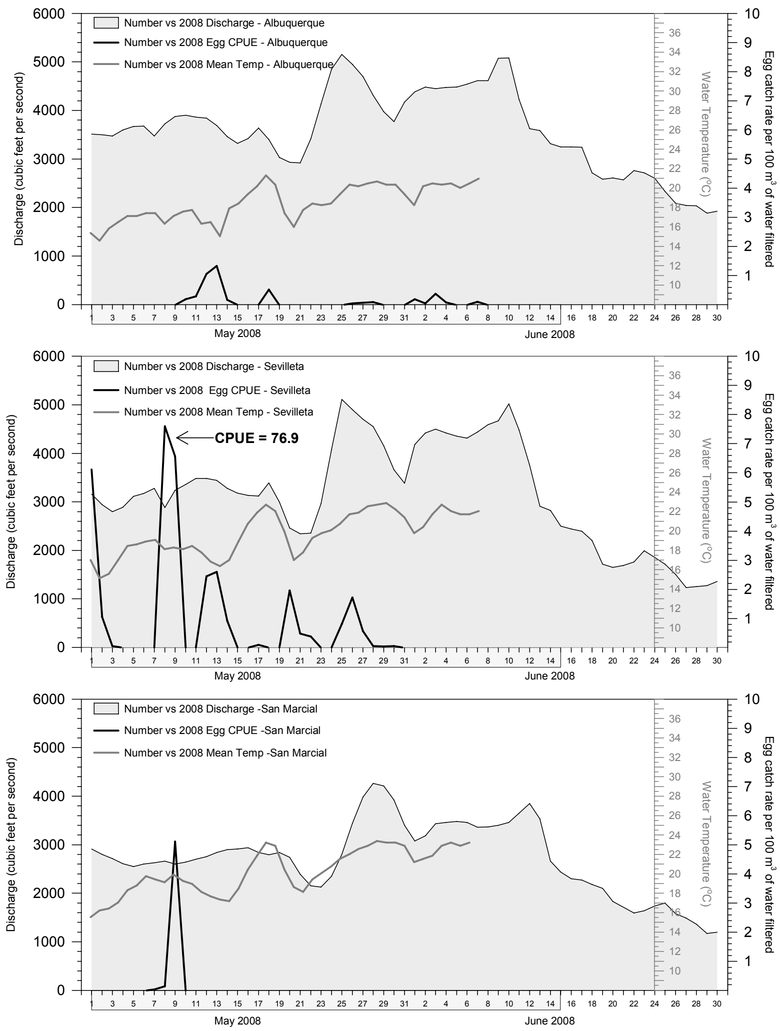
Spatial Spawning Periodicity of Rio Grande silvery minnow during 2008

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



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16 December 2008

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prepared for:

Middle Rio Grande Endangered Species Act Collaborative Program

under USBR contract:

Number 03CR408031
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December 2008

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EXECUTIVE SUMMARY

Systematic monitoring of the reproductive output of Rio Grande silvery minnow at several sites in the Middle Rio Grande was first conducted in 1999 (Platania and Dudley, 2002a) and has continued annually (except 2005) since 2001. Previous studies (Platania and Dudley 2002a, 2002b, 2002c, 2004) demonstrated May and June as the primary period of silvery minnow reproductive activity. The 2006-2008 studies were structured to monitor the spatial and temporal (May-June) reproductive output of Rio Grande silvery minnow in the Middle Rio Grande and therefore, given the downstream drift of the eggs, was conducted near the downstream-most portion of each of the three accessible river reaches (Angostura, Isleta, and San Acacia).

There was a large difference in flow in the Middle Rio Grande in 2008 as compared to 2001-2004 and 2006. The severe drought that enveloped the study region since 2000 was somewhat interrupted in 2004 and 2007 due to a moderate snowpack and wetter than normal April. These precipitation events helped but did not replenish the already diminished water reserves in upstream reservoirs. Spring flow conditions improved markedly during 2007, as compared with 2006, and there was an extended period of time during May and June when flows exceeded 2,000 cfs at the Albuquerque Gauge (USGS Gauge 08330000). Extended high spring flows were even more substantial in 2008 when flows at the Albuquerque Gauge exceeded 3,000 cfs for most of May and June. Mean daily discharge in the Rio Grande at the Albuquerque Gauge (USGS Gauge 08330000) from 1 April through 30 June 2008 ranged between 1,880 and 5,150 cfs (mean value= 3551.6 cfs, SD=719.8).

Sampling at each of the three 2008 Rio Grande silvery minnow spawning periodicity study sites was conducted from 1 May through 15 June 2008 (n= 46 days). The cumulative volume of water sampled at these three Rio Grande sites was 220,037 m^3 (178.4 acre-feet). A cumulative total of 2,132 Rio Grande silvery minnow eggs were collected at the three sites during 2008. The vast majority (n= 1,917; 89.9%) of the catch was taken at the Sevilleta Site while the number and cumulative percent of Rio Grande silvery minnow eggs collected at the Albuquerque (n= 60; 2.8%) and San Marcial sites (n= 155; 7.3%) were low. Dates of egg collection ranged from 7-9 May (three days) at the San Marcial Site, 1 May through 29 May (29 days) at the Sevilleta Site, and 10 May through 7 June (29 days) at the Albuquerque Site. Mean daily water temperatures during spawning in 2008 ranged between 14.3 and 19.3°C at the Albuquerque Site, between 14.1 and 21.6°C at the Sevilleta Site, and between 18.0 and 18.3°C at the San Marcial Site.

Statistical analyses among all years were made using data from the San Marcial sampling locality since that site was the only common one for all years. Analysis of reproductive output revealed a significant difference (F=6.11; p<0.0001) among mean values of catch rate (#/100m^3) for the six years of the study (2002-2004, 2006-2008). The following pair-wise comparisons were significant (p<0.05) over the period of record (2002 vs. 2004, 2002 vs. 2006, 2006 vs. 2007). The natural log-transformed mean egg catch rate (standarized for discharge) was highest in 2002 (5.86 ±0.93), followed by 2007 (4.77±0.37), 2008 (3.22±1.32), 2003 (2.89±0.54), 2006 (1.44±0.72), and 2004 (0.96±1.32). Additional statistical analyses for the Angostura and Isleta reaches were made over the period of time that data were available (2006-2008). Analysis of reproductive output revealed no significant difference (F=0.51; p>0.60) among mean values of catch rate (#/100m^3) for the three years of the study (2006-2008) in the Angostura Reach. However, analysis of reproductive output revealed a significant difference (F=9.83; p<0.0002) among mean values of catch rate (#/100m^3) for the three years of the study (2006-2008) in the Isleta Reach. The following pair-wise comparisons were significant (p<0.05) over the period of record (2006 vs. 2007, 2006 vs. 2008) in the Isleta Reach. The natural log-transformed mean egg catch rate (standarized for discharge) was highest in 2008 (4.28 ±0.45), followed by 2007 (4.19±0.41), and 2006 (1.97±-0.41) in the Isleta Reach.

Rio Grande silvery minnow appear to have had another good year for spawning and recruitment, which should translate into increased numbers of reproductively capable females available to spawn in the spring of 2009. While the population of Rio Grande silvery minnow appears to have stabilized since 2007, the lack of an adequately high spring runoff (high magnitude over an extended duration) could result in a rapid decline to pre-2005 population levels. The future conservation status of Rio Grande silvery minnow appears dependent on ensuring adequate flow conditions during the spawning and early recruitment phases of this species.

INTRODUCTION

The reach of the Rio Grande between Cochiti Dam and Elephant Butte Reservoir (Middle Rio Grande) has been greatly modified over the last 50 years; this has alternatively led to aggradation, degradation, amoring, and narrowing of the river channel in different portions of the reach (Lagasse, 1985). This section of the river flows through the massive Rio Grande rift and historically resulted in a wide floodplain within the sparsely vegetated Rio Grande valley. Extensive braiding of the river through the relatively linear Rio Grande rift valley was common as it flowed over shifting sand and alluvium substrata; flow in the Middle Rio Grande was generally perennial except during times of severe or extended drought (Scurlock, 1998).

The Middle Rio Grande was relatively shallow throughout most of the year because of regionally low precipitation levels (Gold and Dennis, 1985) but was subjected to periods of high discharge. Flow was generally greatest during the annual spring snow melt runoff (April-June), however intense localized rainstorms (monsoonal events that generally occur in July and August) often caused severe flooding and were important in maintaining perennial flow through the summer. The cyclic pattern of drought and flooding over mobile substrata likely helped to promote the active interaction between the river and its floodplain. Historically, the Middle Rio Grande in many ways possessed all of the characteristics distinctive of a semi-arid river ecosystem.

The reduced species diversity typical of semi-arid ecosystems was also reflected in the depauperate ichthyofaunal composition of the Middle Rio Grande. Despite the reduced species richness of the Rio Grande, the river supported many native cyprinids that were endemic to this drainage (Platania and Altenbach, 1998). However, of the few native cyprinids that historically occupied the Rio Grande basin (i.e., speckled chub, *Macrhybopsis aestivalis*, Rio Grande shiner, *Notropis jemezanus*, and Rio Grande bluntnose shiner, *Notropis simus simus*) many have been extirpated from the Middle Rio Grande over the past century. A fourth species, phantom shiner, *Notropis orca*, is extinct (Bestgen and Platania, 1990). Rio Grande silvery minnow, *Hybognathus amarus*, is the only extant member of the native cyprinid fish fauna (Bestgen and Platania, 1991; Platania, 1991) and is found only in the Middle Rio Grande.

This group of native cyprinids shared several life-history characteristics. All were small (generally <100 mm TL), short-lived (2-5 years), fishes that occupied mainstem habitats. Four of the species are characterized as omnivorous while Rio Grande silvery minnow is herbivorous and feeds on epipsammonic algae. In addition to these shared traits, all five species were members of a reproductive guild of fishes that are pelagic spawners laying semibuoyant eggs.

Reproduction in fish in this guild is characterized by the production of non-adhesive eggs that, upon expulsion, swell rapidly with water and become nearly neutrally buoyant. Upon release the eggs are about 1.6 mm in diameter but quickly expand (ca. 3.0 mm) and remain suspended in the water column during development. Egg hatching time is temperature dependent, but rapid, occurring in 24-48 hours. Recently hatched larval fish remain a component of the drift until development of the gas bladder. This physiological development corresponds with a shift in swimming behavior as larvae actively seek low-velocity habitats.

The 3-5 days necessary for propagules to attain the developmental stage necessary to control horizontal movements and freely disperse allows for considerable downstream displacement of eggs and larvae in the Middle Rio Grande. As has been well documented for other aquatic organisms, it is necessary for at least some portion of the drifting propagules to settle in appropriate low-velocity habitats or move upstream to maintain viable populations (Speirs and Gurney, 2001). 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. Historically, there were no permanent barriers to upstream dispersal of fishes in the Middle Rio Grande. There are currently three instream diversion structures between Cochiti Dam and Elephant Butte Reservoir that are barriers to upstream movement of fishes and fragment the once continuous range of the only remaining member of this reproductive guild.

The early life history of Rio Grande silvery minnow has been extensively studied (Platania and Altenbach, 1998). These investigations revealed that silvery minnow is also member of a unique reproductive guild of Rio Grande basin Plains Stream cyprinids. The studies also demonstrated that spawning by Rio Grande silvery minnow is associated with high-flow events such as spring run-off or summer rainstorms.

Systematic monitoring of the reproductive output of Rio Grande silvery minnow at several sites in the Middle Rio Grande was first conducted in 1999 (Platania and Dudley, 2002). That monitoring involved collecting and quantifying catch rate of Rio Grande silvery minnow eggs at several Middle Rio

Grande sites during the relatively short spawning period of this species. Limited Rio Grande silvery minnow egg collecting efforts were also conducted at selected sites in the Middle Rio Grande (Platania and Hoagstrom, 1996) and in the Low Flow Conveyance Channel (Smith, 1998, 1999) between 1996-1999. These latter samples provide information on the magnitude of reproduction during certain times and for specific sites. However, consistent monitoring throughout the spawning season produces the most reliable measure of the duration and magnitude of Rio Grande silvery minnow reproductive output. The first site specific sampling effort to document the magnitude of the reproductive effort of Rio Grande silvery minnow occurred daily throughout May and June 2001 (Platania and Dudley, 2002) at a location near the southern end of the San Acacia Reach of the Middle Rio Grande (River Mile 58.8). Monitoring of the reproductive effort of Rio Grande silvery minnow also occurred daily at this site in May and June 2002 (Platania and Dudley, 2003), 2003 (Platania and Dudley, 2004), and 2004 (Platania and Dudley, 2005). More intensive monitoring efforts were initiated in 2006 (Platania and Dudley, 2006) and resulted in the sampling of the Angostura, Isleta, and San Acacia reaches of the Middle Rio Grande.

Population monitoring efforts of the Middle Rio Grande fish community over the past decade have documented vast changes (i.e., order of magnitude increases and decreases) in the abundance of Rio Grande silvery minnow (Dudley and Platania, 1999, 2000, 2001, 2002; Dudley et. al., 2003, 2004, 2005; Dudley and Platania, 2007, 2008). Recent monitoring efforts (Dudley and Platania, 2008) show that the October density of Rio Grande silvery minnow was significantly lower (p<0.05) in 2007 compared to 2005. However, the October density of this species was higher (p<0.05) in 2007 than in 1996 or 2000-2004. The Angostura Reach yielded most of the Rio Grande silvery minnow in October of 2007, followed by the Isleta Reach, and the San Acacia Reach. This was in contrast to population monitoring in October of 2006, when the largest catch rates were recorded in the San Acacia Reach.

The marked 2002-2003 decline in wild Rio Grande silvery minnow and increased stocking efforts in the upper reaches of its range (Angostura and Isleta reaches) apparently resulted in a temporary reapportioning of this species' relative abundance. Between June 2002 and November 2004, over 301,000 silvery minnow were released in the Angostura and Isleta reaches of the river. While over 90% of the total Rio Grande silvery minnow catch had been recorded in the San Acacia Reach during 2000-2002, by the end of calendar year 2003, the largest percentage (58%) of individuals collected (albeit extremely reduced numbers; n=224) were taken in the Angostura Reach. This trend continued into 2004 and by October of that year, approximately 78% of the cumulative 2004 Rio Grande silvery minnow catch had been taken in the Angostura Reach, 13% in the Isleta Reach, and only 9% in the San Acacia Reach. However, the relative abundance of Rio Grande silvery minnow among reaches has fluctuated from 2005-2007 (e.g., highest densities in the Isleta Reach during 2005 and in the Angostura Reach during 2006 and 2007). This reapportionment of the Rio Grande silvery minnow population, in combination with the meager 2004 catch of reproductive propagules in the San Acacia Reach necessitated a modification of subsequent reproductive monitoring protocols beginning in 2006. Sampling sites are now established in each of the three downstream reaches of the Middle Rio Grande (Angostura, Isleta, and San Acacia) to provide a more complete data set.

