations, and 1 gm of MS-222. Within about one minute, the fish was anaesthetized and a small fin clip taken from the upper lobe of the caudal fin. Fin-clipped fish were held in untreated river water until they recovered from the anaesthesia. The fin clip was placed in a NUNC tube containing 95% EtOH and transferred to Dr. Turner (UNM). Tagged Rio Grande silvery minnow were not subjected to the fin clipping procedure. Once all Rio Grande silvery minnow had been processed, they were released back to the river at about the midpoint if the sampling site.

RESULTS

Rio Grande silvery minnow collection summary

Mark-recapture sampling efforts

The two release sites were each first revisited on 11 January 2002 about 48 h after the initial release of marked Rio Grande silvery minnow. The purpose of this cursory sampling effort was not to assess dispersal but instead to ascertain if marked fish had survived. Sampling was conducted about 100 m up and downstream of the release sites. At the Socorro site, 42 Rio Grande silvery minnow were recaptured of which 25 were marked (green). Three marked individuals were taken at the release point, three VIE tagged specimens were collected 20 m downstream of that site, and 19 (marked) silvery minnow were collected 80 m downstream of the point of release. Water level had increased over 150 cfs since the release of fish which precluded sampling habitats immediately upstream. Sampling conducted several hundred m upstream of the Socorro release point resulted in the collection only of unmarked Rio Grande silvery minnow (ca. 15).

At the downstream most release site, 28 of the 30 Rio Grande silvery minnow collected were marked specimens (yellow). Seven recaptured specimens were taken 125 m downstream of the release site and one was collected 100 m downstream. All Rio Grande silvery minnow collected at or downstream of the release point were VIE tagged specimens. However, most (71%; n=20) of the marked Rio Grande silvery minnow taken in this sampling effort were collected at or immediately upstream of the release site. Eight tagged silvery minnow were collected within 5 m (upstream) of the release site, 11 were collected 25 m upstream, and one tagged individual was taken 80 m upstream. The site 25 m upstream of the release location also yielded a single unmarked specimen.

Sampling efforts during February 2002 focused exclusively on the lower portion of the study area (Figure 2). Between 12-20 February, the intensive sampling covered over four of the seven river miles in the reach between RM 56.5-63.5. Those efforts resulted in the collection of 117 Rio Grande silvery minnow of which 28 were marked (yellow) specimens. Discharge in the Rio Grande during this sampling period, as recorded at the San Marcial Railroad Bridge Crossing Gauge, was low and generally remained between 300-400 cfs.

The three sites downstream of the release point produced only 27% (n=31) of the total Rio Grande silvery minnow catch. However, 27 of the 28 (96%) silvery minnow recaptured during February were collected in the short section sampled downstream of the release site. The first sample was acquired from as far downstream of the release point (ca. 1.2 river miles) as could possibly be attained via land. That site yielded 13 marked Rio Grande silvery minnow from the total of 16 collected. Most of those specimens (69%; n=9) were the larger cohort of yellow tagged silvery minnow (>45 mm SL) and appeared to be in good health. At this site, all Rio Grande silvery minnow were taken exclusively in low velocity habitats while aquatic habitats characterized by water velocity of zero failed to produce silvery minnow.

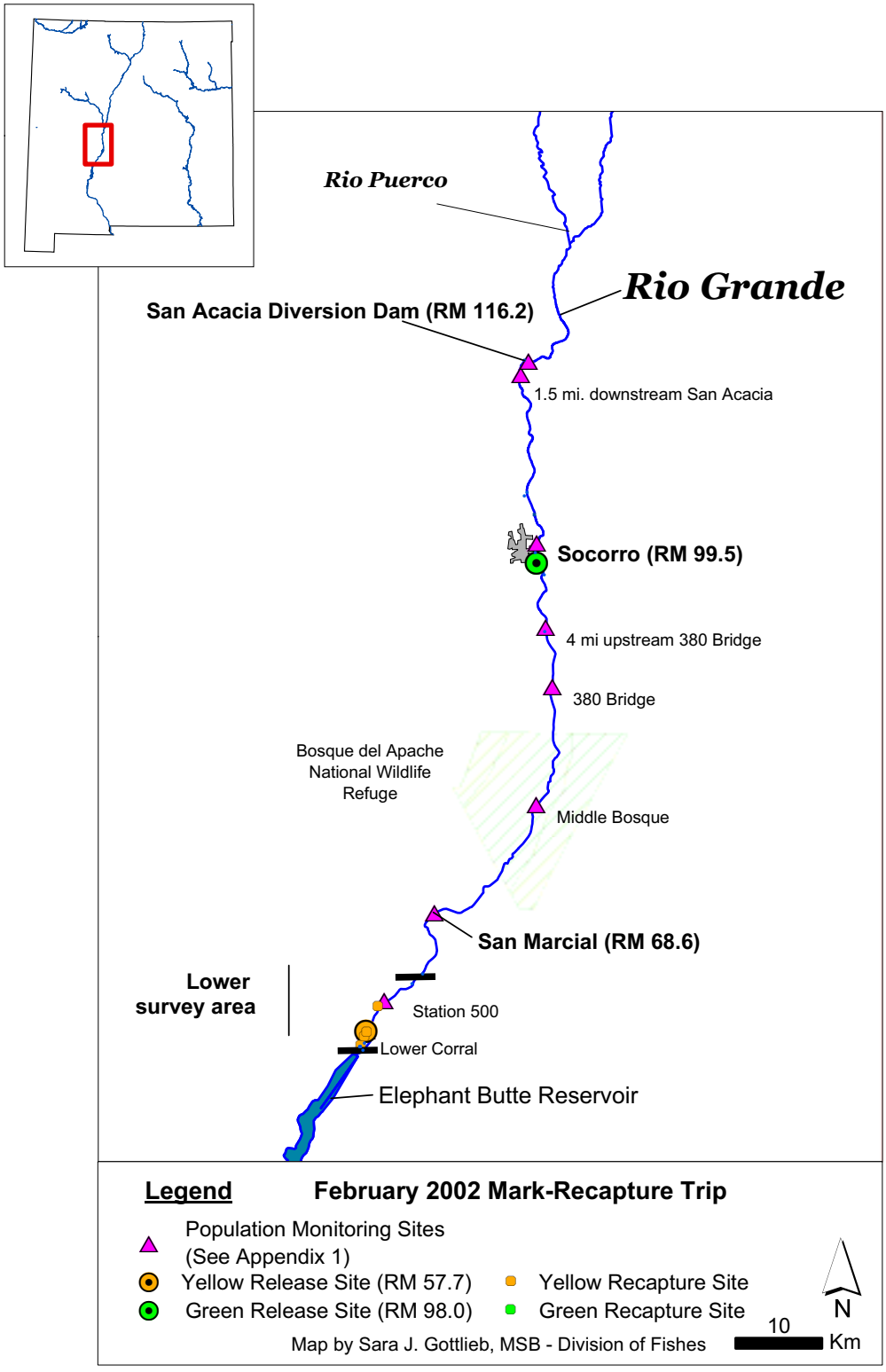

Figure 2. Summary of the February 2002 Rio Grande silvery minnow recapture information from the San Acacia Reach of the Rio Grande.

The next two upstream sites encompassed about 0.6 river miles from the southern boundary of the release point downstream. A total of 15 Rio Grande silvery minnow were captured in these samples of which 14 were VIE tagged individuals. Nine of the marked fish were members of the larger cohort of yellow tagged silvery minnow (>45 mm SL) as was the single non-marked specimen. There was considerably less low velocity habitat at these sites, compared with the site immediately downstream, and water velocity >0.5 m/s was not uncommon. Rio Grande silvery minnow were not encountered in the high water velocity habitats but instead were collected in habitats where water depth and velocity were lower than that which characterized the site.

The 5.8 river miles sampled during February 2002 above the release point produced numerous Rio Grande silvery minnow (n=86) but only one of those specimens was marked. The sites closest to the release point (within 1.6 river miles) generally produced the fewest Rio Grande silvery minnow (3 sites, total n=10) while up to 24 individuals were taken in selected short (0.3 river mile), more upstream, segments. All except one of the Rio Grande silvery minnow collected above the release point were >45 mm SL (range= 48-60 mm SL). An aberrant silvery minnow specimen, considered so because of its small size (length) for that time of year, was collected near the upstream most portion of the study reach. The fish was carefully examined for any indication that it might have been a marked specimen of the small (length) cohort of yellow tagged silvery minnow that had expelled the VIE tag but none was apparent.

The single February 2002 marked Rio Grande silvery minnow taken above the lower release point was collected syntopically with five conspecifics. A total of 11 Rio Grande silvery minnow were collected at that site, all of which were >45 mm SL and appeared to be in good condition. Those fish were taken in a small side channel where water velocity was relatively low (10-20 cm/s) and depth shallow (<50 cm). This was the most upstream and final collection of a yellow marked Rio Grande silvery minnow during this study..