The study conducted herein is at its core a continuation of the systematic 2006-2007 Rio Grande silvery minnow reproductive monitoring research activity, fulfills multiple recovery goals and will provide detailed catch-per-unit-effort (CPUE) values for Rio Grande silvery minnow eggs in each of the three Middle Rio Grande reaches that this species is known to still occur. Differences in inter-annual spawning magnitude based on mean catch rates, and standardized for flow magnitude, was assessed using ANOVA. As in previous years, selected samples of wild eggs collected during this study were provided to appropriate research personnel for an ongoing population viability study and genetic studies of captive and wild populations of this endangered fish. Starting in 2004, collection of wild Rio Grande silvery minnow eggs for use in propagation activities was made a separate project (from the reproductive monitoring effort) although personnel from each project remain in close contact during to help facilitate the separate efforts. Systematic studies of the reproductive periodicity of Rio Grande silvery minnow are also designed to provide insight to success of recent stocking efforts. Long-term monitoring of the reproductive effort of Rio Grande silvery minnow remains extremely necessary for recovery efforts and to facilitate effective management decisions.

Institutional background and considerations

Monitoring the reproductive effort of Rio Grande silvery minnow was identified as a requirement of the 29 June 2001 Programmatic Biological Opinion of the Effects of Actions Associated with the U. S. Bureau of Reclamation's, U. S. Army Corps of Engineers', and Non-Federal Entities

Discretionary Actions related to Water Management on the Middle Rio Grande, New Mexico as authored by the U. S. Fish and Wildlife Service. This work was part of an ongoing effort to document changes in the distribution and abundance of the federally endangered Rio Grande silvery minnow. This research effort provided an assessment of the reproductive output (eggs) for Rio Grande silvery minnow within the Middle Rio Grande and specifically addressed the task: "Evaluate the status and trend of the Rio Grande silvery minnow" as identified by the Middle Rio Grande Endangered Species Collaborative Program (ESA Workgroup).

The Rio Grande silvery minnow Recovery Plan (U. S. Fish and Wildlife Service, 1999) also outlined research objectives (2.2. Determine spawning periodicity of silvery minnow under multiple flow regimes; 2.2.1. Determine environmental factors that cue spawning in silvery minnow) that were addressed through this research. This investigation provided an assessment of the relative magnitude of the Rio Grande silvery minnow spawning effort and yielded information useful for resource management decisions in the Middle Rio Grande. This project was also a central component of the Rio Grande silvery minnow propagation and genetics research efforts, both requirements of the 29 June 2001 Programmatic Biological Opinion (see "Project Objectives" 2 and 3).

In 2002-2003, ESA Workgroup members met and discussed Rio Grande flow issues and impacts of the hydrological conditions on Rio Grande silvery minnow. The dismal 2002-2003 snow pack in the Rio Grande headwaters meant there would not be a natural spring flow spike in 2003 in the Middle Rio Grande and, therefore, it was unlikely that there would be a spring spawn by silvery minnow. Personnel from ESA Workgroup agencies decided to create an artificial flow spike during mid-May 2002, using reservoir storage, to initiate a spawn by silvery minnow. As 2003 climatic conditions were similar to those experienced in 2002, an artificial flow spike was also created in the Rio Grande in 2003, using reservoir storage, to initiate spawning of Rio Grande silvery minnow. Snowpack and ambient flow conditions in 2004 were sufficient enough that, for the first time in two years, this was not necessary. This document presents the results of the 2008 spawn of Rio Grande silvery minnow and compares data collected under the auspices of this study during 2001-2004 and 2006-2008.

STUDY AREA

The principal area of interest in the Middle Rio Grande is the reach between the outflow of Cochiti Reservoir and inflow to Elephant Butte Reservoir as it encompasses the known range of Rio Grande silvery minnow (Figure 1). Five upstream reservoirs and numerous irrigation diversion dams regulate flow in the Middle Rio Grande. Cochiti Reservoir has been operational since 1973, is located 76 km upstream of Albuquerque, and is the primary flood control reservoir that regulates flow in the Middle Rio Grande. Reach names are taken from the diversion structure at the upstream boundary of that reach of river. In the Cochiti Reach (between Cochiti Dam and Angostura Diversion Dam), the Rio Grande flows through Cochiti, Santo Domingo, and San Felipe pueblos, respectively.

The reproductive effort of Rio Grande silvery minnow has, in the past, been sporadically determined at selected collecting localities in the Angostura and Isleta reaches. In 2003 and 2004, our sampling efforts were restricted to the single San Acacia Reach collection location. The San Acacia Reach of the Middle Rio Grande is about 56 miles (91 km) long extending from the apron of San Acacia Diversion Dam to the head of Elephant Butte Reservoir. Sections of this reach are characterized by a wide river channel, braided flow, sand substrate, high suspended sediment load, and broad variety of aquatic mesohabitats. Conversely, some segments in this reach are relatively narrow and result in increased water velocity and decreased habitat heterogeneity. The 12 mile (19 km) reach of the Rio Grande downstream of San Marcial Railroad bridge crossing is confined to a channel that is about 50 m wide. Substrate in this segment of the river is predominately sand but braiding of the channel is uncommon except under conditions of relatively low flow.

In 2004, this study was restructured to monitor the spawning periodicity of Rio Grande silvery minnow in the Middle Rio Grande while securing eggs for the propagation facilities was assigned to others. Given the downstream drift of the eggs the location of the collecting activities was selected so as to maximize the potential number of eggs collected and potentially rescue eggs destined to drift into Elephant Butte Reservoir where, if hatched, larvae would be subjected to a wide array of nonnative predators. The Rio Grande silvery minnow egg collecting site was located about 10 miles (16 km) downstream of the San Marcial Railroad bridge crossing at River Mile 58.8 (UTM Zone 13: 3716150 Northing; 307846 Easting). This site was located near the downstream-most point in the San Acacia Reach. In addition to easy accessibility and favorable river conditions, (i.e., wide river channel,

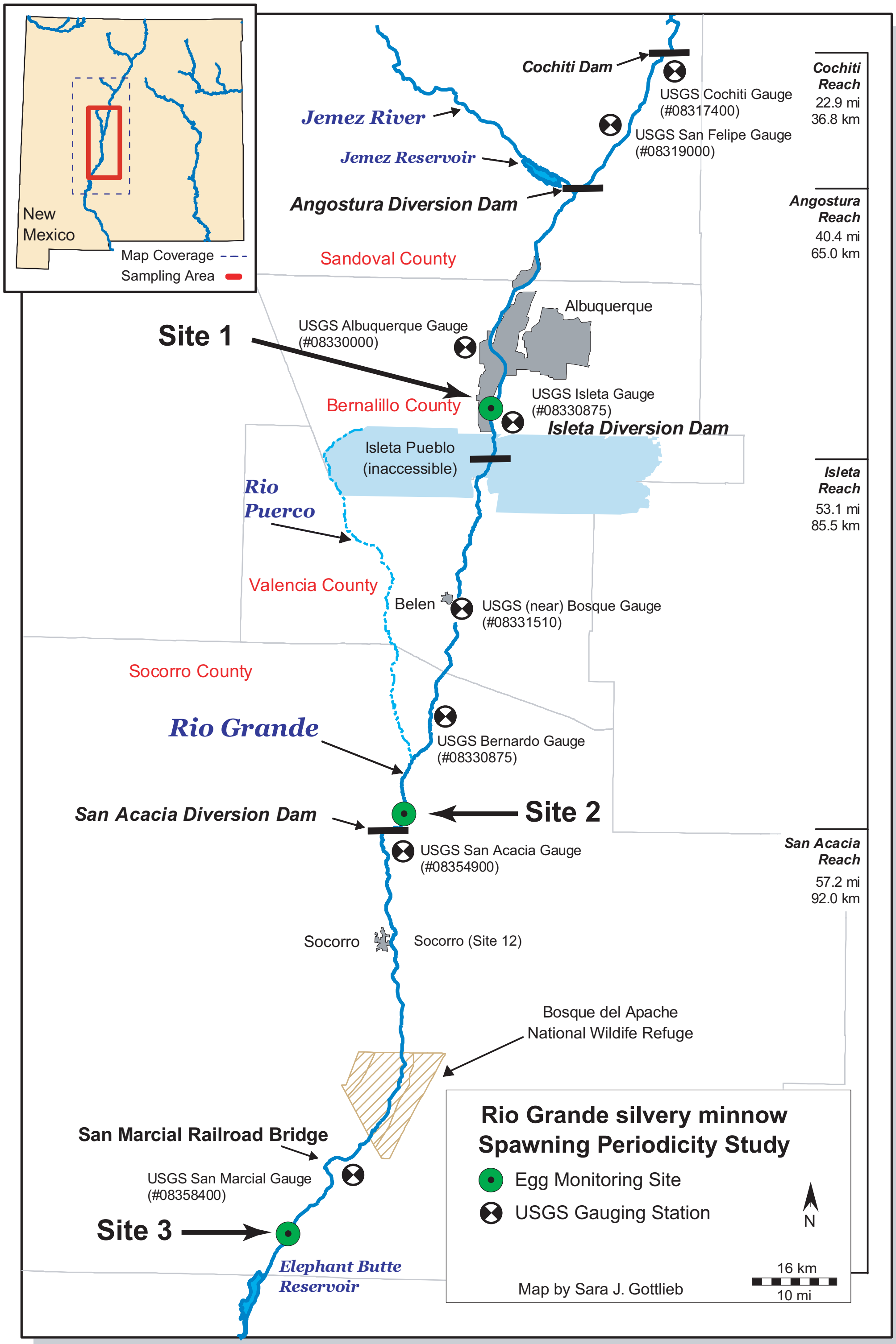

Figure 1. Map of the Middle Rio Grande, New Mexico, and the 2008 study site locations.

current being carried through a single river channel, gently sloped banks, moderate gradient) the only means of vehicle access to this site was gated and could be secured.

The 2006-2008 studies were structured to monitor the spatial and temporal reproductive output of Rio Grande silvery minnow in the Middle Rio Grande and therefore, given the downstream drift of the eggs, was conducted near the downstream-most portion of each of the three accessible river reaches (Angostura, Isleta, and San Acacia). The Angostura Site selected for sampling from 2006-2008 was last systematically sampled during the 1999 spatial spawning periodicity study of this species (Platania and Dudley, 2002), is with about seven river miles of the end of that reach, and is in close proximity to a U. S. Geological Survey stream gauging station (# 08330875). The Rio Grande-Isleta Reach Site selected for sampling from 2006-2008 is on Seviletta National Wildlife Refuge and about 4.8 river miles upstream of the downstream end of the Isleta Reach (near confluence of the Rio Grande and Canada Ancha). The Seviletta Site was is within five river miles of a U. S. Geological Survey stream gauging station (# 08354900). The final site is in the San Acacia Reach and is in close proximity to the collecting locality used annually since 2001 (site moved about 0.5 miles upstream due to channel incision that occurred in 2005). The San Acacia Reach Site is located downstream of San Marcial and is within one-two river miles of the end of that reach (depending on the lake elevation of Elephant Butte Reservoir). The U. S. Geological Survey stream gauging station at the San Marcial Railroad Bridge Crossing (#08358400) provides the hydrologic information for the San Acacia Reach egg sampling site (Figure 2).

MATERIALS AND METHODS

The egg collecting device, developed specifically for the collection of large numbers of live and undamaged semibuoyant fish eggs (Moore Egg Collector; MEC), was the only sampling apparatus used in this project (Altenbach et al., 2000). Numerous modifications have been made to the collecting gear, since the original publication detailing the construction and operation of the MEC (Altenbach et al., 2000), that have resulted in increased effectiveness and efficiency of the MEC (i.e., greater catch rate per sampling period). Catch rate of Rio Grande silvery minnow eggs in the Middle Rio Grande was determined following the sampling protocol described in Altenbach et al. (2000). A mechanical flow-meter was attached to the MEC so that volume of water filtered could be calculated and catch rate per unit of water determined. The catch-per-unit-effort (CPUE) of drifting eggs was calculated as the total number of eggs collected · volume of water sampled^{-1} · 100 (i.e., N [eggs] · m^3 water^{-1} · 100).

Previous studies (Platania and Dudley 2002, 2003, 2004, 2005, 2006) demonstrated May and June as the primary period of silvery minnow reproductive activity. The normal sampling regime was comprised of three daily efforts (morning, noon, and evening), each of two-hour duration. Two MEC's were generally operated so as to increase the volume of water sampled per unit of time. Research personnel were present daily at each of the three sampling sites from 1 May through 15 June 2008.

Volumetric determination of the number of Rio Grande silvery minnow eggs collected, as employed in 2001, lacked the rigor necessary for effective evaluation of the relative level of spawning by this species. Minor changes initiated in the 2002 sampling protocol were instituted to increase the amount and utility of the information acquired from this research activity. The result was that the two principal 2002 project objectives, determining the reproductive output of Rio Grande silvery minnow and obtaining eggs for use in Rio Grande silvery minnow propagation activities, were accomplished through slightly different sampling protocols. The aforementioned differences in egg catch rate determination between 2001 and 2002-2003 preclude use of 2001 data for quantitative or statistical comparison with 2002-2004 data. There have not been changes in the method for quantitative determination of egg catch rate between 2002 and 2008.

Rio Grande silvery minnow egg CPUE values are (in part) dependent on flow conditions thereby precluding unadjusted between year comparison of catch rates (e.g., higher flow volume will result in lower CPUE assuming number of eggs in water column remains constant). To account for these differences, catch rate was standardized (CPUE_S) to CPUE (N [eggs]/m^3) based on mean daily discharge (MDD) using the formula: CPUE_S = CPUE · MDD.

Assumptions of normality in annual Rio Grande silvery minnow egg catch rates were evaluated using the Shapiro-Wilk test. This statistical procedure has been shown to be excellent when testing for departures from a normal distribution. Critical values of W were calculated and significant differences assessed using a goodness-of-fit procedure. The 2002-2004 and 2006-2008 egg catch rate time-series distributions were compared with a normal distribution using the Shapiro-Wilk test. To meet the assumptions of normality, all data were log-transformed (X'=ln(X+1). Normal quantile plots of

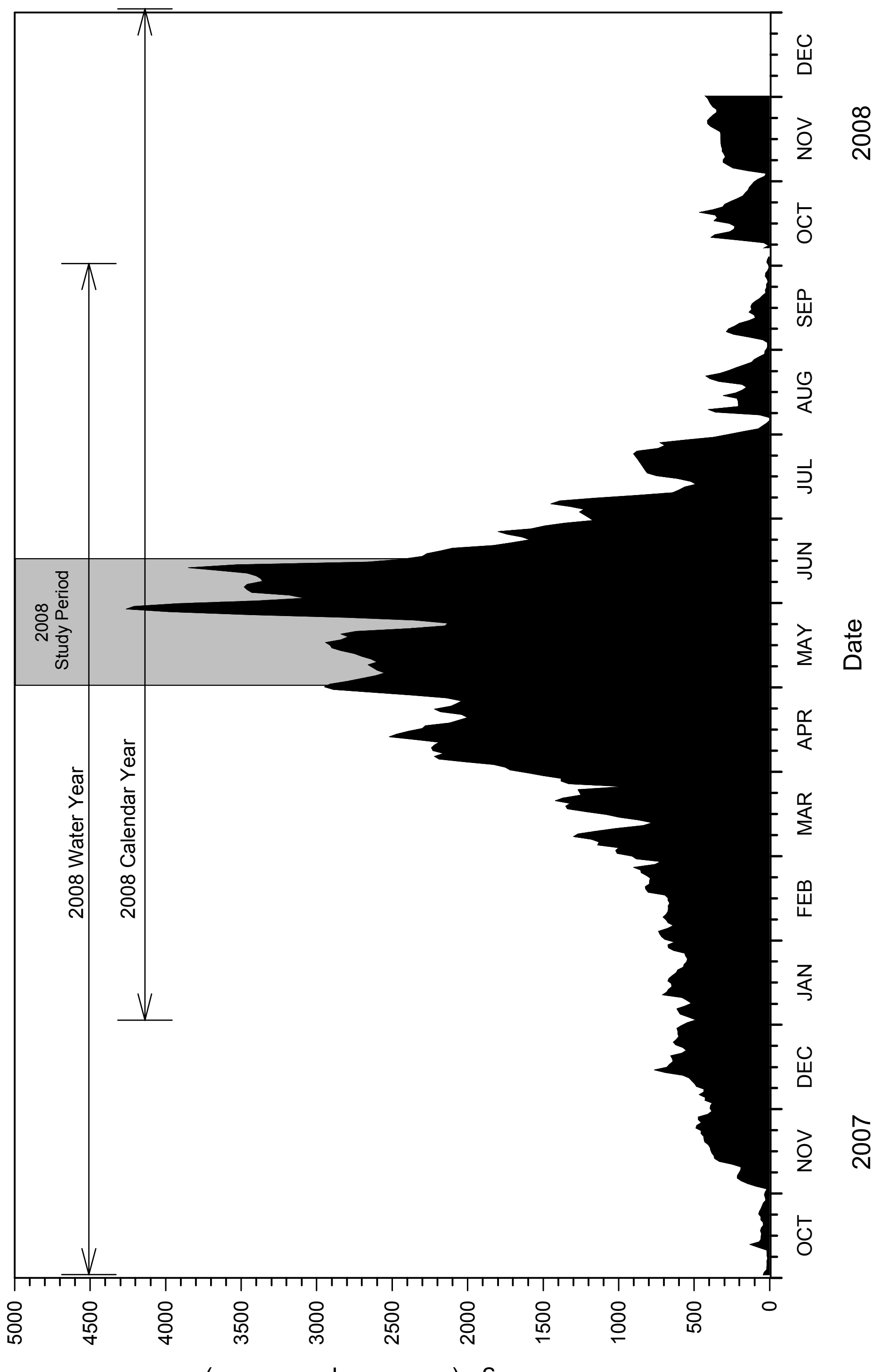

Figure 2. Hydrograph of the Rio Grande, New Mexico, at the San Marcial Gauging Station before, during, and after the 2008 study period.

empirical data were also examined in reference to Lilliefor's confidence bounds.

The CPUE_S values were compared among years and sites to determine general differences in spawning magnitude. Differences among independent samples were tested using ANOVA. This statistical procedure was used to detect differences between years (at a single site) and among sites (during a single year). Differences between sample means were evaluated based on the critical value of F based on sample size. Multiple pair-wise comparisons were made using the Tukey-Kramer HSD procedure.

Water temperature was recorded by temperature logging devices deployed at the study site and programmed to record hourly water temperature. Hourly water temperature data from the primary temperature logger were synthesized and are presented in this report as mean, minimum, and maximum daily water temperatures.

RESULTS

Hydrology during 2008

There was a large difference in flow in the Middle Rio Grande in 2008 as compared to 2001-2004 and 2006 (Figures 3-8). The severe drought that enveloped the study region since 2000 was somewhat interrupted in 2004 due to a moderate snowpack and wetter than normal April. These precipitation events helped but did not replenish the already diminished water reserves in upstream reservoirs. Despite the presence of more normal spring runoff in 2004, an artificial flow spike was released (as was done in 2002 and 2003) to stimulate spawning in Rio Grande silvery minnow. Snowpack runoff in 2005 was larger (greater magnitude and duration) in 2005 than any of the previous four study years (egg sampling was not conducted in 2005). Conversely flow in the Rio Grande during 2006 (prior 27 June) was extremely low due to a lack of spring snowmelt runoff. There were no "official" artificial flow spikes in 2006 as there had been during previous years nor were there any significant increases in flow due to natural rainstorm events prior to 27 June 2006. Spring flow conditions improved markedly during 2007, as compared with 2006, and there was an extended period of time during May and June when flows exceeded 2,000 cfs at the Albuquerque Gauge (USGS Gauge 08330000). Extended high spring flows were even more substantial in 2008 when flows at the Albuquerque Gauge exceeded 3,000 cfs for most of May and June.

Mean daily discharge in the Rio Grande at the Albuquerque Gauge (USGS Gauge 08330000) from 1 April through 30 June 2008 (Figure 9) ranged between 1,880 and 5,150 cfs (mean value= 3551.6 cfs, SD=719.8). From 1 April to 23 May 2008, discharge fluctuated betwen 2,760 and 4,070 cfs but exhibited no clear trend. Flows began to rise more substantially on 22 May and continued to rise to a peak of 5,150 on 25 May. An extended period of higher flow lasted until 10 June; flows declined from 5,080 cfs on 10 June to 4,220 cfs on 11 June and contined their steady decline through the remainder of the month.

Base flow in the Rio Grande at the San Acacia Gauge (USGS Gauge 08354900) during April, May, and early June 2008 was generally between 2,500 and 4,000 cfs. Mean daily discharge at the Isleta Reach study site (Seviletta) for the period 1 April-30 June 2008 was 3,150 cfs (SD=828.5) which was only slightly less than that recorded at the Albuquerque Site. From 22-27 May, there was a substantial spike in flow as mean daily discharge rose from 2,020 to over 5,000 cfs (26-27 May); flows then declined rapidly until 1 June (3,120 cfs) when a second smaller peak began. Similar to the Albuquerque Gauge, there was a final steady decline in flow for the month that went from 4,360 cfs (11 June) to 1,530 cfs (30 June).

Discharge in the Rio Grande at the San Marcial Railroad Bridge Crossing (USGS Gauge 08358400) during the 2008 water year closely mirrored that of the San Acacia Gauge (except at a reduced magnitude). From 1 April-30 June 2008 daily discharge in the Rio Grande at the San Marcial Gauge ranged from 1,170 to 4,260 cfs (mean value= 2,559.8 cfs, SD=667.8). Mean daily discharge at the San Marcial Site was over 500 cfs lower than flows recorded at either the Albuquerque or Isleta gauges. Flows peaked on 28 May and then declined to a lower plateau of about 3,000 cfs until mid-June; flows during the latter half of June declined to a low of 1,170 cfs (29 June).

Water temperature

There was little difference (ca. 1-2°C) in mean daily water temperatures at the three sites during the beginning of this study. The Albuquerque Site almost always had the lowest mean water temperatures with all dates in early May(1-14 May 2008) registering water temperatures <17° C

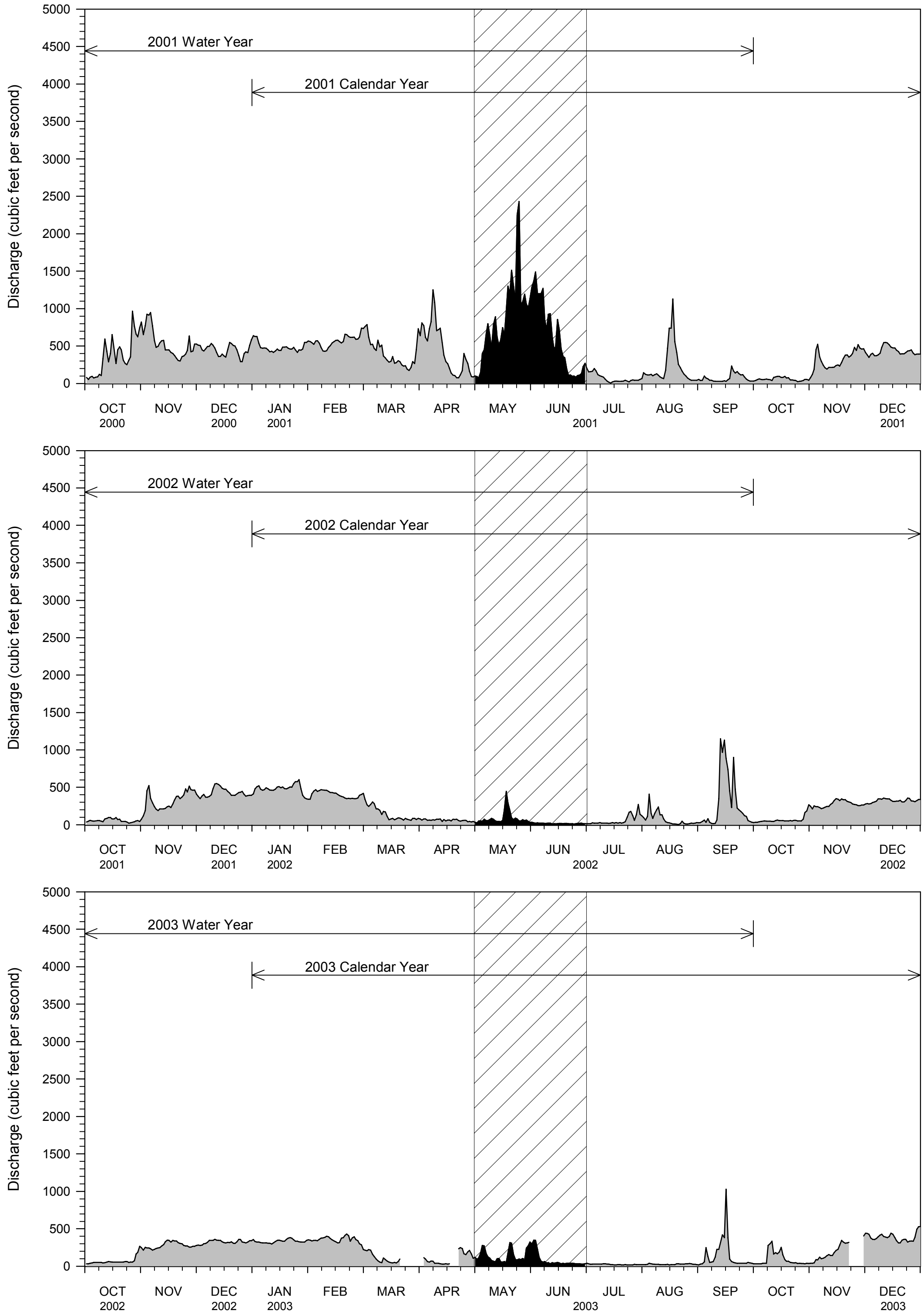

Figure 3. Annual hydrographs of the Rio Grande, New Mexico, at San Marcial before, during, and after the 2001-03 Rio Grande silvery minnow spawning periodicity study periods. Cross-hatching indicates annual study periods.

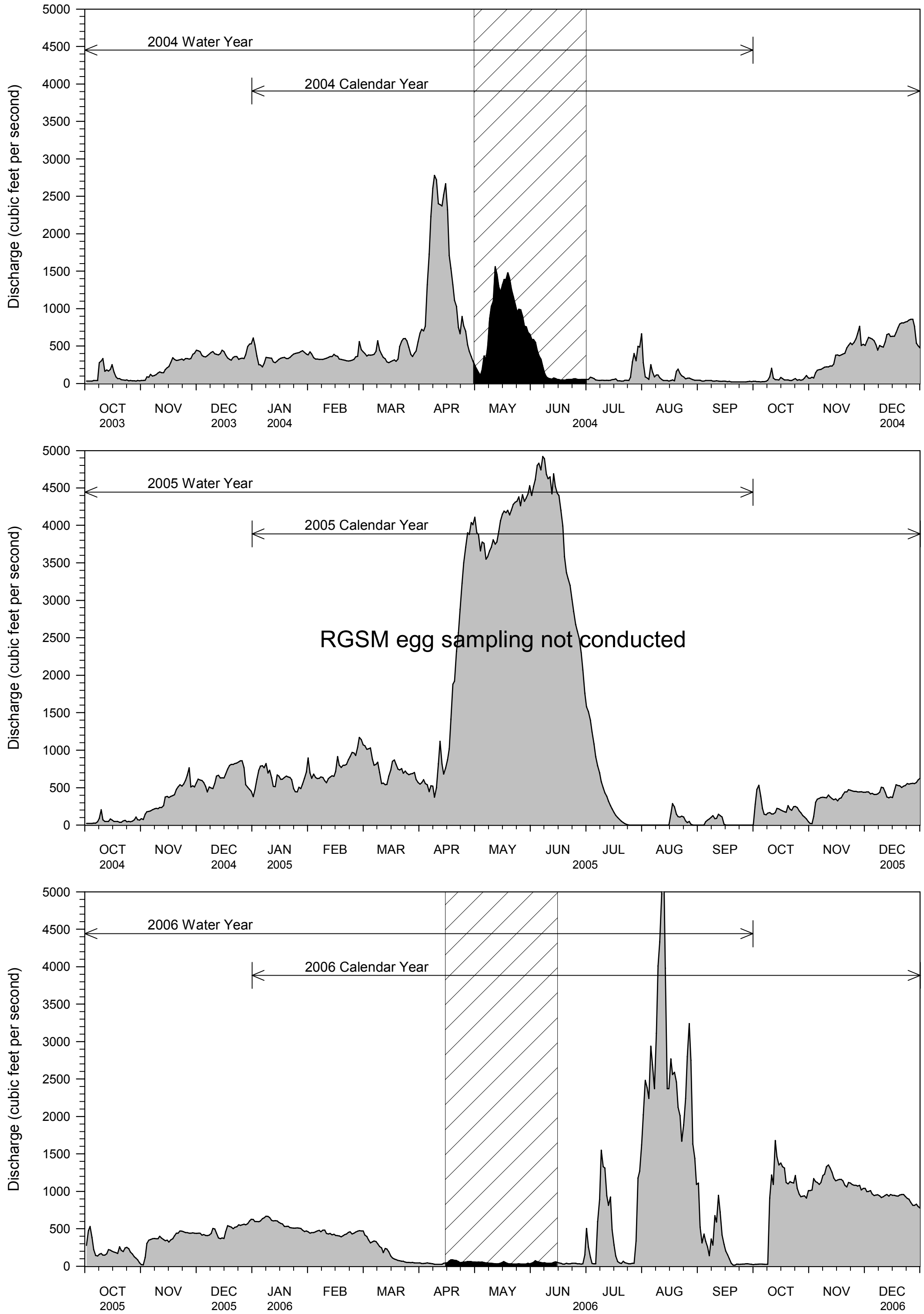

Figure 4. Annual hydrographs of the Rio Grande, New Mexico, at San Marcial before, during, and after the 2004 and 2006 Rio Grande silvery minnow reproductive monitoring study periods. Cross-hatching indicates annual study periods. Sampling was not conducted in 2005.