The March 2002 sampling effort for marked Rio Grande silvery minnow was directed exclusively towards the collection of green tagged specimens in the upper portion of the San Acacia Reach (Figure 3). Sampling occurred from 4-6 March and encompassed a total of about 12.5 river miles. The upstream most samples were taken about 5.6 miles from the release point while the downstream most collection occurred 6.9 miles from the point of release. The March 2002 samples resulted in the largest cumulative collection of Rio Grande silvery minnow (n=401) during this study, the second greatest number of tagged individuals (n=19), and Rio Grande silvery minnow in each of the 12 samples. Mean daily discharge in the Rio Grande at San Acacia Diversion Dam during this sampling period (4-6 March 2002) remained between 497-628 cfs.

The downstream sampling sites produced both fewer wild Rio Grande silvery minnow (41%; n=164) than upstream sites (59%; n=237) and a disproportionate number of marked fish. Only about 41% of the total Rio Grande silvery minnow catch was from sites downstream of the release point but 79% of the recaptured fish were taken in those collections. In addition, four of the six downstream samples resulted in the recapture of silvery minnow while only one of six upstream collections contained tagged fish.

The March 2002 sampling site immediately downstream of the Socorro release point (0.1-0.2 river miles) was not only devoid of marked fish but also yielded the fewest Rio Grande silvery minnow (n=15) in the samples taken during March. The relatively low number of specimens was unexpected as the river channel was broad and considerable habitat diversity present. Low velocity side channels and pools were the numerically dominant habitat types present at the lowermost site.

The sample from a 0.3 mile reach of the Rio Grande located about 1.1 river miles south of the release point contained numerous marked (n=5) and unmarked Rio Grande silvery minnow (n=22). This was the highest capture ratio of marked to unmarked (green tagged) Rio Grande silvery minnow recorded during this study. A similar catch ratio (15%) was also documented at the next downstream

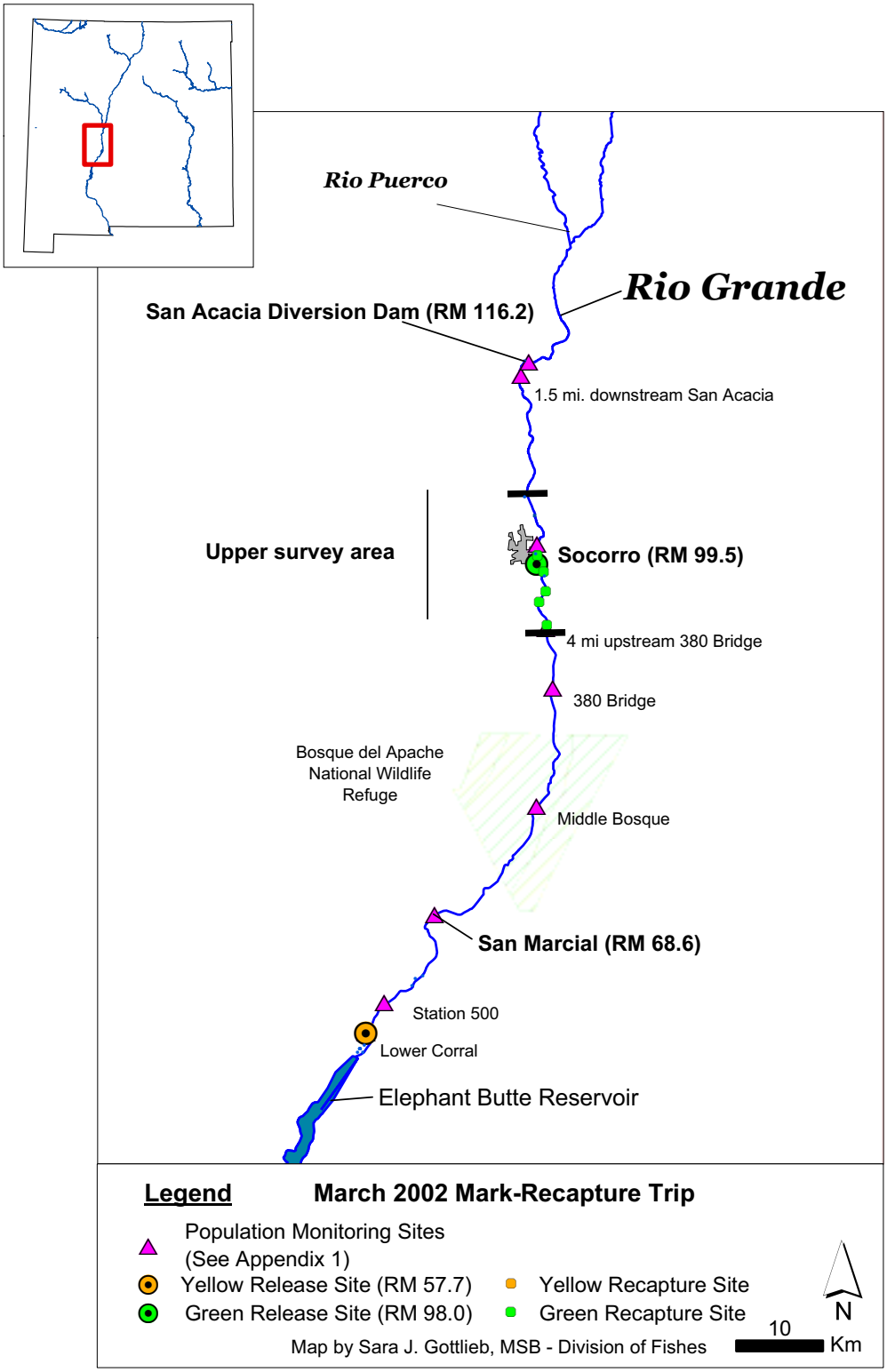

Figure 3. Summary of the March 2002 Rio Grande silvery minnow recapture information from the San Acacia Reach of the Rio Grande.

sampling station located about 3.8-4.0 river miles downstream of release site. Six of the 33 Rio Grande silvery minnow taken in that 0.2 river mile sample were tagged specimens. The most downstream collection of green tagged Rio Grande silvery minnow (n=2) was between 6.6-6.9 river miles below the point of release. That sample also produced the second largest number of silvery minnow (n=34) taken in downstream samples.

The multiple islands and sandbars present in the five-mile reach of the Rio Grande from River Mile (RM) 97-91 at the discharge during early March 2002 resulted in an extremely braided river channel and a marked diversity of aquatic habitats. The number of marked and unmarked Rio Grande silvery minnow taken in that reach suggest those conditions proved quite conducive for silvery minnow during the early portion of the year. As in the lower reach, marked Rio Grande silvery minnow were taken in seine hauls that also contained unmarked conspecifics. Although quantitative data were not recorded, it was noted that wild (=unmarked) silvery minnow in this reach of the river were generally 10-15 mm larger than their tagged counterparts. Regardless of their smaller relative length, the 15 marked specimens from downstream of the Socorro release point appeared to be in good condition and did not present any external parasites.

The relatively large number of Rio Grande silvery minnow (n=237) taken during March 2002 from near the release site to a point 5.6 river miles upstream did not equate to the collection of numerous marked specimens. The four green-tagged March 2002 Rio Grande silvery minnow recaptured upstream of the release point were taken in a reach 0.4-0.7 river miles above that location. That study reach was characterized by an extremely complex series of side and secondary channels and extensive river braiding. Any seine sample in that reach that produced marked silvery minnow also yielded unmarked conspecifics.

The five other upstream March 2002 samples were also very productive in regards to the number of Rio Grande silvery minnow collected. Over 200 silvery minnow were collected in the 4.5 river mile reach from the northern boundary of the city of Socorro upstream to near Escondida. All of those specimens were >45 mm SL with most individuals about 55-60 mm SL. Several of the silvery minnow specimens were age-2 individuals. As at the other sample sites in the Socorro portion of the San Acacia Reach, islands served to create extensive side channel networks and a plethora of diverse low velocity habitats utilized by Rio Grande silvery minnow. Conversely, the northern extent of the upstream-most sampling station was in the vicinity of the Escondida Bridge (RM 104.8). In the immediate area of the bridge, the Rio Grande is channelized and habitat primarily high velocity runs. Rio Grande silvery minnow were not collected in that segment of the sampling area.