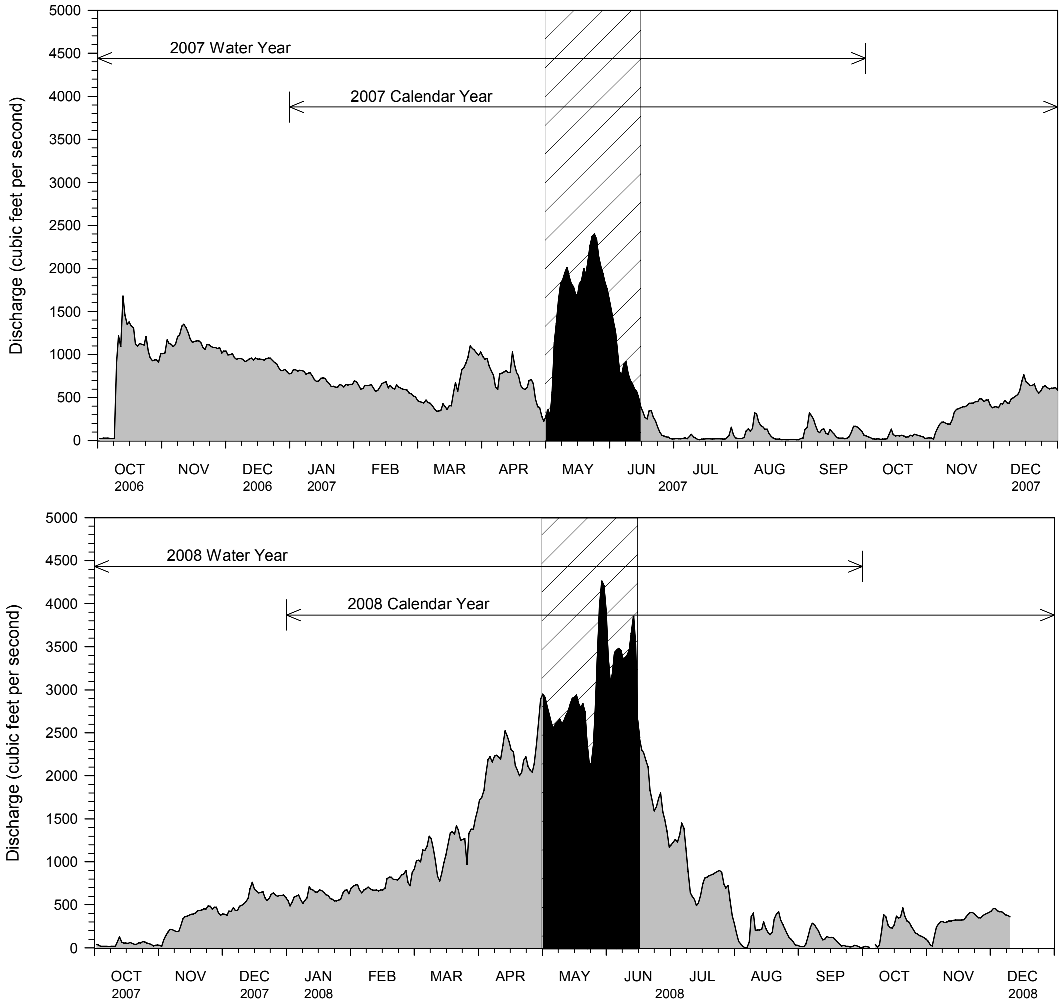

Figure 5. Annual hydrographs of the Rio Grande, New Mexico, at San Marcial before, during, and after the 2007 and 2008 Rio Grande silvery minnow reproductive monitoring study periods. Cross-hatching indicates annual study periods.

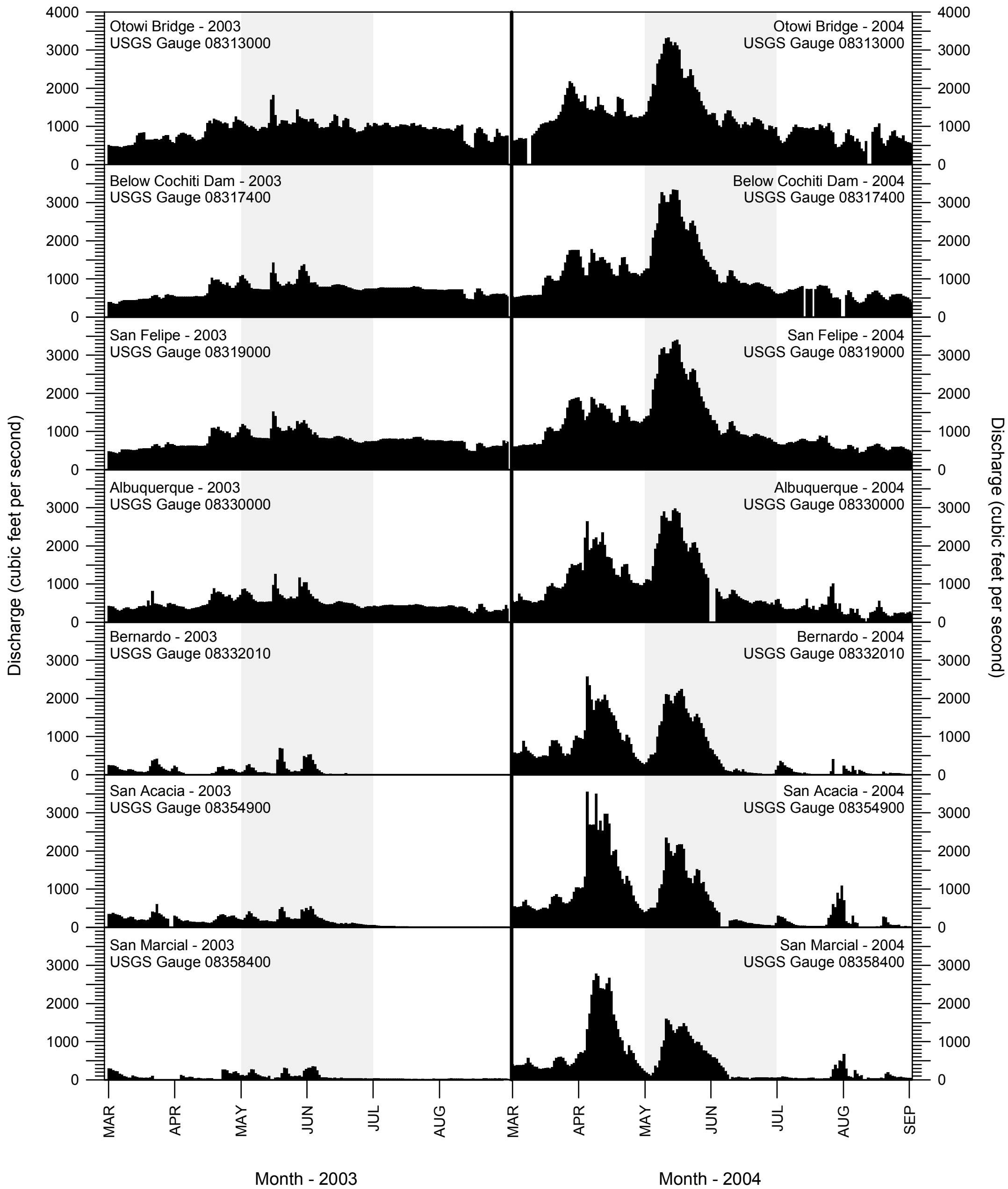

Figure 6. Rio Grande discharge from March through August 2003 and 2004 at seven U. S. Geological Survey Gauge Stations (see Figure 1). The Otowi Bridge gauge site is about 25.5 river miles upstream of Cochiti Dam, not covered with the area of Figure 1, and provided for reference. Discharge data are provisional and subject to change.

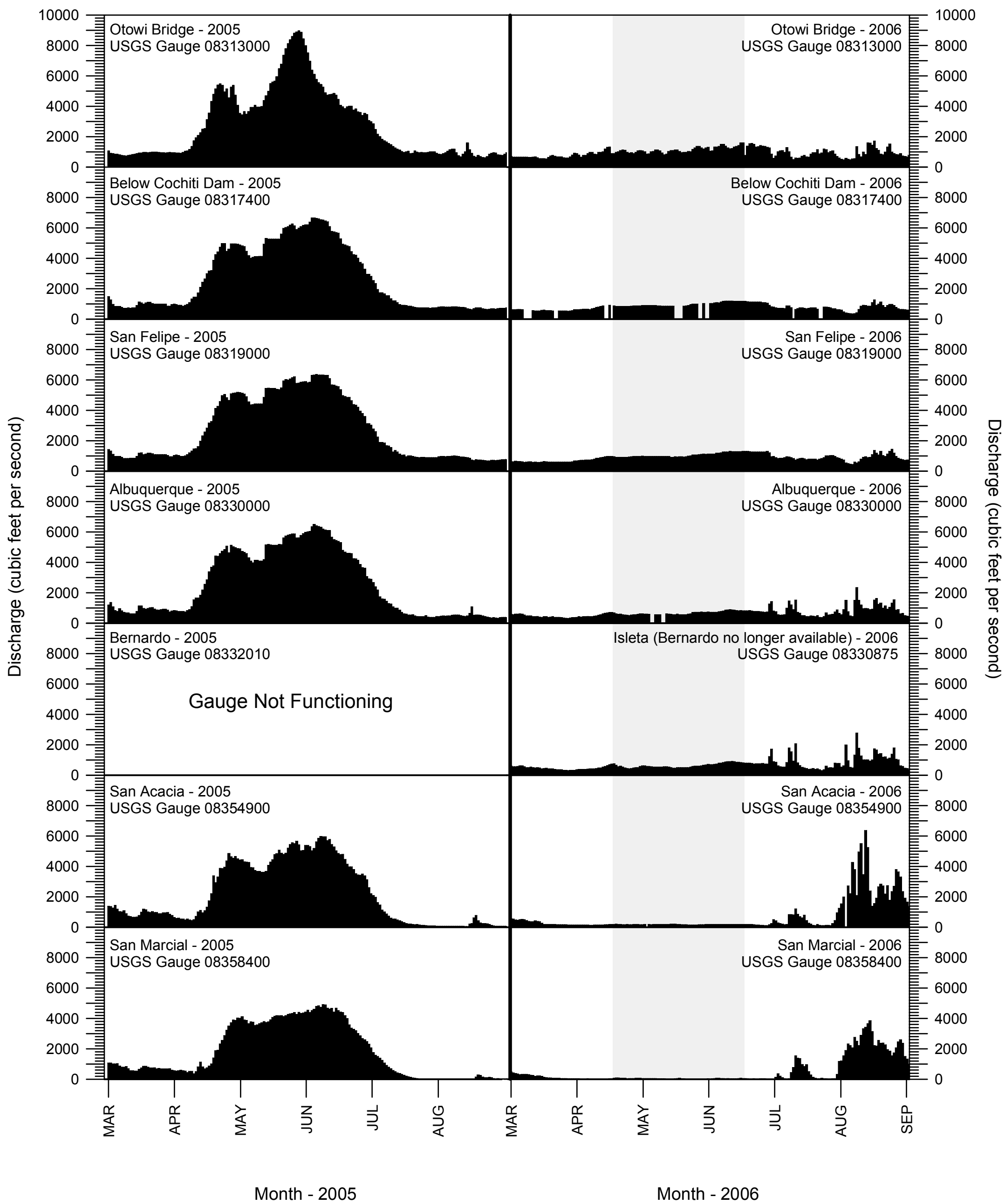

Figure 7. Rio Grande discharge from March through August 2005 and 2006 at seven U. S. Geological Survey Gauge Stations (see Figure 1). The Otowi Bridge gauge site is about 25.5 river miles upstream of Cochiti Dam, not covered with the area of Figure 1, and provided for reference. Discharge data are provisional and subject to change.