The April 2002 collecting effort included fish sampling in both the upper (Socorro) and lower portions of the San Acacia Reach in an attempt to located green and yellow VIE tagged Rio Grande silvery minnow (Figure 4). With the initiation of irrigation season withdrawals from the river and the absence of a spring snowmelt runoff, flow in the Rio Grande was markedly lower than normal. Flow in the lower section of the study area during the April 2002 sampling effort was only 60-75 cfs while in the vicinity of Socorro, discharge in the river was only between 150-200 cfs. The impact of this minimal discharge was reflected in the extremely low number of Rio Grande silvery minnow taken during April 2002. The 10 samples from the lower reach collectively produced only 11 silvery minnow while a total of 246 silvery minnow were taken in eight upper reach samples. Marked fish were encountered in three separate samples in the Socorro area but absent from the lower segments of the study reach. The April 2002 effort had tentatively been planned as the final trip dedicated exclusively to sampling for hatchery-reared and marked Rio Grande silvery minnow. However, the continued drought and extremely low number of wild spawned 2002 Rio Grande silvery minnow resulted in the reinitiation of the dedicated sampling in September 2002.

There was about 1.1-1.3 miles of sampleable (=accessible) habitat downstream of the release site of yellow tagged Rio Grande silvery minnow during April 2002. Channel dredging and reshaping

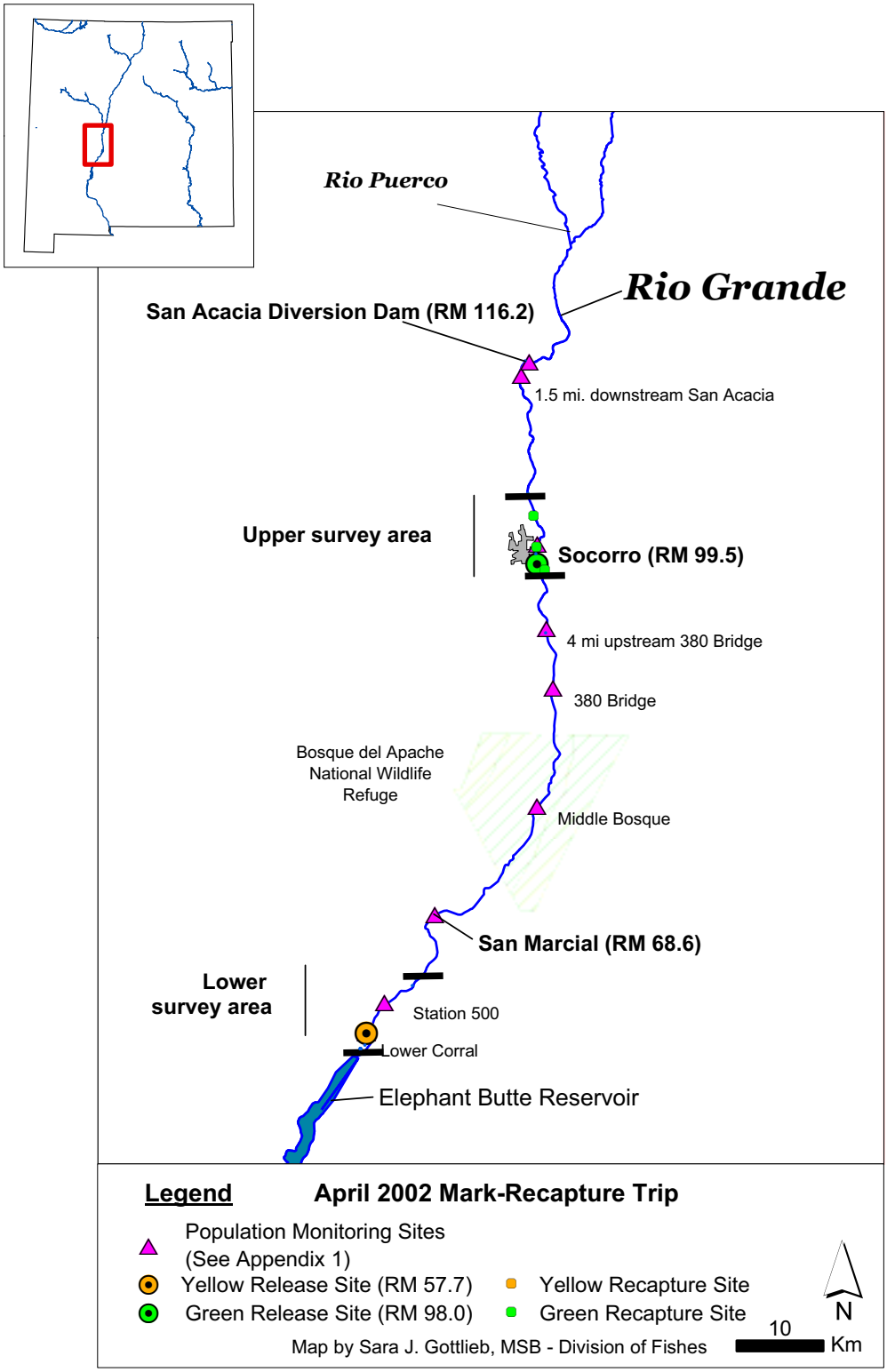

Figure 4. Summary of the April 2002 Rio Grande silvery minnow recapture information from the San Acacia Reach of the Rio Grande.

activities conducted by the U. S. Bureau of Reclamation were ongoing in the lower one mile reach of the study area. The instream construction work had markedly reduced aquatic habitat diversity and created a narrow, uniform channel (pilot channel) that was relatively devoid of fish. Less than 100 fish were collected in this reach with over 95% being small age-1 red shiner, *Cyprinella lutrensis.* The three Rio Grande silvery minnow that were collected were unmarked and presented no external indication of being gravid.

The April 2002 sample taken at the downstream release site failed to produce any Rio Grande silvery minnow. Low discharge, narrow river channel, poor habitat conditions, and minimal habitat diversity resulted in a small catch of fish. Similar habitat conditions were present almost continuously from the release site upstream about 1.5 miles. Embedded debris was also common in the main channel throughout this reach. Red shiner numerically dominated the meager catch with a single (unmarked) Rio Grande silvery minnow also taken.

There were five discrete samples taken in the segment from 1.6 to 6.4 miles above the release station. Four of those collections contained Rio Grande silvery minnow but none were marked individuals. Habitat diversity in that 4.8 river mile reach was greater than that encountered downstream and was characterized by low water levels, considerable river braiding, and the presence of numerous island complexes. A total of seven silvery minnow were collected of which two were females with extremely distended abdomens indicating a relative magnitude of reproductive readiness. Several large river carpsucker, *Carpiodes carpio,* (> 500 mm SL) were taken in deep backwater habitat where they had apparently become trapped. The shallow depth of the water near the mouth of the backwater likely prevented these fish from reentering the main channel while the deep pool within the mesohabitat provided short-term refuge. Both the number of fish and number of Rio Grande silvery minnow taken in the lower study reach was markedly lower than that encountered during the February 2002 collecting effort.

The April 2002 sampling effort in the upper portion of the San Acacia Reach was more productive than that in the lower section of the river. The 249 Rio Grande silvery minnow taken in these samples also included nine marked specimens. Sampling began about 0.6 river miles downstream of the release point and continued upstream to the vicinity of the Escondida Bridge. Additional sampling downstream of Socorro was not pursued because of low water levels. The three samples taken in the immediate vicinity of the upper release site (both up and downstream of) produced 21 Rio Grande silvery minnow of which one was VIE tagged. Habitat in that portion of the river was relatively diverse as the river channel was broad and braided with islands bisecting most main channel runs. Low velocity habitats, especially those with depths >0.5 m, generally produced Rio Grande silvery minnow. Almost all female silvery minnow were gravid as indicated by their distended abdomens. The single marked fish did not present any indication of reproductive state and was notably smaller than its wild conspecifics. Gravid fathead minnow, *Pimephales promelas,* were also collected during the sampling effort and females of this species freely expressed eggs when slight pressure was applied to their abdomens.

The three collection stations in the middle portion of the April 2002 upper sample reach accounted for 76% (n=211) of the total Rio Grande silvery minnow catch and 89% (n=8) of the marked fish. Collections of 64, 66, and 81 silvery minnow were taken with the two smaller collections containing five and three marked fish, respectively. Most Rio Grande silvery minnow were taken in low velocity habitats with deep water. Backwaters and pools immediately downstream of instream debris piles were particularly productive mesohabitats for the collection of Rio Grande silvery minnow.

The sampling site about 1.1 river miles upstream of the Socorro release station produced 64 Rio Grande silvery minnow (48-67 mm SL), five of which were marked. Most silvery minnow were collected in either a backwater or adjacent to shoreline debris piles. Two of the five marked fish were taken in a backwater habitat along with numerous conspecifics. All five marked fish were smaller

than the smallest wild specimen and none of the marked individuals exhibited any external indication of reproductive readiness. Conversely, many of the wild silvery minnow were notable gravid.

The general river segment (3.1-3.5 river miles upstream of release site) that produced 51 Rio Grande silvery minnow (0 recaptures) during the March 2002 collecting effort yielded 81 silvery minnow in April 2002 but was again devoid of marked fish. Most of the April 2002 silvery minnow were collected in deep (0.5-1.25 m) low velocity habitats such as backwaters and pools. Several of those seine hauls produced 5-10 silvery minnow, many of which were gravid females. Further upstream, a single large backwater immediately below the confluence of the Rio Grande and North Socorro Conveyance Channel produced about 50% of all of the Rio Grande silvery minnow taken in that study reach (n=66) and all three of the marked fish at that sampling station (4.9-5.0 river miles upstream of release site). Included in that sample was the first marked and obviously gravid female Rio Grande silvery minnow (based on the large, distended abdomen). An additional marked Rio Grande silvery minnow (n=1) was subsequently captured at this site by personnel from the New Mexico Ecological Service's Branch of the U. S. Fish and Wildlife Service.

The final two upstream-most sites were within about 0.8 river miles of the Escondida Bridge. A total of 17 Rio Grande silvery minnow were collected in these samples but none of the fish contained a VIE tag. However, an individual in the sample of 11 silvery minnow from collection (5.5 to 5.8 miles above release point) appeared to be a marked fish that had lost its tag. The specimen was considerably smaller (SL) than the other 10 silvery minnow collected at the site but, more importantly, had a blister on the left, dorsal portion of its body just anterior to the origin of the insertion of the dorsal fin. This was the region of the body in which fish had been tagged. As the specimen in question was not retained, examination in the laboratory was not possible. In the absence of conclusive evidence the specimen will remain classified a wild (=unmarked) fish.

The September 2002 survey effort (Figure 5) comprised two discrete sampling periods and resulted in the collection of 85 (unmarked) Rio Grande silvery minnow. During the first portion of the month (4-6 September 200), sampling efforts were conducted in the upper portion of the San Acacia Reach, between San Acacia Diver Dam and Socorro, while collecting efforts in the lower reach (RM 63.3-56.9) were conducted 18-19 September 2002. A large portion of the river channel, upstream of Socorro, had recently been dry when a small spate originating in the Rio Puerco and Rio Salado watershed rewetted the previously dried segments of the Rio Grande. Highly turbid water, rising water velocity and level, and the appearance of flotsam and drifting woody debris announced the arrival of the spate. Dead fish were discovered, as the water receded, on the recently wetted sandbars and shorelines. Large-bodied fish, primarily common carp, *Cyprinus carpio*, river carpsucker and channel catfish, *Ictalurus punctatus,* comprised the majority of the stranded specimens. Several live large fish were also collected in shallow and isolated backwaters. Flathead chub, *Platygobio gracilis,* was the numerically dominant small-bodied species observed stranded and dead on the sandbars while it was noted that many of the live flathead chub collected were infected with the parasite *Lernaea* sp.

A total of 65 Rio Grande silvery minnow were taken in early September 2002 between San Acacia Diversion Dam and Socorro, of which only four were age-0 and the remainder age-1 (n=61) fish. None of the captured Rio Grande silvery minnow contained a VIE mark. Most silvery minnow (71%; n=46) were collected from the lower three-mile segment of the study reach which was unexpected as much of that segment had been dry. It is likely that the recent spate induced a downstream dispersal of fishes which was manifested in the relatively high catch of Rio Grande silvery minnow near the previously dry Socorro reach.

Discharge in the lower study area during the September sampling period rose (from 50 cfs) to over 1,000 cfs for the first time in 13 months (since 17 August 2001). Sampling was able to be conducted, in most cases, ahead of the mid-September spate allowing relatively efficient collecting

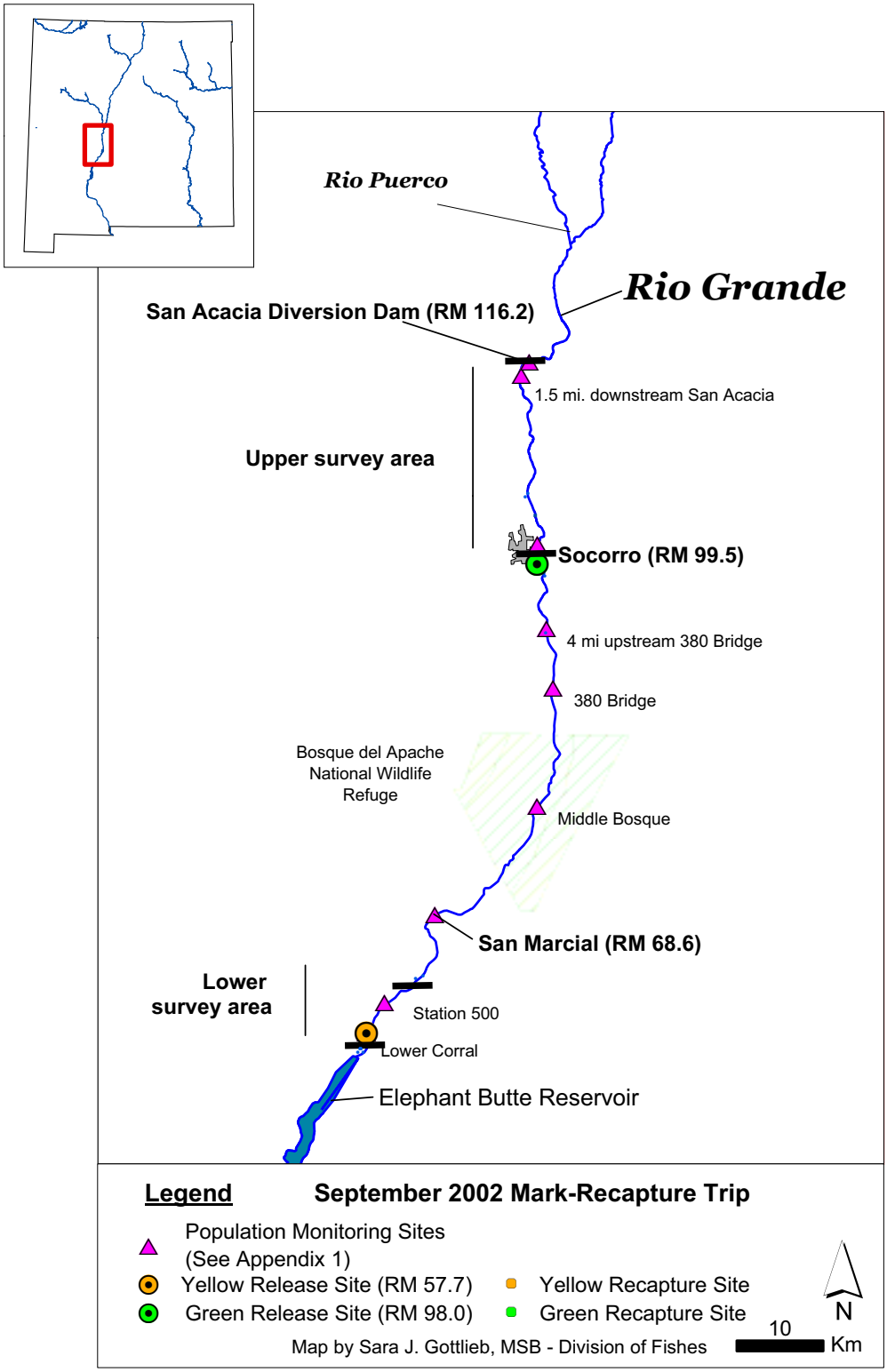

Figure 5. Summary of the September 2002 Rio Grande silvery minnow recapture information from the San Acacia Reach of the Rio Grande.

efforts to occur. Age-0 channel catfish was the most abundant fish with overall fish catch rate being relatively low. Only 24 Rio Grande silvery minnow were collected in September 2002 in the lower study area and again, none of those fish had been marked with a VIE implant. In contrast to the upstream reach, the age-0 cohort of Rio Grande silvery minnow numerically dominated the meager catch of that species in the lower reach (88%; n=21).

As during September 2002, the October survey for marked Rio Grande silvery minnow in the San Acacia Reach was conducted as two separate sampling efforts (Figure 6). The upper portion of the study reach was sampled during 9-11 October while the lower section was surveyed 16-18 October. Discharge in the Rio Grande during these periods fluctuated moderately at San Acacia Diversion Dam but remained constant at San Marcial Railroad Bridge Crossing. Mean daily discharge rose from 100 cfs (4 October 2002) to 165 cfs on 9 October and peaked at 224 cfs on 11 October 2002. Conversely, mean daily discharge at San Marical before, during, and after the 16-18 October sampling effort was 55 cfs (± 5 cfs). This consistency in flow was, in part, because the source of most of the flow in the Rio Grande from the southern boundary of Bosque del Apache National Wildlife Refuge downstream to Elephant Butte Reservoir was water pumped from the Low Flow Conveyance Channel into the river channel. Water pumps at two locations (southern boundary of Bosque del Apache National Wildlife Refuge and Fort Craig) maintain consistent flow in this reach.