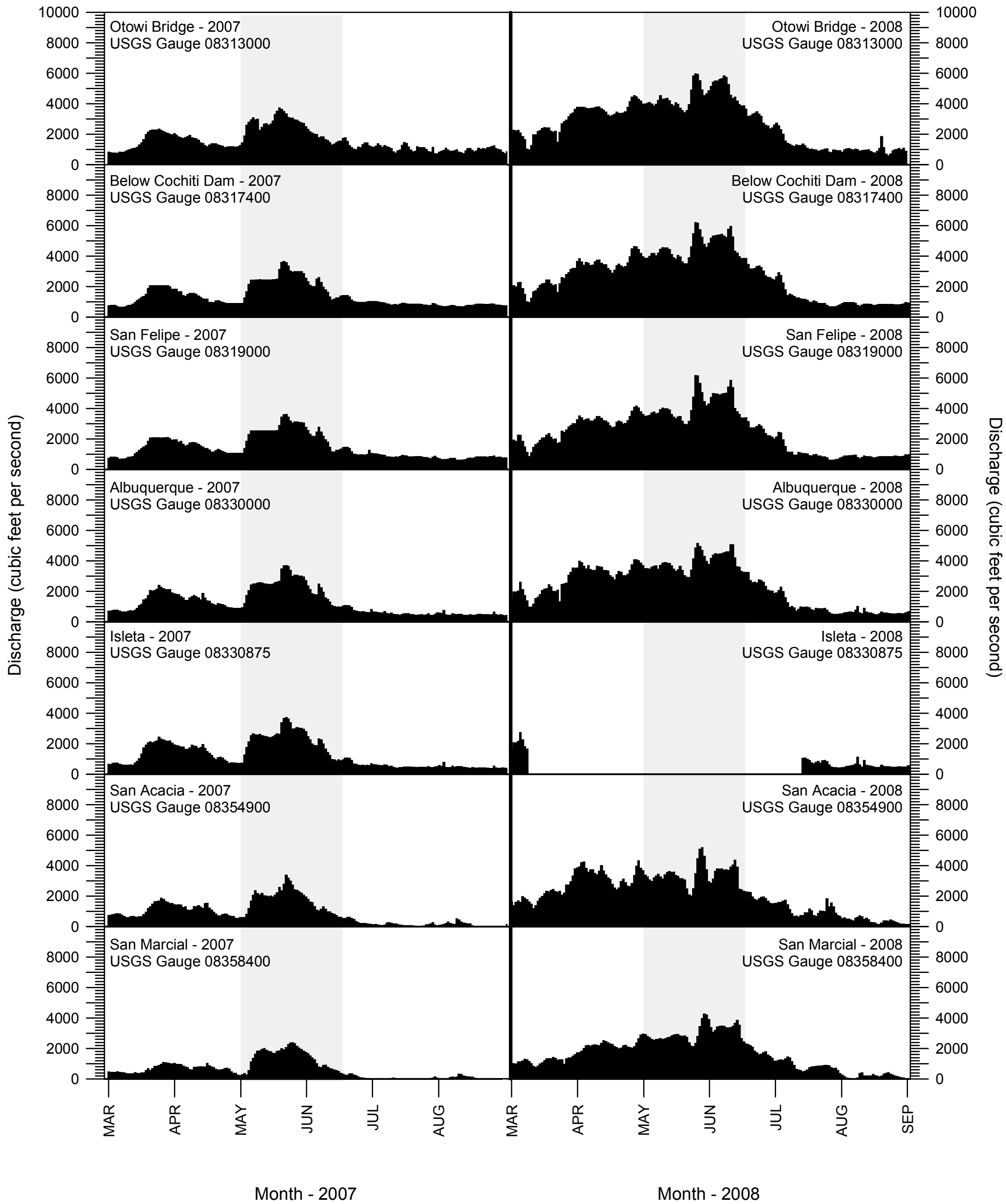

Figure 8. Rio Grande discharge from March through August 2007 and 2008 at seven U. S. Geological Survey Gauge Stations (see Figure 1). The Otowi Bridge gauge site is about 25.5 river miles upstream of Cochiti Dam, not covered with the area of Figure 1, and provided for reference. Discharge data are provisional and subject to change.

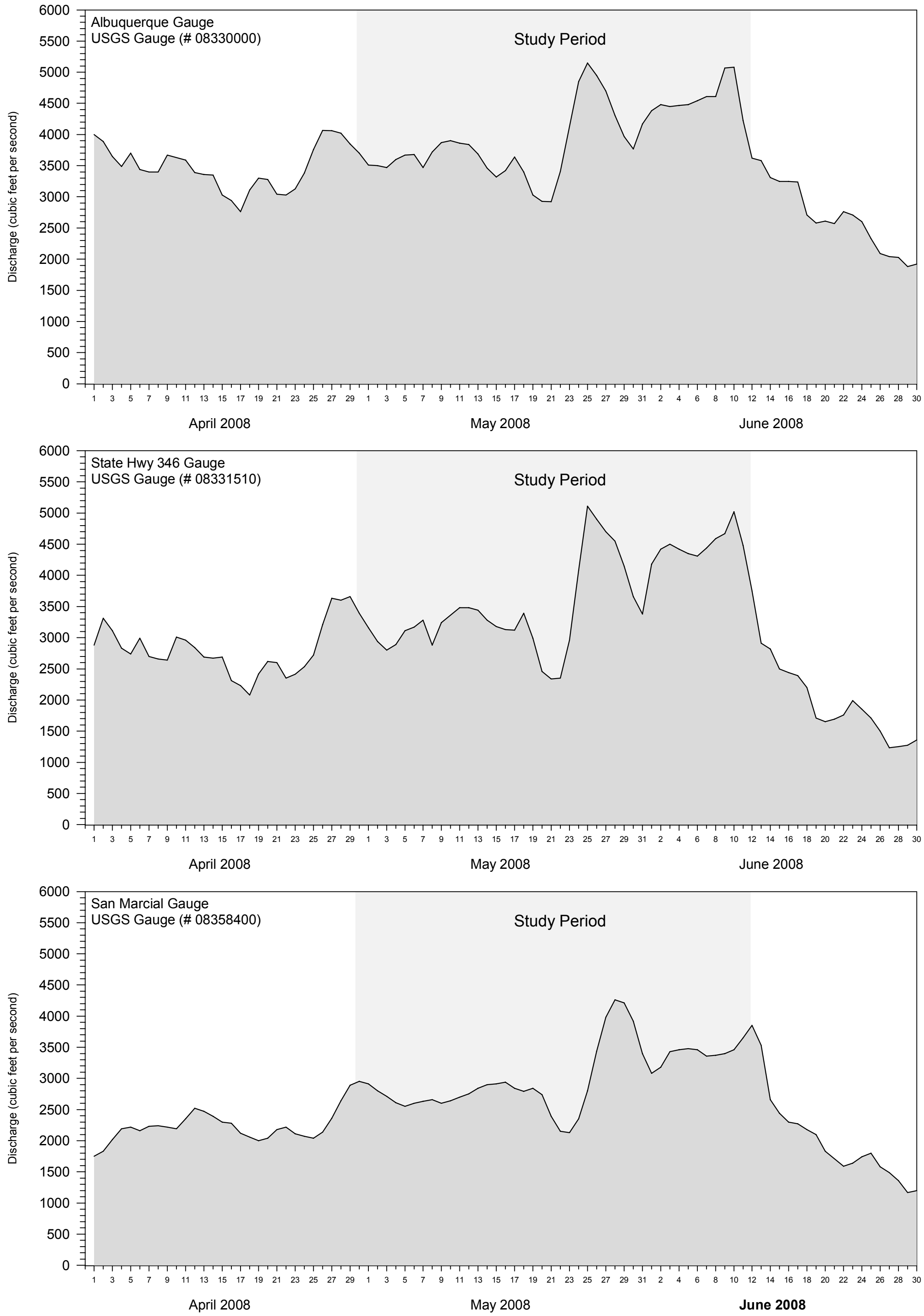

Figure 9. April-June 2008 hydrographs (dark gray) of the Rio Grande, New Mexico, from Albuquerque, San Acacia, and San Marcial gauges. The 2008 study period is highlighted in light gray.

(Figure 10). Mean daily water temperature at the study site rose rapidly during the third week in May but then declined again within a week. There was a steady increase in mean daily water temperature at all sites from about 16°C on 21 May to about 20°C late May. The San Marcial Site was the first to consistently generate mean daily water temperatures of 20°C or more (after 24 May). The Sevilleta Site reached a mean daily water temperature of 20°C on 25 May while the Albuquerque Site did not reach this temperature until 8 June 2008. By mid-June, mean daily water temperatures were about 21-22°C at the Albuquerque and Sevilleta sites and were about 23°C at the San Marcial Site.

More important and informative than the mean daily water temperatures were maximum daily water temperatures. Maximum water temperatures were 21.0°C at the Albuquerque study site, 22.0°C at the Seviletta Site, and 23.2°C at the San Marcial Site. Maximum daily water temperature exceeded 20°C on five occasions at the Albuquerque Site, on 17 occasions at the Sevilleta Site, and on 21 occasions at the San Marcial Site. Minimum water temperatures followed a similar pattern as the maximum water temperatures with the coldest temperatures recorded at the Albuquerque Site.

Mean water temperatures during May and early June varied considerably from 2006-2008 (Figure 11). Low discharge in 2006 contributed to the wide variation in temperatures (i.e., difference between minimum and maximum daily temperature) observed that year. However, mean temperatures followed approximately the same gradual trajectory for each of the most recent study years (2006-2008). Most of the differences in mean temperature among years occurred during the early May and were likely caused by subtle annual differences in ambient conditions during that month.

2008 Rio Grande silvery minnow spatial spawning periodicity studies

Sampling at each of the three 2008 Rio Grande silvery minnow spawning periodicity study sites was conducted from 1 May through 15 June 2008 (n= 46 days). Sampling in the Rio Grande for silvery minnow eggs was conducted for at least 6 hours per day in three discrete 2-hour sampling efforts at each of the sites. This increased effort resulted in a great volume of water sampled (as compared with years prior to 2006).

The cumulative volume of water sampled at these three Rio Grande sites was 220,037 m^3 (178.4 acre-feet). There was a marked decline, from upstream to downstream, in the total volume of water filtered per sampling site (Table 1). The cumulative volume of water sampled at the Albuquerque Site was 54,334 m^3 (44.0 acre-feet) was 24.7% of the study total, the amount sampled at the Sevilleta Site was 82,598 m^3 (67.0), and the total amount of water sampled at the San Marcial Site was 83,105 m^3 (67.4 acre-feet).

A cumulative total of 2,132 Rio Grande silvery minnow eggs were collected at the three sites during 2008 (Table 2). The vast majority (n= 1,917; 89.9%) of the catch was taken at the Sevilleta Site while the number and cumulative percent of Rio Grande silvery minnow eggs collected at the Albuquerque (n= 60; 2.8%) and San Marcial sites (n= 155; 7.3%) were low. Rio Grande silvery minnow eggs were collected on 14 days at the Albuquerque Site, 17 days at the Seviletta Site, and three days at the San Marcial Site. On six days, Rio Grande silvery minnow eggs were taken concurrently at both the Albuquerque and Seviletta sites while eggs were collected concurrently at the Seviletta and San Marcial sites on only two dates. There were no dates that Rio Grande silvery minnow eggs were collected at all three sites.

Dates of egg collection ranged from 7-9 May (three days) at the San Marcial Site, 1 May through 29 May (29 days) at the Sevilleta Site, and 10 May through 7 June (29 days) at the Albuquerque Site. Spawning (as indicated by the collection of eggs) by Rio Grande silvery minnow in the Albuquerque Reach occurred three days after spawning near San Marcial and six days after the first spawning event recorded at the Seviletta Site. Daily egg catch rates (on dates that eggs were taken) at the Albuquerque Site ranged between 0.04 and 1.33 eggs per 100 m^3 of water sampled (n= 1 and n= 18, respectively). Cumulative egg catch rate at the Albuquerque Site during the 14 days that eggs were taken was 0.27 eggs per 100 m3 of water sampled versus 0.11 eggs per 100 m^3 during the tenure of the study. Mean daily eggs catch rates at the Seviletta and San Marcial sites during dates that eggs were taken were 5.24 and 1.81 eggs per 100 m^3 of water sampled, respectively (Figure 12).

The presence of Rio Grande silvery minnow eggs in the Albuquerque Reach during 2008 was first documented on 10 May. Eggs were collected at the Albuquerque Site on 13 of the remaining 36 days of the study. From 10-14 May, 34 eggs or 57% of the total Albuquerque Site catch was taken while from 1-7 June, 14 eggs or 23% of the total Albuquerque Site catch was taken. Silvery minnow eggs at the Seviletta Site were present in most daily samples from 8-29 May. Those 22 sampling dates yielded 1,738 eggs or 91% of the total Seviletta Site egg catch. Catch rate at that site during that period ranged from 0.04 to 76.87 eggs per 100 m^3 of water sampled.

Rio Grande silvery minnow egg sampling at the San Marcial Site resulted in one discrete

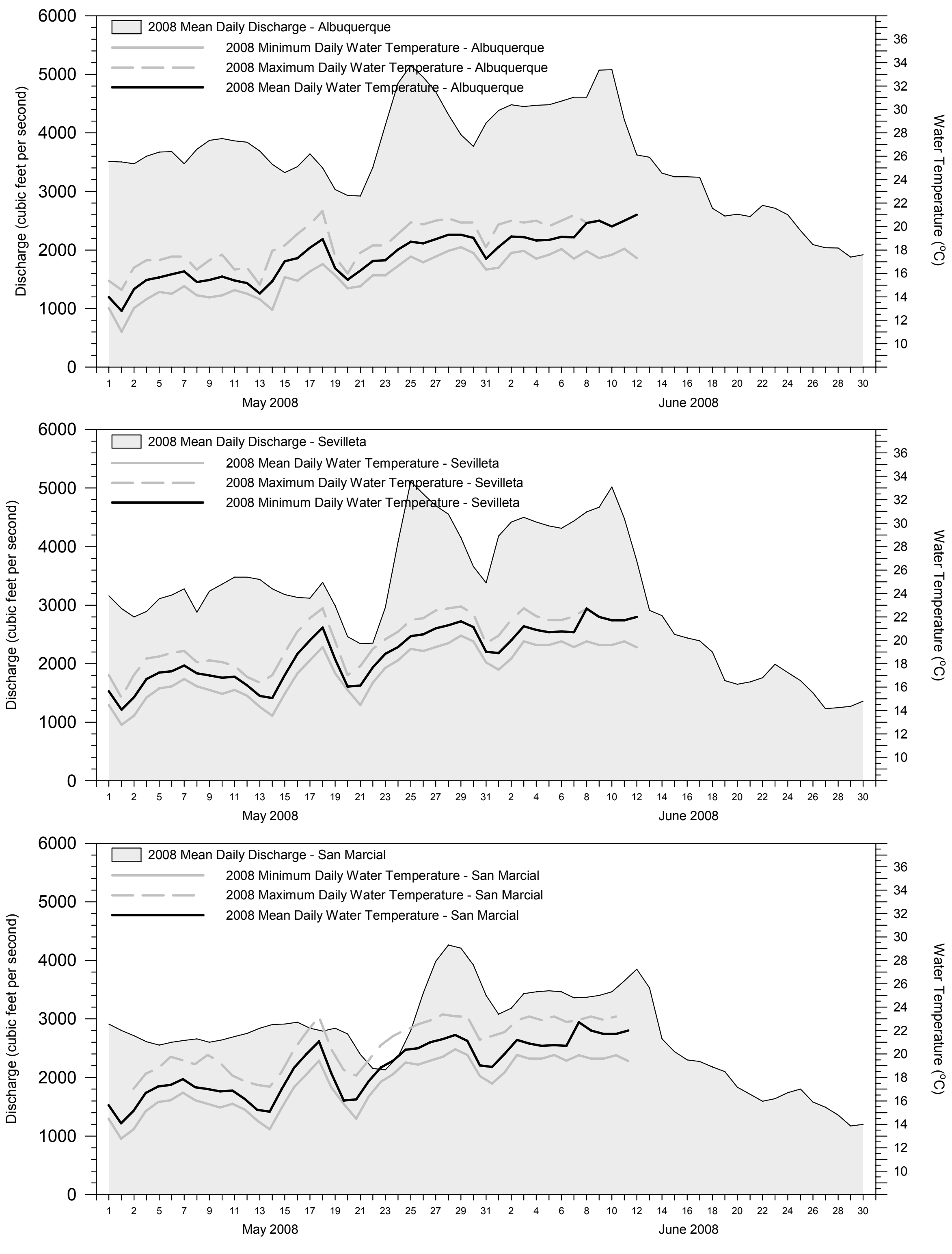

Figure 10. Daily water temperatures (mean, minimum, and maximum) at the 2008 Rio Grande silvery minnow spawning periodicity sampling sites (1 May - 15 June 2008). Approximate mean daily discharge in the Rio Grande at each sampling site is highlighted in light gray.