The final dedicated mark-recapture sampling effort yielded the fewest Rio Grande silvery minnow during this study and again failed to produce any VIE tagged specimens. A total of 19 Rio Grande silvery minnow were collected during the October 2002 mark-recapture sampling. The downstream-most portion (vicinity of U. S. Hwy 380 Bridge) of the upper study reach yielded the fewest fish probably as a result of river drying during summer 2002. In addition, fish in that portion of the river were noted to be in poor health based on emaciated morphological appearance and presence of parasitic infestation. Conversely, the highest catch rate was in the uppermost segment of the upper study reach (at San Acacia Diversion Dam). Only six Rio Grande silvery minnow were collected in the upper study reach with four of those individuals being age-1 fish (64-74 mm SL). Two age-0 silvery minnow were collected in the upper portion of the San Acacia Reach during October 2002 (46 and 53 mm SL) and one of those individuals had *Lernaea* affixed near its dorsal fin.

Most Rio Grande silvery minnow (68%; n=13) taken during October 2002 were collected in the lower portion of the San Acacia Reach. All 13 of those specimens were age-0 fish ranging in length from 32-53 mm SL. Eight of the 13 Rio Grande silvery minnow were collected in relatively deep, low-velocity habitats at a site ca. 1.5 miles downstream of San Marcial Railroad Bridge Crossing. Field personnel noted that all of those specimens appeared in good condition as suggested by the lack of external parasites and distended gut. That site also produced a relatively large number of fish. The up-and-downstream most sites in the lower study area continued to yield relatively few fish or Rio Grande silvery minnow as the river in those sections regularly dried.

A unique artificial habitat was created by the five water pumps at the southern boundary of Bosque del Apache National Wildlife Refuge. The volume of water being pumped into the river channel was slightly more than the river channel and slope could transport and therefore backed up river about 250 m from the pump outfall. The habitat created by this upstream discharge was a very large backwater with a wide range of water depths (up to 1 m) and shoreline habitats. This mesohabitat was occupied by many aquatic species including two age-0 Rio Grande silvery minnow (40, 51 mm SL), one white bass, *Morone chrysops*, (ca. 200 mm SL), and a painted turtle. These latter two organisms are rarely encountered in this portion of the Rio Grande. No additional dedicated mark-recapture samples were made.

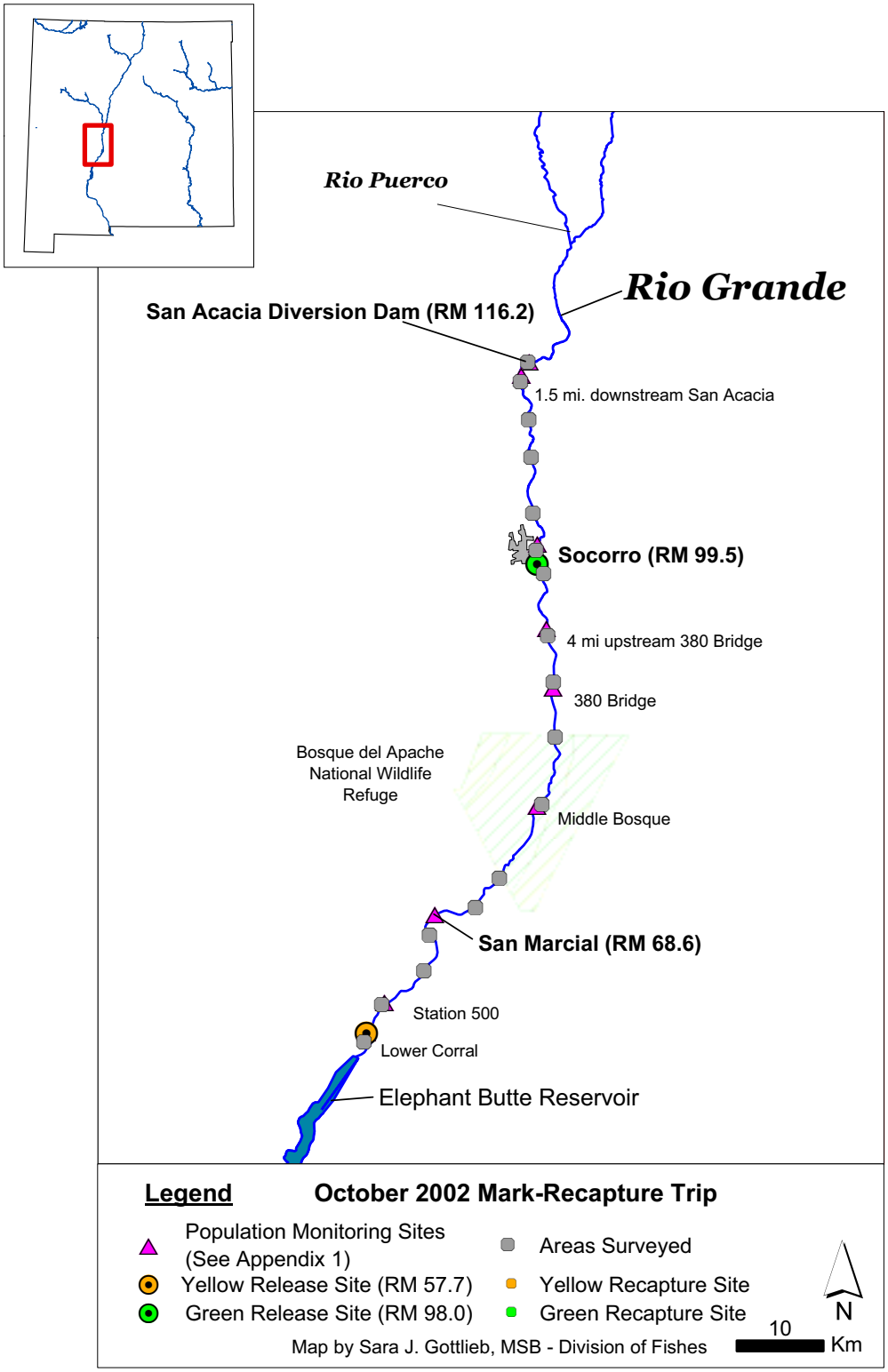

Figure 6. Summary of the October 2002 Rio Grande silvery minnow recapture information from the San Acacia Reach of the Rio Grande.

Rio Grande silvery minnow population monitoring sampling efforts

There were 12 monthly samples made at nine sites in the San Acacia Reach of the Rio Grande between January 2002 and December 2002. Those samples resulted in the collection of over 42,000 fish and 1,017 Rio Grande silvery minnow in the 70,500 m^2 sampled. Ten marked Rio Grande silvery minnow were taken, in five separate samples, between 22 January and 22 May 2002 in the population monitoring collections. Samples containing six and one yellow tagged silvery minnow were taken in January and February 2002, respectively, at the population monitoring station in the immediate vicinity of the lower release site. Single green tagged silvery minnow were collected on 25 March, 24 April, and 22 May 2002. Specimens were taken as far south as the U. S. Hwy 380 Bridge Crossing at San Antonio and as far north as the apron of San Acacia Diversion Dam. Noteworthy was that the individuals collected at San Antonio represented the southernmost record of movement while the individual taken at San Acacia Diversion Dam was the upstream-most record for a marked specimen during this study. In addition, the 24 April 2002 specimen (1.5 miles downstream of San Acacia Diversion Dam) was a gravid female while the 22 May 2002-San Acacia Diversion Dam specimen was a female that had released eggs (=spent).

Rio Grande silvery minnow recapture and movement summary

A total of 66 VIE tagged Rio Grande silvery minnow were collected during the tenure of this study. About half (47%; n=31) of the recaptured specimens were green-marked fish taken in 11 separate samples in the upper portion of the San Acacia Reach (Table 1; Figure 7). Slightly more (n=35) yellow-marked silvery minnow were recaptured, than green-marked, however 69% of the yellow-tagged silvery minnow (n=24) were taken (collectively) in two samples and they were not nearly as equally distributed throughout the study area as green-tagged fish.

Green-tagged fish were first recaptured 54 days after being released (4 March 2002) and last taken 133 days post-release (22 May 2002). Most of the recaptured green-tagged fish (n=19) were collected within 55 days of release. Fish in the lower portion of the study area were first collected 13 days after being released and last taken 42 days after release. All except one of the yellow-tagged recaptures was taken within 36 days of the release.

The general tendency was for downstream dispersal of marked fish. Collectively, 67% (n=44) of the marked fish moved downstream while 77% (n=51) of the fish were collected either at or downstream of the release site. Seventeen of the 31 (55%) of the green-tagged Rio Grande silvery minnow were collected downstream of the point of release. Only one (3%) of the 35 yellow-tagged silvery minnow was taken upstream of the release site. Seven yellow-tagged specimens (20%) were recaptured at the release site (RM 57.7) while the remainder (77%; n=27) were taken in the 1.3 mile reach of river downstream of RM 57.7.

The distance traveled by recaptured fish (excluding those recaptured at the release site) ranged from 0.26 km (0.16 mi) to over 25 km (15.54 mi). The seven longest distances traveled, based on individual samples versus the number of individuals present in the sample, were by Rio Grande silvery minnow containing a green VIE tag. In those seven samples, the distance of dispersal ranged from 3,360 m (2.09 mi) to 25,170 m (15.64 mi). The longest distance traveled by a recaptured yellow-tagged silvery minnow was 2,930 m (1.82 mi). Four of the five longest distances recorded for recaptured Rio Grande silvery minnow were based on the capture of a single tagged specimen. The exception to the convention of a single specimen was the collection of two green-marked silvery minnow 7,910 m downstream of the release site. In general, the recapture of marked fish was negatively correlated with distance from the respective release site.

Fish that were collected the greatest distance from the release site did not necessarily travel the greatest distance per day. The highest rate of travel was by the green tagged Rio Grande silvery minnow captured 105 days after and about 14.4 miles from the release site (Table 2). Mean daily

Table 1. Summary of 2002 Rio Grande silvery minnow recapture information from the San Acacia Reach of the Rio Grande.

FIELD #	N	Recapture Date	Recapture Location (RM)	Number of Days post Release	Distance * Traveled (river miles)	Distance * Traveled (m)
			Green VIE Tagged			
RELEASED	ca. 7,300	09 Jan 02	98.0			
MAF02-019	4	04 Mar 02	98.6	54	+ 0.7	+ 1,070
MAF02-021	5	04 Mar 02	96.7	54	- 0.7	- 1,050
MAF02-022	6	05 Mar 02	94.1	55	- 2.1	- 3,360
MAF02-023	2	05 Mar 02	93.2	55	- 3.0	- 4,860
MAF02-025	2	05 Mar 02	91.3	55	- 4.9	- 7,910
SPP02-051	1	25 Mar 02	87.1	75	- 9.4	- 15,140
MAF02-045	5	08 Apr 02	99.2	89	+ 1.3	+ 2,090
MAF02-048	3	09 Apr 02	103.0	90	+ 4.0	+ 6,400
MAF02-051	1	10 Apr 02	97.4	91	- 0.5	- 760
SPP02-079	1	24 Apr 02	114.6	105	+ 14.4	+ 23,140
SPP02-095	1	22 May 02	116.2	133	+ 15.6	+ 25,170
Total Green	31					
			Yellow VIE Tagged			
RELEASED	ca. 4,600	09 Jan 02	57.7			
SPP02-005	6	22 Jan 02	57.7	13		0
MAF02-006	13	12 Feb 02	53.7	34	- 1.2	- 1,950
MAF02-007	11	12 Feb 02	54.3	34	- 0.5	- 830
MAF02-008	3	12 Feb 02	54.7	34	- 0.2	- 260
MAF02-012	1	14 Feb 02	57.1	36	+ 1.8	+ 2,930
SPP02-027	1	20 Feb 02	57.7	42		0
Total Yellow	35					
GRAND TOTAL	66					

* calculated as the unidirectional distance between release and recapture points within the river channel
- indicates downstream movement, + indicates upstream movement

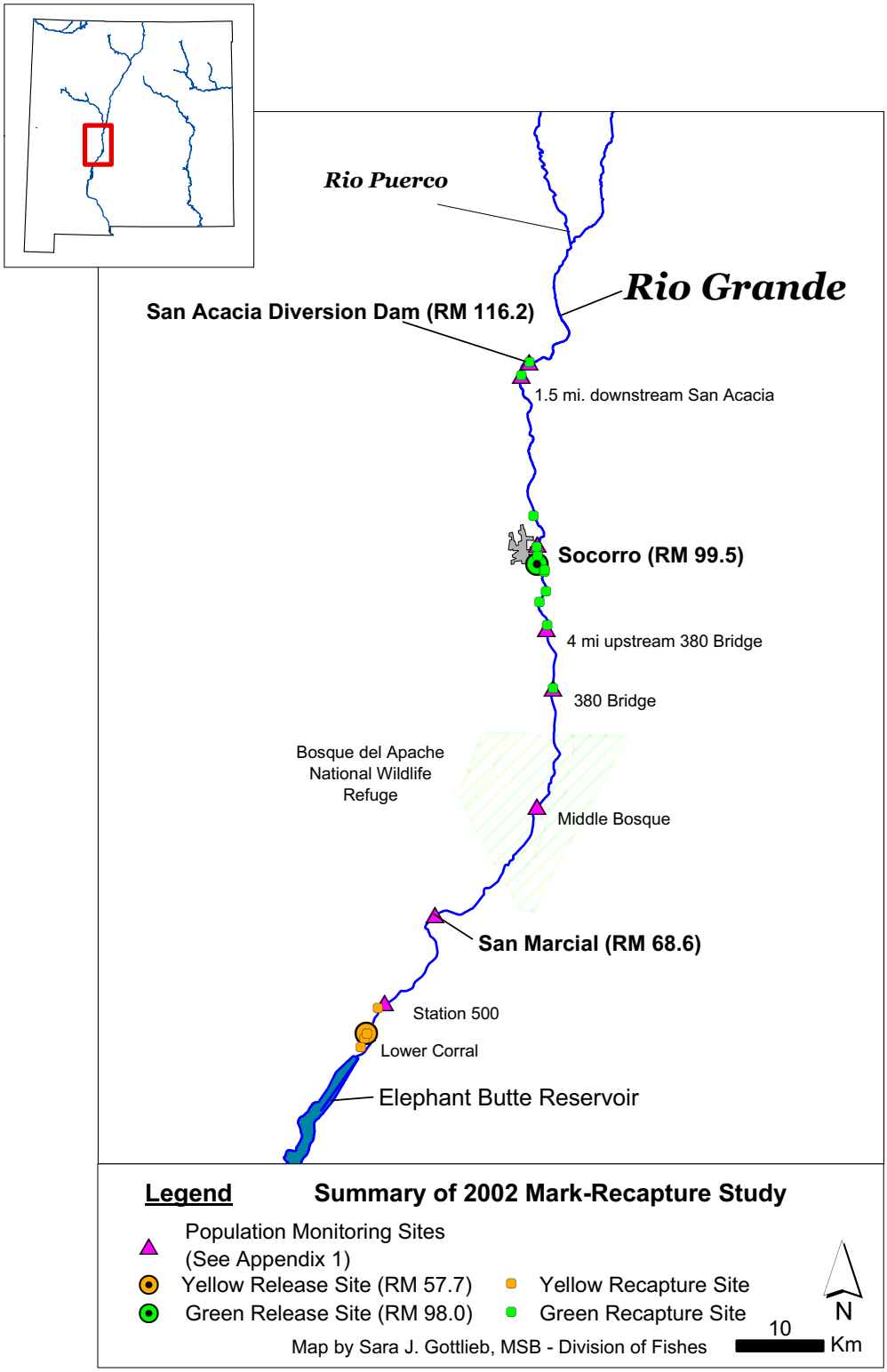

Figure 7. Summary of the 2002 Rio Grande silvery minnow recapture information from the San Acacia Reach of the Rio Grande.

Table 2. Summary of 2002 Rio Grande silvery minnow rate of travel information from the San Acacia Reach of the Rio Grande.

FIELD #	N	Recapture Date	Days Post Release	Distance [1] Traveled river miles	Distance [1] Traveled (m)	Travel Rate m/day	Body-lengths [2] per day	Total # body-lengths
			Green VIE Tagged					
RELEASED	ca. 7,600	09 Jan 02						
MAF02-019	4	04 Mar 02	54	0.7	1,070	20	305	16,462
MAF02-021	5	04 Mar 02	54	0.7	1,050	19	299	16,154
MAF02-022	6	05 Mar 02	55	2.1	3,360	61	940	51,692
MAF02-023	2	05 Mar 02	55	3.0	4,860	88	1,359	74,769
MAF02-025	2	05 Mar 02	55	4.9	7,910	144	2,213	121,692
SPP02-051	1	25 Mar 02	75	9.4	15,140	202	3,106	232,923
MAF02-045	5	08 Apr 02	89	1.3	2,090	23	361	32,154
MAF02-048	3	09 Apr 02	90	4.0	6,400	71	1,094	98,462
MAF02-051	1	10 Apr 02	91	0.5	760	8	128	11,692
SPP02-079	1	24 Apr 02	105	14.4	23,140	220	3,390	356,000
SPP02-095	1	22 May 02	133	15.6	25,170	189	2,912	387,231
Total Green	31							
			Yellow VIE Tagged					
RELEASED	ca. 4,600	09 Jan 02						
SPP02-005	6	22 Jan 02	13	0	0	---	---	---
MAF02-006	13	12 Feb 02	34	1.2	1,950	57	882	30,000
MAF02-007	11	12 Feb 02	34	0.5	830	24	376	12,769
MAF02-008	3	12 Feb 02	34	0.2	260	8	118	4,000
MAF02-012	1	14 Feb 02	36	1.8	2,930	81	1,252	45,077
SPP02-027	1	20 Feb 02	42	0	0	---	---	---
Total Green	35							
GRAND TOTAL	66							

[1] calculated as the unidirectional distance between release and recapture points within the river channel

[2] Based on a body-length of 65 mm TL

distance traveled by that individual was 220 m/day. The green-tagged Rio Grande silvery minnow collected at RM 87.1 on 25 March 2002, 75 days after release, exhibited a mean daily travel rate of 202 m/day. Conversely, the individual that was captured the farthest distance from the release site had only the third highest mean daily rate of dispersal (189 m/day). All of the recaptured yellow-tagged Rio Grande silvery minnow exhibited mean daily travel rates <100 m/day. The yellow-tagged silvery minnow collected the greatest distance from the lower release site had the greatest mean daily rate (81 m/day) of dispersal and, following suite, the yellow-tagged fish that traveled the second farthest had the second highest daily rate (57 m/day) of travel.