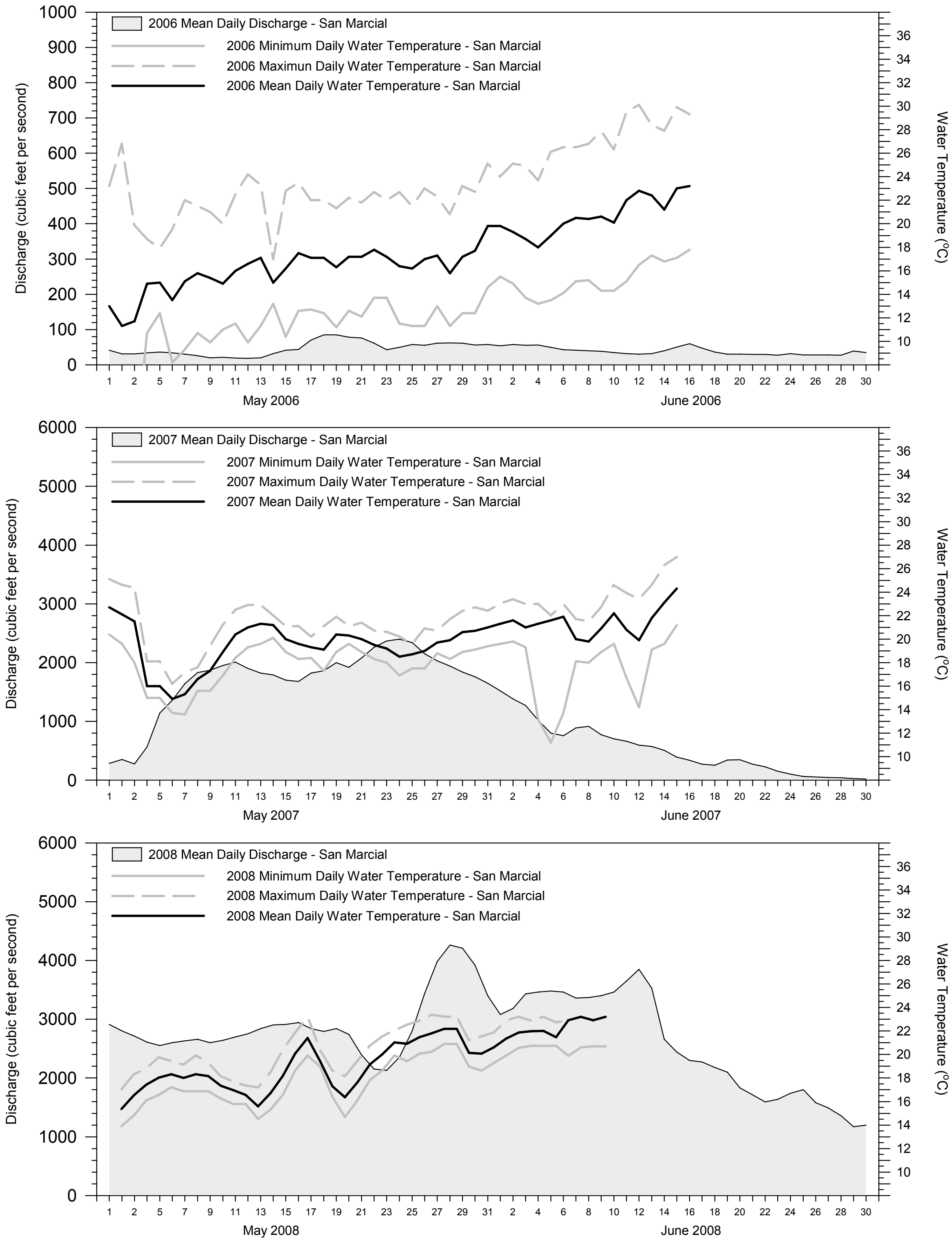

Figure 11. Comparison of the 2006-2008 daily water temperatures (mean, minimum, and maximum) at the San Marcial-Rio Grande silvery minnow spawning periodicity sampling site. Approximate mean daily discharge in the Rio Grande at San Marcial is highlighted in light gray. Note change in Y-axis scale (discharge) in the 2006 graph.

Table 1. Summary of 2008 mainstem Rio Grande sampling effort for Rio Grande silvery minnow eggs by site.

Sampling Information System:	Site	Number of Eggs	Egg Catch Rate [1]	Volume of Water Sampled (m^3)	Number of Days Sampled	Dates Sampled Start	Dates Sampled Stop
Rio Grande:	Albuquerque	60	0.11	54,334	46	1 May 08	15 June 08
Rio Grande:	Sevilleta	1,917	2.32	82,598	46	1 May 08	15 June 08
Rio Grande:	San Marcial	155	0.19	83,105	46	1 May 08	15 June 08

[1] = Value based on number of Rio Grande silvery minnow eggs collected per 100 m^3 of water sampled

Table 2. Number of Rio Grande silvery minnow eggs collected per day by site. Table does not include dates that eggs ***were not*** collected.

LOCATION : RIVER MILE :	ALB SITE RM 176.4	SEVILLETA RM 121.0	CORRAL RM 58.8
01-May-08	0	157	0
02-May-08	0	21	0
03-May-08	0	1	0
07-May-08	0	0	1
08-May-08	0	1398	4
09-May-08	0	100	150
10-May-08	1	0	0
11-May-08	2	0	0
12-May-08	9	46	0
13-May-08	18	44	0
14-May-08	4	16	0
17-May-08	0	2	0
18-May-08	8	0	0
20-May-08	0	33	0
21-May-08	0	8	0
22-May-08	0	7	0
25-May-08	0	19	0
26-May-08	1	47	0
27-May-08	1	15	0
28-May-08	2	1	0
29-May-08	0	2	0
01-Jun-08	4	0	0
02-Jun-08	1	0	0
03-Jun-08	6	0	0
04-Jun-08	1	0	0
07-Jun-08	2	0	0
TOTALS	**60**	**1,917**	**155**
%	**2.81**	**89.92**	**7.27**

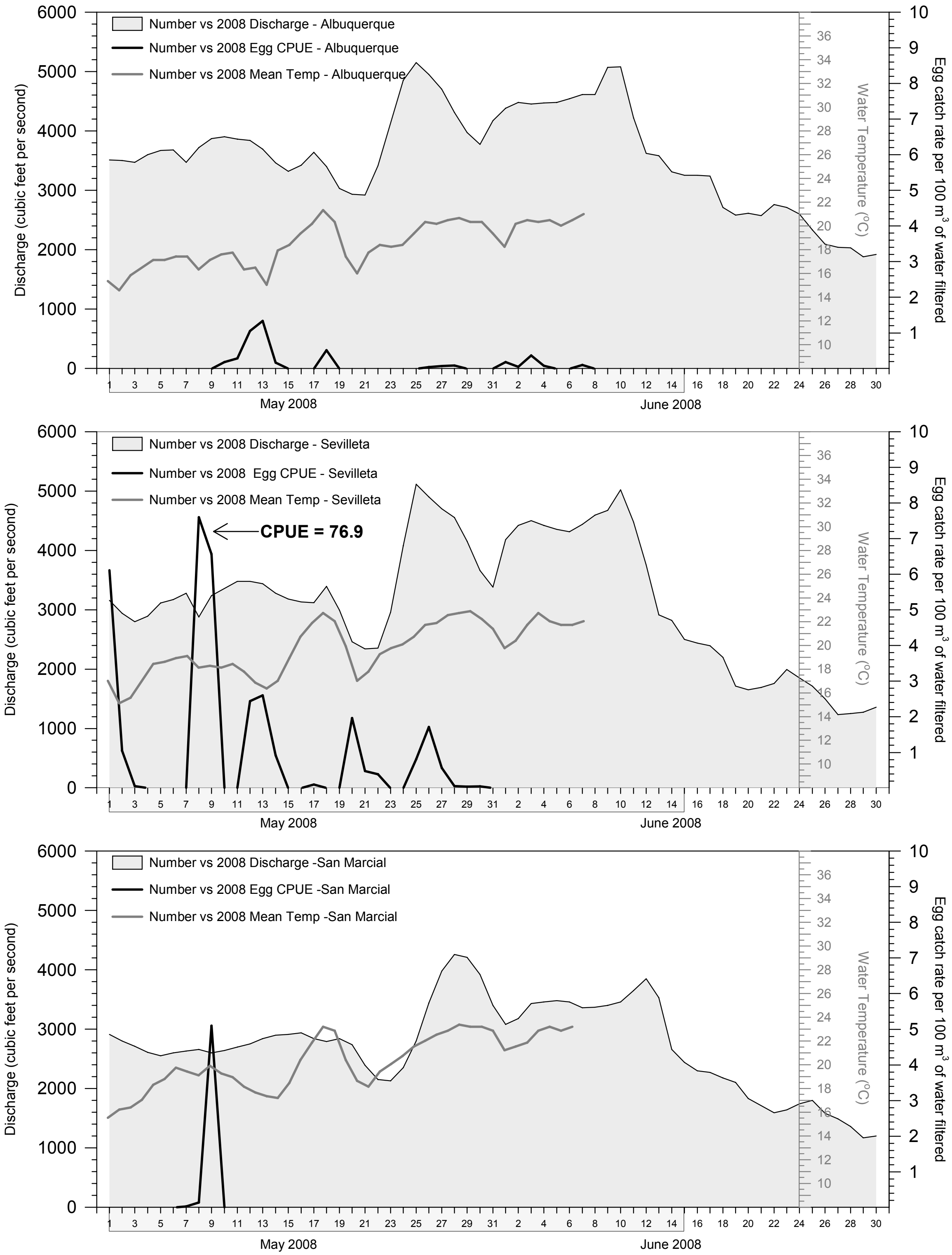

Figure 12. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2008 Rio Grande silvery minnow spawning periodicity study period (sampling period is highlighted in gray along the abscissa axis).

periods of during which eggs were taken. This period was 7-9 May (three days). Eggs were collected during each of those dates with a total of 155 eggs (range= 1 to 150) taken accounting for 100% of the total San Marcial Site catch.

COMPARISON OF 2001-2004, 2006-2008 RESULTS

There are several similarities apparent regarding Rio Grande silvery minnow reproduction during 2001-2004 and 2006-2008 (Tables 2 and 3). Based on the results of data taken from all years of the project, there was an apparently extended duration of spawning (April-July). However, over the period of record (2001-2004 and 2006-2008), spawning consistently occurred during the early to middle portion of May. In 2008, spawning at the San Marcial Site occurred in early May with the peak being on 9 May. The duration of the spawning season varied across years with 38 days recorded between the first and last 2001 spawning event and 29 days between the first and last collection of eggs in 2003. In 2002, there were only two weeks between the first and final Rio Grande silvery minnow spawning event which was likely due, in part, to the absence of elevated flows. Spawning in 2004 was even less protracted and only occured from 7-11 May. In 2006, Rio Grande silvery minnow eggs were collected at the Albuquerque Site starting on 23 May, at the Sevilleta Site starting on 2 May, and at the San Marcial Site starting on 26 April. Spawning started on 8 May 2007 at the Albuquerque Site but was documented on 4 May at the Sevilleta Site and 1 May at the San Marcial Site. A similar early spawning pattern was observed in 2008 when eggs were first collected on 10 May at the Albuquerque Site, 1 May at the Sevilleta Site, and 7 May at the San Marcial Site.

Mean daily water temperatures during the initial and peak spawning events were relatively similar across years (Figures 13-15). In 2001, maximum spawning of Rio Grande silvery minnow occurred when water temperatures ranged between 19-20°C while 2002 mean daily water temperatures during maximum spawning were 18-20°C. That water temperatures during the extended 2003 Rio Grande silvery minnow spawning period were higher (20-24°C) than recorded during previous years was likely the result of low flows and higher ambient temperatures. During the putative 2004 spawn (7-12 May), mean daily water temperatures were 20-22°C with maximum daily water temperatures of 21-27°C. In 2006, mean daily water temperatures during the late May-early June 2006 Albuquerque spawn were 22-24°C. At the Seviletta Site, during that same period, mean daily water temperatures were 20-26°C. Mean daily water temperatures during spawning at the San Marcial Site were 18°C in late April, 23°C in mid-May, and 24°C in early June 2006. Mean daily water temperatures during peak spawning (13-15 May) in 2007 ranged between 20.0 and 21.3°C at the San Marcial Site. The range of mean daily water temperatures over the full period of spawning (4 May to 10 June) was between 14.9 and 22.2°C. Mean daily water temperatures during spawning in 2008 ranged between 14.3 and 19.3°C at the Albuquerque Site, between 14.1 and 21.6°C at the Sevilleta Site, and between 18.0 and 18.3°C at the San Marcial Site.

Statistical analyses among all years were made using data from the San Marcial sampling locality since that site was the only common one for all years. Analysis of reproductive output revealed a significant difference (F=6.11; p<0.0001) among mean values of catch rate (#/100m^3) for the six years of the study (2002-2004, 2006-2008). The following pair-wise comparisons were significant (p<0.05) over the period of record (2002 vs. 2004, 2002 vs. 2006, 2006 vs. 2007). The natural log-transformed mean egg catch rate (standarized for discharge) was highest in 2002 (5.86 ±0.93), followed by 2007 (4.77±0.37), 2008 (3.22±1.32), 2003 (2.89±0.54), 2006 (1.44±0.72), and 2004 (0.96±1.32). Additional statistical analyses for the Angostura and Isleta reaches were made over the period of time that data were available (2006-2008). Analysis of reproductive output revealed no significant difference (F=0.51; p>0.60) among mean values of catch rate (#/100m^3) for the three years of the study (2006-2008) in the Angostura Reach. However, analysis of reproductive output revealed a significant difference (F=9.83; p<0.0002) among mean values of catch rate (#/100m^3) for the three years of the study (2006-2008) in the Isleta Reach. The following pair-wise comparisons were significant (p<0.05) over the period of record (2006 vs. 2007, 2006 vs. 2008) in the Isleta Reach. The natural log-transformed mean egg catch rate (standarized for discharge) was highest in 2008 (4.28 ±0.45), followed by 2007 (4.19±0.41), and 2006 (1.97±-0.41) in the Isleta Reach.

Comparison of 2001-2008 water temperatures at the study site during May and June demonstrate relatively few differences in mean daily water temperatures across this period. The minimum and maximum daily water temperatures for 2006 were somewhat lower (minimum) and higher throughout the study period than during previous or subsequent years (Figures 16 and 17).

Table 3. Catch rates of Rio Grande silvery minnow eggs by year, site, and category (mean annual, maximum daily, mean sample, and flow spike induced).

Sampling Information Year: Site			Mean Annual Catch Rate[1] (# / 100 M^3)	Maximum Daily Catch Rate (# / 100 M^3)	Maximum Sample Catch Rate (# / 100 M^3)	Peak Spawning Mean Catch Rate[2] (# / 100 M^3)
2001	Rio Grande:	San Marcial	251.00	510.00	2,878.00	536.00
2002	Rio Grande:	San Marcial	2,031.00	14,222.00	96,558.00	3,367.00
2003	Rio Grande:	San Marcial	59.00	476.00	1,027.00	221.00
2004	Rio Grande:	San Marcial	0.17	0.09	0.22	NA
2005			Not Sampled	Not Sampled	Not Sampled	Not Sampled
2006	Rio Grande:	Albuquerque	3.78	19.15	22.64	19.15
2006	Rio Grande:	Sevilleta	5.07	44.88	53.82	44.88
2006	Rio Grande:	San Marcial	47.88	289.33	621.97	289.33
2007	Rio Grande:	Albuquerque	0.11	0.94	1.43	0.94
2007	Rio Grande:	Sevilleta	3.77	147.13	158.56	147.13
2007	Rio Grande:	San Marcial	12.99	106.12	201.55	106.12
2008	Rio Grande:	Albuquerque	0.11	1.33	2.65	1.33
2008	Rio Grande:	Sevilleta	2.32	76.87	136.31	76.87
2008	Rio Grande:	San Marcial	0.19	5.10	7.67	5.10

[1] Catch rate determinations only incorporate samples that contained Rio Grande silvery minnow eggs.
[2] Catch rate is determined from the period that produced the majority of the total annual catch.

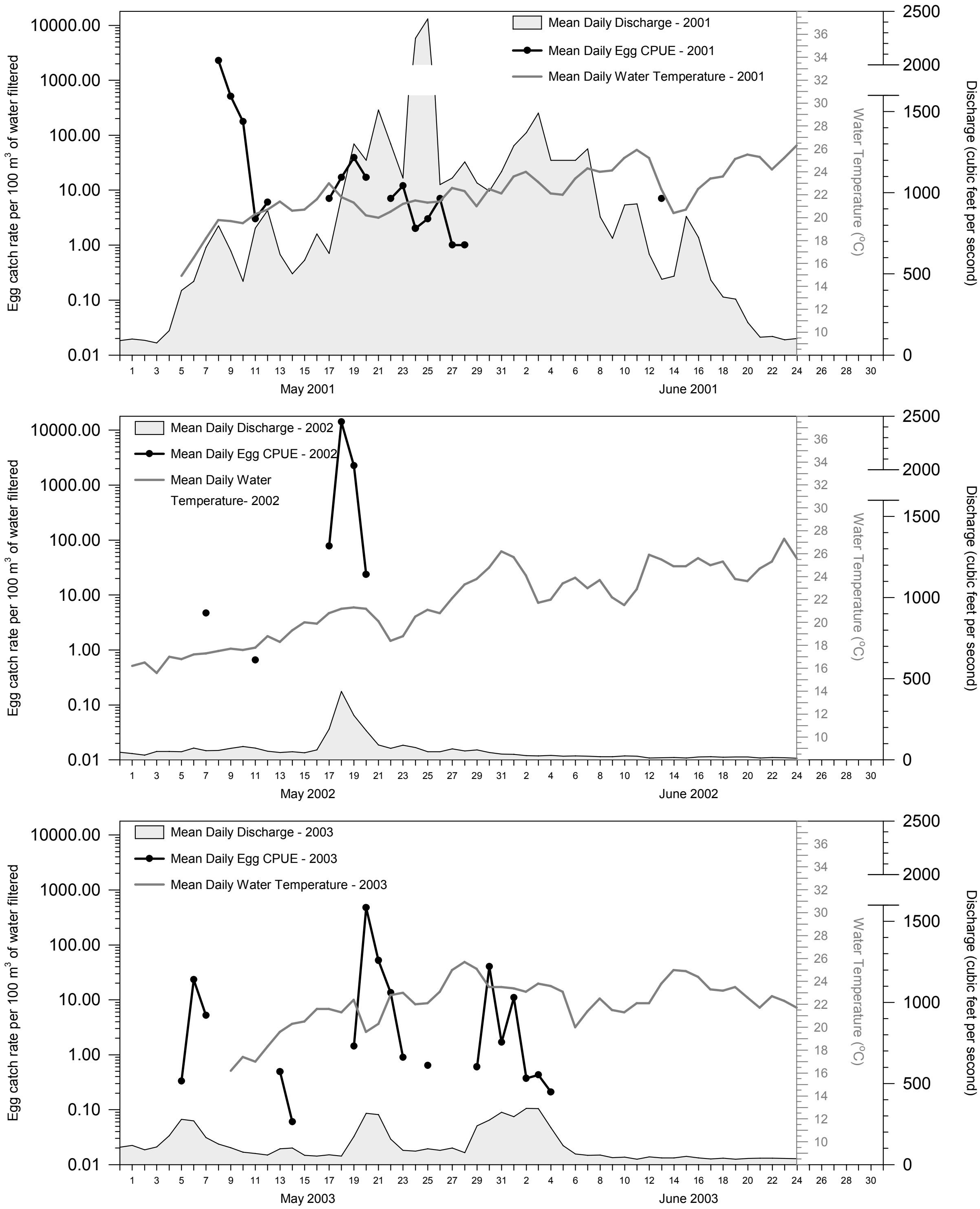

Figure 13. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2001-03 Rio Grande silvery minnow spawning periodicity study periods at San Marcial. Note that the Y-axis for egg catch rate is a log-scale.

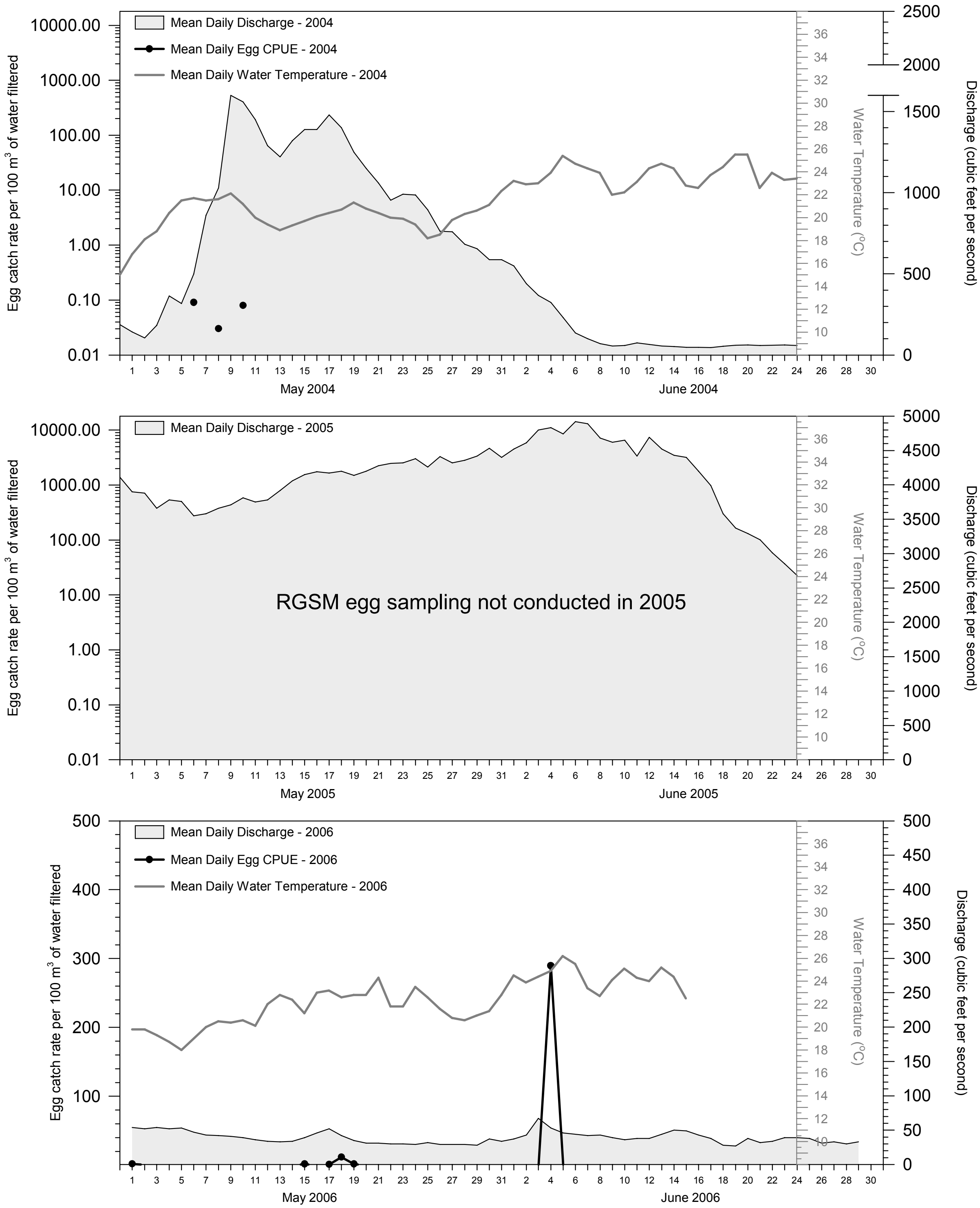

Figure 14. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2004-06 Rio Grande silvery minnow spawning periodicity study periods at San Marcial. Note that the Y-axis for egg catch rate is a log-scale. The 2006 graph is repeated on the next page.

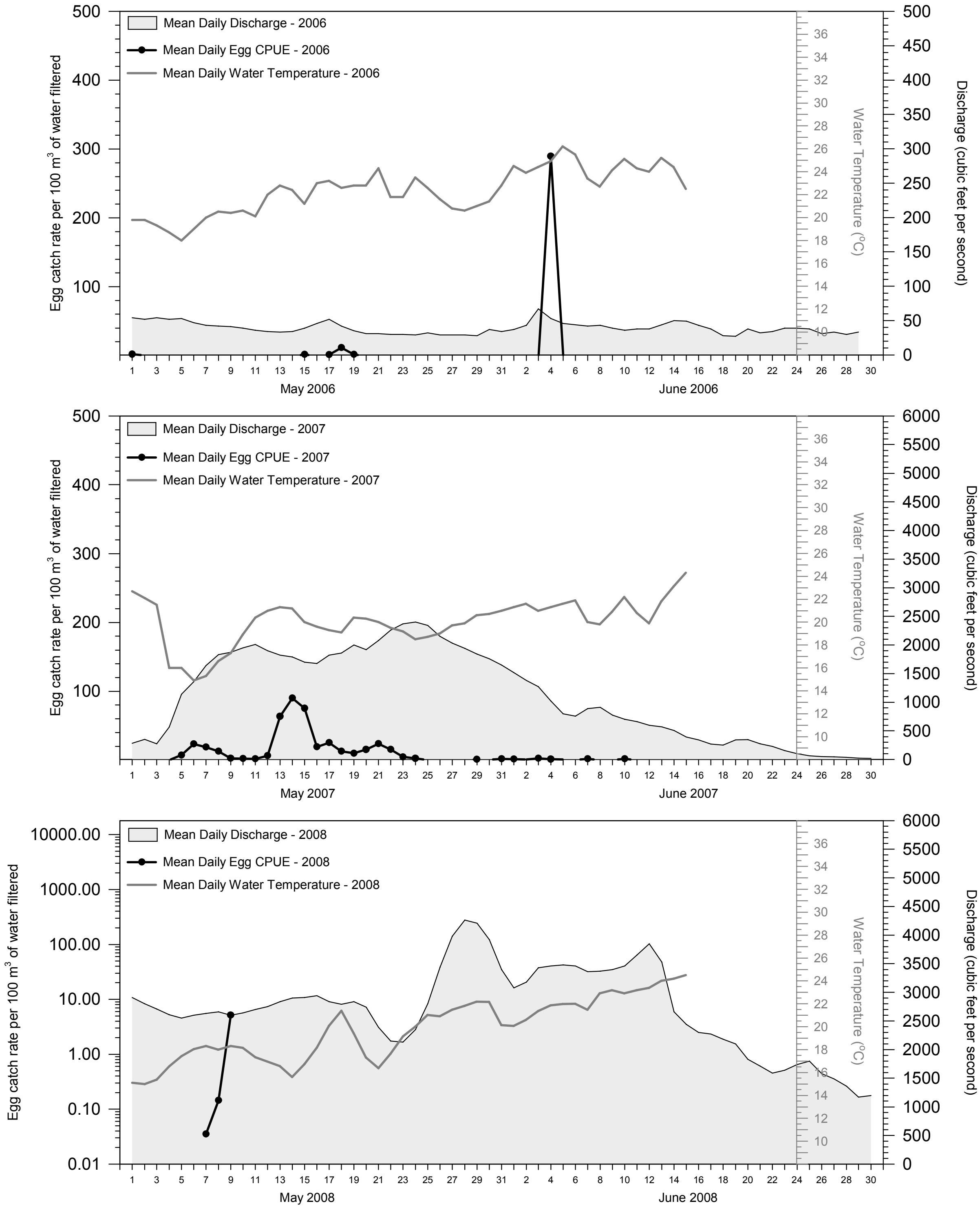

Figure 15. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2006-08 Rio Grande silvery minnow spawning periodicity study periods at San Marcial. Note that the Y-axis for egg catch rate is a log-scale.

The highest May maximum daily water temperatures during the 2001-2008 studies were recorded in 2006 with water temperatures ranging between 25 and 32°C. Previously, the highest maximum daily water temperatures were in 2002 with the lowest maximum daily water temperatures generally in 2001 or 2004. Subsequent to 2006, the 2007 and 2008 maximum daily water temperatures were quite low (i.e., <24°C from 5 May until 2 June 2008). The principal reason for these patterns, besides ambient temperature, was the volume of water in the river channel during the respective study periods. The relatively high flows present in 2001, 2004, 2007, and 2008 served to ameliorate water temperatures and minimize diel variation. Conversely, the very low flow conditions present in 2002, 2003, and 2006 typically resulted in large daily temperature fluctuations. The pattern of water temperatures in 2003 was similar to that of 2002 except that post-flow spike minimum and maximum water temperatures were within 10-11°C of each other.