Distance traveled (and swimming speed) is often presented in relative terms, such as body-length, to provide additional perspective to daily and overall dispersal. Recaptured yellow-tagged Rio Grande silvery minnow traveled a mean total distance of about 23,000 body-lengths while the mean total body-length distance traveled by green-tagged specimens was 127,000. The individual Rio Grande silvery minnow collected at San Acacia Division Dam had to travel over 387,000 body-lengths to arrive at that point while the green-marked fish that was recaptured at RM 87.1 traveled a minimum of 233,00 body lengths to reach that locality. Eleven of the recaptured fish averaged traveling a distance of over 1,000 body-lengths each day prior to capture.

DISCUSSION

It is prudent to reiterate, at this point in the report, the original scope and goal of this study, circumstances that dictated modification of the proposed research activities, an accounting of those modifications, and finally the resulting revised scope and goal. This project began specifically as a pilot study designed to evaluate the utility of the VIE marking technique on a laboratory population of Rio Grande silvery minnow and perform an initial assessment of recapture ability and rate. If initial laboratory marking and field recapture efforts were successful, the pilot study would incorporate field marking and recapture of wild young-of-the-year individuals in the San Acacia Reach during 2002 and assess those efforts. Marking of wild Rio Grande silvery minnow would have been initiated (presumably) about 12 weeks after spawning and their movements tracked through the end of 2002.

The number of fish available for the initial marking and release portion of the proposed study was <25% of that estimated to be available when the project was proposed. Even the number of fish originally projected to be available for the project was considered small and perhaps marginal for successful recapture efforts. The severe underestimation of individuals available was unavoidable as an accurate accounting could not be acquired until the ponds at Dexter National Fish Hatchery and Technology Center that housed Rio Grande silvery minnow had been drained and the fish collected and marked. Despite the relatively small number of individuals ultimately available for this study, the considerable success (survivorship and marking of small fish) achieved during marking provided the impetus for the continuation of the project.

The revised scope included intensive short-term (pre-runoff) sampling for the 12,000 released marked silvery minnow and retained the component regarding field marking and recapture of young-of-the-year wild produced Rio Grande silvery minnow in 2002. The intensive sampling activities rapidly documented the downstream dispersal of marked fish and indicated that recapture rates from only 12,000 fish would be extremely low. Drought conditions in the Upper and Middle Rio Grande Basin, beginning in winter 2001-2002 with meager snowfall, were manifested in a significantly reduced 2002 spring runoff that continued throughout the summer. Concurrently, the number of wild and recaptured Rio Grande silvery minnow declined throughout winter and spring 2002 and few larval silvery minnow were present after the 17-20 May 2002 artificial spike of water released to induce spawning in this species. Sampling in June, July, and August 2002 documented the continued decline of Rio Grande silvery minnow in the San Acacia Reach and indicated that the population was insufficient to support the originally proposed mark-recapture activities of wild fish.

The lack of wild young-of-the-year Rio Grande silvery minnow resulted in an additional modification to the study plan. Efforts were reinitiated, in September 2002, to conduct intensive sampling to recapture silvery minnow that had been released in January 2002. The last date that an individual had been recaptured was 22 May 2002 and it was noteworthy because that fish had moved further than any other recaptured specimen. Intensive sampling directed towards the recapture of marked Rio Grande silvery minnow occurred in both September and October 2002 but, because it failed to produce any recaptures, was terminated in late October 2002.

The a posteriori scope and goal of the project retained the core elements of the original proposal. The project remained a pilot effort designed to evaluate the efficacy, under laboratory conditions, of the VIE marking technique on Rio Grande silvery minnow. In addition, the study addressed the ability of researchers to recapture marked specimens. Low flow conditions in the Rio Grande and the dearth of young-of-the-year silvery minnow precluded the ability to incorporate the field marking and recapture component of the research design into the 2002 study.

There are few studies that attempt to document the movement of small-bodied native fishes, even fewer that dealt with small-bodied fish movement in large rivers, and none that have examined these variables in Great Plains stream fishes. Hill and Grossman (1987a) used subcutaneous marks to determine home ranges of three species of fish in a small fourth order stream in the Blue Ridge Mountains of North Carolina. Two of the three species in the study were benthic (longnose dace, *Rhinichthys cataractae,* and mottled sculpin, *Cottus bairdi*) but the third taxon (rosyside dace, *Clinostomus funduloides*) occupied mid-water column microhabitats. Home range estimates for each of the three species was small (<20 m) and the maximum distance moved was about 100 m by rosyside dace. They also published information regarding the marking technique (injected colored acrylic paint) employed in that study (Hill and Grossman, 1987b). Freeman (1995) examined movements by two small-bodied fishes (blackbanded darter, *Percina nigrofasciata,* and redbreast sunfish, *Lepomis auritus)* in a large Coastal Plain stream (Ichawaynochaway Creek) in the Apalachicola River Basin of southwestern Georgia. The creek where the investigation occurred was characterized as 30-40 m wide and 0.5 to 7 m deep. Freeman (1995) employed the marking procedure described by Hill and Grossman (1987b) and tagged over 2,500 specimens in the study area. About 90% of the approximately 300 recaptures had moved <33 m with a maximum movement of 420 m by a single blackbanded darter. Freeman (1995) considered any movement >100 m by individuals of either of these two species to be “a considerable distance.”

In the American Southwest, research on movement of a cyprinid species in a large river drainage has been ongoing for over 15 years. Investigation of Colorado pikeminnow, *Ptychocheilus lucius,* movement has been conducted throughout the Colorado River Basin since the late 1980s. Radio-tagging studies have documented the home range, dispersal pattern, and movement during the spawning season of this species in the Green River (Tyus, 1990), Upper Colorado River (McAda and Kaeding, 1991; Osmundson, et al., 1998), and White River (Irving and Modde, 2000). However, Colorado pikeminnow is different than Rio Grande silvery minnow in most life history attributes. Despite being in the minnow family (Cyprinidae), Colorado pikeminnow is a large-bodied fish that can achieve lengths of up to 1,000 mm TL, mass >10 kg, and is long-lived (ca. 20-40 years). The biological, ecological, and zoogeographical differences between these two taxa mean that there is little that can be gleaned from Colorado pikeminnnow movement studies that would contribute to the base of knowledge regarding Rio Grande silvery minnow home range and dispersal.

The 2002 mark-recapture study of hatchery reared wild-produced Rio Grande silvery minnow resulted in the acquisition of extremely valuable information in the fields of fish marking techniques and behavior, and archetypal data regarding movement of a small-bodied Great Plains stream fish. The study clearly demonstrated not only that a large number of Rio Grande silvery minnow can be marked in a relatively short time, but also that a substantial percentage of the marks are retained, that

small fish (15-35 mm SL) can be successfully tagged, and that the combination of multiple colors and placement of VIE tags provides a system for hundreds of unique marks.

Availability of qualified personnel is the principal limiting factor of the number of fish that can be marked. A team of four to six experienced individuals can tag up to 5,000 large (45-65 mm SL) Rio Grande silvery minnow every eight hours (not including setup time). The high viscosity of the elastomer in concert with the small diameter of the needle (28 gauge) require exertion of extreme pressure on the small plunger-head of the 0.3-cc syringe. Unfortunately, this results in rapid fatigue in the hand of the individual implanting the VIE tags. Use of the "hand injector" adaptor bulb supplied by the VIE manufacturer diminishes but does not eliminate this fatigue. This important factor, in combination with the need to ensure the consistent placement, amount, and distribution of elastomer, means that the individual responsible for tag implantation must be relieved or replaced frequently and regularly. Capable support personnel are also crucial for these efforts as they capture, retrieve, anaesthetize, and return the marked fish to holding facilities.

Fish as small as 15 mm SL were marked during this research effort and did not exhibit, in the laboratory, a higher mortality than large individuals. Small fish marking techniques (<20 mm SL) will be especially important if studies to determine patterns of movement in wild young-of-the-year Rio Grande silvery minnow (8-12 weeks old) are to be undertaken. Such a study would provide information on the upstream dispersal of silvery minnow within two to three months of their downstream displacement as eggs and larvae. It is important to discern not only the timing of redistribution of this cohort, but also to understand the mechanism of dispersal.

There appears to be considerable misunderstanding, as indicated in part by the frequent misuse of terms related to the dispersal of Rio Grande silvery minnow, regarding this aspect of the species' ecology. Dispersal is characterized as the one-way permanent movement away from an established home range, natal area, or point of origin (Ricklefs, 1990). This relatively specific behavior has been frequently misrepresented as being synonymous with migration. In contrast, migration is the directed movement between locations or areas (often a two-way movement) which usually occurs immediately prior to reproduction and results in the initiation of reproductive or feeding responses. Another important distinction between the two behaviors is that migration occurs at the population level while dispersal is an individual event. The upstream redistribution of Rio Grande silvery minnow necessary to offset their downstream displacement as propagules is clearly accomplished through dispersal rather than migration.

Tag retention in marked Rio Grande silvery minnow remained high (>80%) even 400 days after initial insertion. Likewise, there was no little mortality of specimens associated with the tagging procedure. Both of these values are expected to improve as marking techniques become refined and individual researchers acquire additional experience with the intricacies and functioning of the marking equipment as well as handling tolerance of the fish. An important consideration of the successful marking procedure was that the work was conducted in a laboratory setting. It will not be possible to reproduce controlled laboratory conditions in the field and therefore one should expect a decline in variables associated with laboratory marking (survivorship, retention, rate of marking). The extent and magnitude of modification to the laboratory marking protocol that will be necessary to allow for the efficient marking in the field of large numbers of wild young-of-the-year Rio Grande silvery minnow will require additional trials and study.

The principal limitation of this and future Rio Grande silvery minnow mark-recapture investigations is low recapture rate. Sampling efforts during 2002 were highly intensive (labor and area covered) and occurred during a hydrologic period when, due to low discharge (100-400 cfs), sampling efficiency and recapture rate should have been very high. This was not realized and it is likely that future recaptures will also be very low. It should also be assumed, in general, that recapture rate is negatively correlated (can be expected to decline) with increasing discharge.

Although extensive use of passive collecting gear would reduce the amount of labor expended per unit of time sampled, there is no reason to assume that such a modification would result in a significant increase in catch rates. In fact, given the life history and ecology of Rio Grande silvery minnow, it is more likely that passive sampling would result in a markedly lower catch rate per unit time than seining. Increasing the number of marked specimens in the study area is the most probable means of increasing the number, but not cumulative rate, of recaptured fish. While the initial rate of recapture would also be expected to be greater than that previously encountered, the recapture rate (between studies) is likely to equilibrate rapidly thereafter.

Besides hydrologic conditions, recapture rate is ultimately dependent on various life history aspects and behavior of the fish in addition to the habitat occupied. Species of fish that can be relatively easy to recapture include benthic taxa (darters and sculpins), those that are habitat specialists (cave and spring fishes), species in which all ontogenetic stages are sedentary (stonerollers), and forms that occupy low-order streams. Great Plains stream fishes such as Rio Grande silvery minnow or Pecos bluntnose shiner, *Notropis simus pecosensis,* are neither habitat specialists, benthic, nor sedentary but rather they are inhabitants of the water column and have evolved life history characteristics which serve to define their home ranges as extensive. In addition, the numerous, dynamic, and large patches of habitat present in Great Plains stream allow these species to range throughout continuous portions of the stream systems. Collectively these factors contribute to a low Rio Grande silvery minnow recapture rate.

Several important and encouraging interactions of released (marked) Rio Grande silvery minnow with wild conspecifics were documented during this investigation. Survival of hatchery reared individuals and their incorporation into the population of wild individuals may be necessary for the survival of the species. That the hatchery reared fish were usually collected with wild conspecifics bodes well for the survival of the former individuals because it implies a level of ecological normalcy regarding life history attributes compared with wild fish. At a minimum, collection of marked fish with conspecifics implies a repatriation of a least a portion of the hatchery fish population with the wild fish. Unfortunately, the smaller size (SL) of the hatchery reared fish, compared to wild collected specimens, was consistently evident. Future propagation and release efforts will need to address these differences as the generally accepted principle is that larger individuals are more fit and have greater likelihood of survival.

The synchronous collection of marked and unmarked gravid female Rio Grande silvery minnow during April 2002 provided additional evidence that hatchery reared fish were expressing selected life history attributes, at the correct time of year, characteristic of this species. This also suggests the elevated likelihood of survival and reproduction of hatchery stocks of fish. This observation was further validated by the 22 May 2002 collection of a hatchery-reared female silvery minnow that appeared to have recently spawned. The principal period of reproduction of Rio Grande silvery minnow in the San Acacia Reach of the Rio Grande during 2002 was 17-20 May (Platania and Dudley, 2003). The collection of the gravid marked Rio Grande silvery minnow in April and the subsequent collection of a reproductively spent female in May (post-spawn by wild population) demonstrated that those individuals had not only exhibited the normal life-history functions of the species but expressed them concurrently with members of the wild population.

The 2002 mark-recapture study also documented two very important facets of movement in Rio Grande silvery minnow. The study highlighted the propensity of hatchery reared silvery minnow to redistribute in a downstream direction and the ability of individuals to move extensive distances upstream in a relatively short time (Hendrickson and Brooks, 1991, and references therein). There is a wealth of information available on the behavior of hatchery reared fish upon release to the wild and the tendency for large numbers of individuals to rapidly redistribute downstream. While the 2002 mark-recapture study was not designed specifically to assess the timing, rate, and magnitude of this

movement, it did provide evidence suggesting that this behavior was prevalent in hatchery reared Rio Grande silvery minnow. Detailed attention to that behavior will have to be addressed as part of the ongoing propagation effort. This will likely include modification and experimentation in rearing and holding procedures at the propagation facilities. Unfortunately, almost all previous studies have reported little success in curtailing the behavioral tendency in hatchery reared fish to rapidly disperse downstream (Hendrickson and Brooks, 1991, and references therein).

Finally, this study provided verification of the ability of Rio Grande silvery minnow to move considerable distances upstream. The term "verification" is purposely used herein as opposed to "documentation" so as to distinguish between that which is already known and that which is hypothesized. Drift, as broadly defined in stream ecology, is passive downstream movement of early life stages of aquatic organisms (Walters, 1972). The dynamics of drift are such that organisms that drift must actively move back upstream or there will be a net downstream loss of individuals followed by loss of populations and ultimately localized extinction. The presence of adult stages (of organisms that employ drift as an aspect of their life history) in upstream reaches provides the "documentation" of their upstream movement. Conversely, collection of an individual several km upstream of the point of release is "verification" of that which was already implicit in the discipline of drift.

The maximum distances traveled by Rio Grande silvery minnow documented in this study far surpass those reported by other researchers studying small-bodied fishes (Freeman, 1995; Hill and Grossman, 1987; Warren and Pardew, 1998). In those studies, the distance that fish moved were reported in terms of 10's or 100's of m while silvery minnow movements are best expressed in terms of km. These distances again serve to highlight the importance of a continuous river ecosystem to Great Plains stream fishes, especially those which are members of the reproductive guild characterized by pelagic spawning and semibuoyant eggs (Platania and Altenbach, 1998). Likewise, these data also punctuate the deleterious effects of river fragmentation on the continued existence of Rio Grande silvery minnow and indicated as paramount for recovery of Rio Grande silvery minnow in the Middle Rio Grande the need for a reconnected river.

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Appendix I. San Acacia Reach collection localities for 2002 Rio Grande silvery minnow population monitoring study.

SAN ACACIA REACH SITES

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

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

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

New Mexico, Socorro County, Rio Grande, ca. 4.0 miles upstream of US Highway 380 bridge crossing.
River Mile 91.7 SAN ANTONIO QUADRANGLE
UTM Easting: 328140 UTM Northing: 3761283 Zone: 13

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

New Mexico, Socorro County, Rio Grande, directly east of Bosque del Apache National Wildlife Refuge Headquarters.
River Mile 79.1 SAN ANTONIO, SE QUADRANGLE
UTM Easting: 327055 UTM Northing: 3740839 Zone: 13

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

Appendix I. San Acacia Reach collection localities for 2002 Rio Grande silvery minnow population monitoring study (continued).

SAN ACACIA REACH SITES

New Mexico, Socorro County, Rio Grande, at its former confluence with the Low Flow Conveyance Channel; 16 miles downstream of the southern end of the Bosque del Apache National Wildlife Refuge; ca. 8 miles downstream of San Marcial Railroad bridge crossing.
River Mile 60.5 PARAJE WELL QUADRANGLE
UTM Easting: 309487 UTM Northing: 3718178 Zone: 13

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