DISCUSSION

As rivers have become increasingly fragmented, an important factor limiting the recolonization of upstream reaches is the downstream transport of reproductive products below barriers or displacement into highly degraded downstream riverine habitats and reservoirs. The potential negative impacts of dam-related modifications of flow and habitat on Great Plains stream cyprinids that employ drifting eggs and larvae as an early life history strategy have been well documented (Stanford and Ward, 1979; Cross et al., 1983; Cross et al. 1985, Cross and Moss, 1987; Winston et al., 1991; Luttrell et al., 1999). In the Middle Rio Grande, many of the eggs and larvae of the federally endangered Rio Grande silvery minnow are rapidly displaced downstream of diversion dams and into Elephant Butte Reservoir. The loss of this reproductive effort from upstream sources is one factor that has led to the currently imperiled state of this species. Reducing the rate of downstream transport, allowing upstream passage, and salvaging eggs destined for Elephant Butte Reservoir are all options that will, to some degree, improve the current status of Rio Grande silvery minnow.

In addition to the problem created by river fragmentation, the loss of habitat heterogeneity also likely contributes to increased downstream displacement of the reproductive effort of Rio Grande silvery minnow. The closure of Cochiti Dam resulted in a greatly reduced passage of fine sediments through the Middle Rio Grande which, in turn, has contributed to channel degradation, armoring, and narrowing (Lagasse, 1985). The reduction in the number and size of low velocity mesohabitats has likely led to reduced egg retention in upper reaches of the Middle Rio Grande. Arroyos have been shown to be important in the retention of eggs because their off-channel location results in low or no water velocities depending on proximity to their confluence with the mainstem river (Porter and Massong, 2004). Additionally, it has been suggested that nursery habitat can be constructed for Rio Grande silvery minnow in areas that are currently degraded (Massong et al., 2004). Increasing the habitat heterogeneity of the Rio Grande will likely result in the increased retention of Rio Grande silvery minnow eggs upstream. However, it is important to note that this habitat must remain wetted for an extended time period (ca. six weeks) to allow for newly hatched larvae to begin exogenous feeding and grow to a larger size. Extended periods of inundation during spring runoff have resulted in increased autumnal abundance of Rio Grande silvery minnow (Dudley and Platania, 2008) and this is probably caused by the improved recruitment conditions afforded by shallow low velocity mesohabitats.

River fragmentation and habitat degradation are two factors that have contributed to the decline in the distribution and abundance of Rio Grande silvery minnow by reducing recruitment. Both processes result in the loss of eggs to downstream environments (e.g., reservoirs or irrigation networks) that harbor piscivorous nonnative fishes. River fragmentation also prevents upstream recolonization, increasing overall extinction risk. However, the relative scales at which these processes operate can be difficult to grasp. Habitat restoration must be conducted simultaneously with dam removal to ensure that the efforts of one complement the other. The likelihood of recovery success for the Rio Grande silvery minnow is greatly diminished if either activity (i.e., fish passage or habitat restoration) is not pursued fully. It is important to note that large-scale changes in current conditions (e.g., dam removal and restoration of the nature flow and sediment regime) will likely be necessary to result in large-scale improvement in the conservation status of Rio Grande silvery minnow.

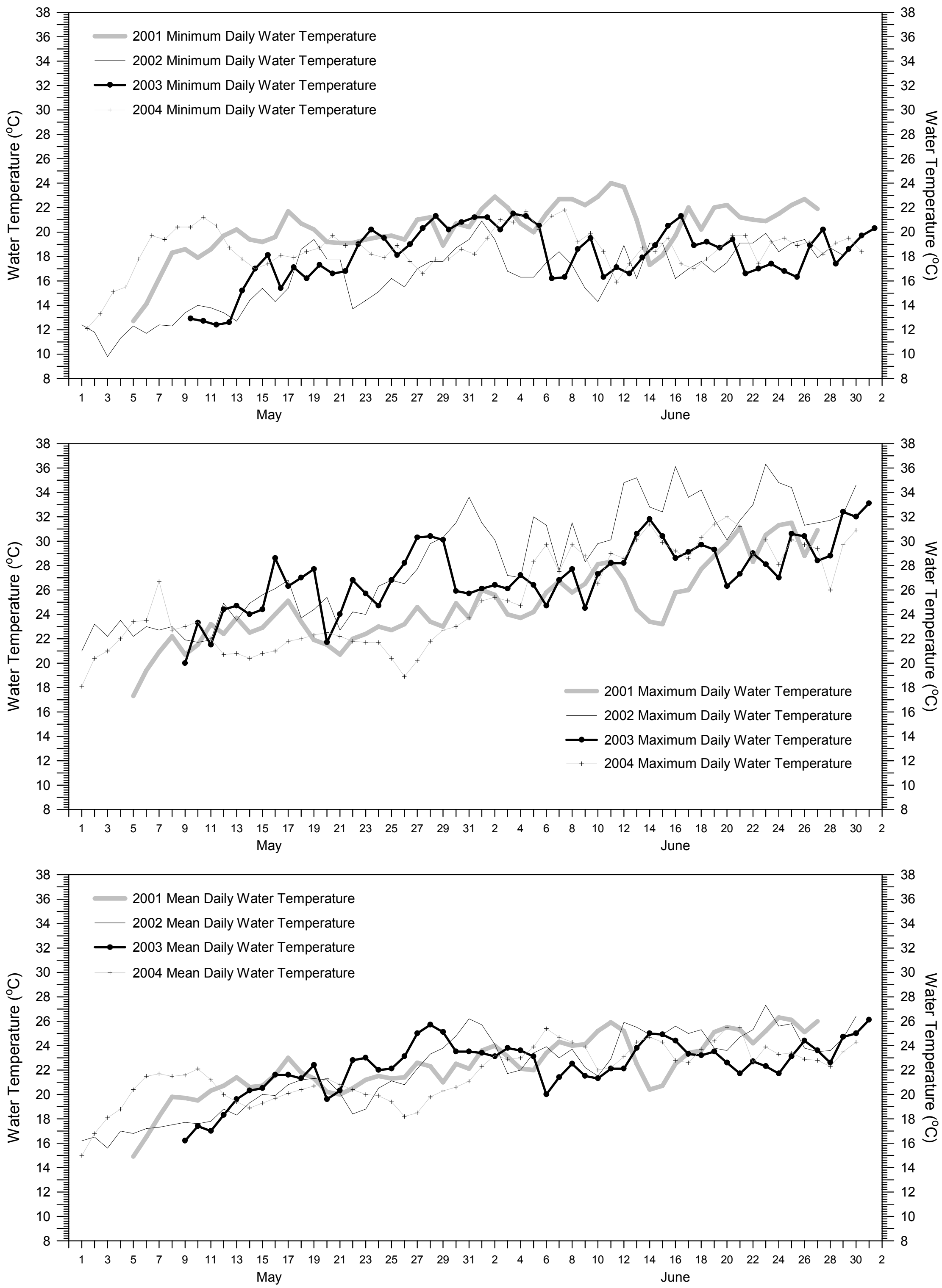

Figure 16. Comparisons of annual minimum, maximum, and mean daily water temperatures during the 2001-04 Rio Grande silvery minnow spawning periodicity study periods.

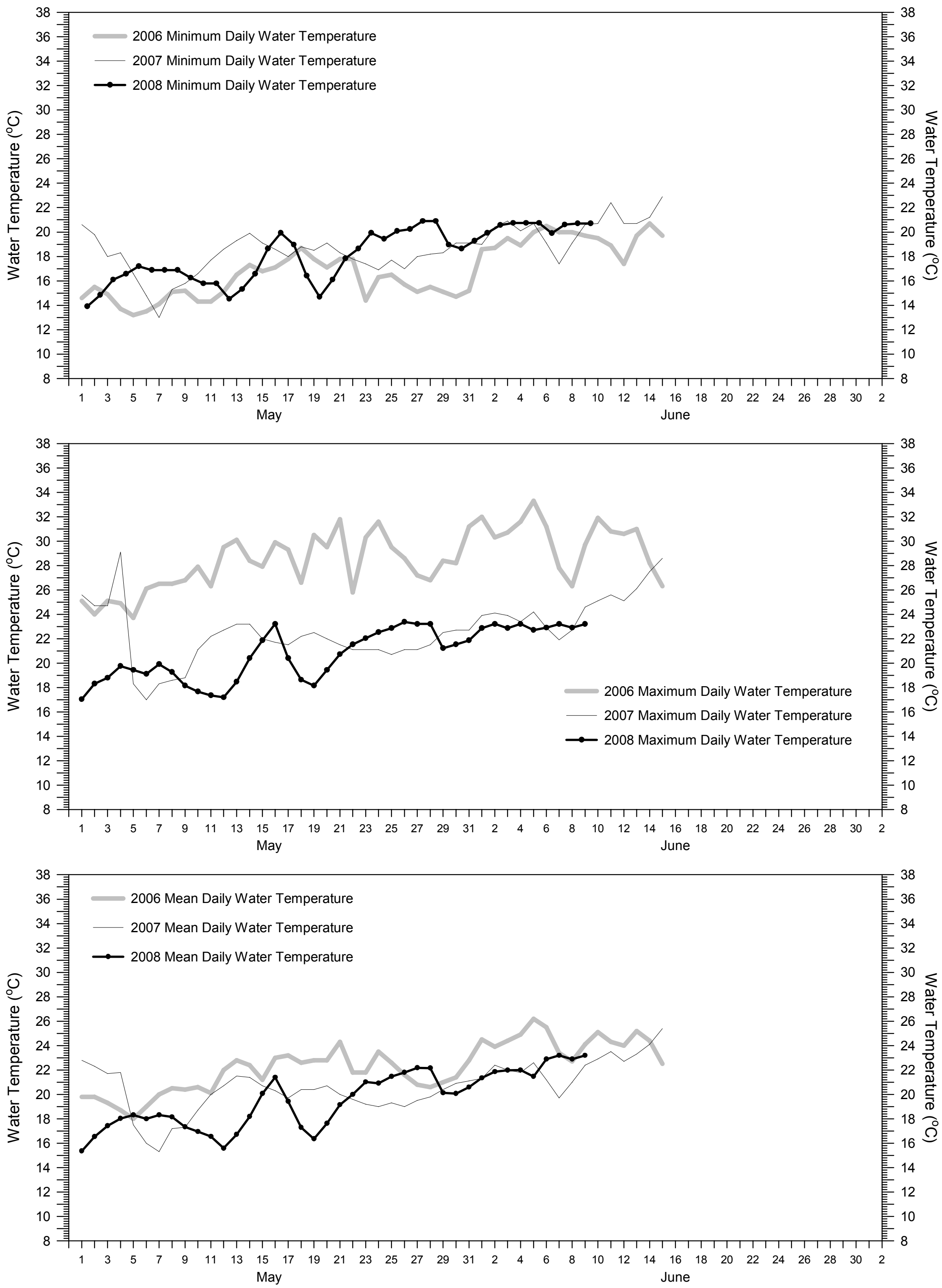

Figure 17. Comparisons of annual minimum, maximum, and mean daily water temperatures at the San Marcial site during the 2006-08 Rio Grande silvery minnow spawning periodicity study periods.

Since Rio Grande silvery minnow is the only extant species of the previously discussed reproductive guild in the Middle Rio Grande, the species-specific identification of any semibuoyant egg collected during this study is unambiguous. The only other eggs that we have captured in the Middle Rio Grande during this and previous investigations that look (to the untrained individual) remotely similar to those of Rio Grande silvery minnow are the eggs of common carp, *Cyprinus carpio*. Fortunately, there are numerous differences between eggs of these species that aid in identification. As the eggs of common carp are adhesive, there are usually small pieces of particulate matter attached to the chorion. Additionally, common carp eggs are smaller and more opaque than silvery minnow eggs, and the eyes of carp embryo become pigmented very early in development. Conversely, the egg of Rio Grande silvery minnow is clear, nonadhesive, smooth, large, and the embryo lacks discernible pigment.

Spawning of Rio Grande silvery minnow and other members in its reproductive guild (Platania and Altenbach, 1998) appear to be triggered by specific environmental cues. These fishes exhibited a strong positive correlation between flow and spawning. The peak spawning event by Rio Grande silvery minnow generally occurs soon after the initiation of runoff (often during the first two weeks of May). Egg catch rates in the Pecos River and Rio Grande appear most closely correlated with increased flow and not absolute water volume. This relationship has been observed throughout the Middle Pecos River from early-May until late-September. Spawning was closely correlated to sharp increases in flow from local rainstorms and egg catch rates would drop as soon as flows began to drop. This sequential pattern (increased flow, increased spawning, decreased flow, decreased spawning) occurred throughout the summer in the Pecos River, NM. By late-September, the association between spawning and flow was minimal, indicating the end of the reproductive season for the five members of the reproductive guild that occupy the Pecos River.

Downstream displacement of drifting fish eggs and larvae in aquatic ecosystems pose a unique problem for resource managers. While the most simple solution would appear to be collecting eggs from downstream localities and transporting them to rearing facilities, this method has only short term significance. Additionally, the capture of eggs using current techniques and levels of effort will result in the collection of only a minuscule fraction of the total reproductive effort that is destined for Elephant Butte Reservoir. The ability to efficiently sample 1% of the entire volume of water that carries these reproductive propagules requires a monumental effort. The low flow in May 2002 and 2003 and subsequent collecting efforts that resulted meant that a larger portion of the river was sampled during that Rio Grande silvery minnow egg collecting effort than had ever previously occurred.

The 2004 Rio Grande silvery minnow population monitoring efforts continued to document the decline of this species in the Middle Rio Grande. The 2004 monthly sampling efforts produced almost 13,000 specimens during the first third of the year (January-April) of which only 103 (0.08%) were Rio Grande silvery minnow. At least 22 of the 103 silvery minnow collected during this period were hatchery fish that had stocked in the river. Rio Grande silvery minnow collected during this period were members of the cohort capable of spawning in 2004. Given the extremely low numbers of adult silvery minnow present in pre-spawning 2004 samples, it is not surprising that the catch rate of Rio Grande silvery minnow propagules was markedly lower in 2004 than during any of the previous egg collection activities

However, populations rebounded notably during 2005 and maintained relatively high levels (as compared to 2002-2003) from 2005-2008 (Dudley and Platania, 2008). The 2008 population monitoring effort during October yielded 868 Rio Grande silvery minnow that comprised 23% of the total fish catch (Tables 4 and 5). Those values were notably higher than those recorded from 2000-2004. The high snowpack runoff and elevated discharge that stimulates spawning by Rio Grande silvery minnow resulted in a modest spawning effort during the 2008 study period. Summer monsoonal rainstorms that began in July and continued sporadically through September 2008 contributed considerable water to the Middle Rio Grande and helped maintain flow throughout the study area. The effect of these storms (and elevated discharges) on Rio Grande silvery minnow reproduction was not quantified because the study was terminated on 15 June 2008. However, the broad range in sizes of age-0 Rio Grande silvery minnow (21-55 mm SL) in October 2008 population monitoring samples indicates some spawning occurred (at least sporadically) in association with the rainstorms. Rio Grande silvery minnow appear to have had another good year for spawning and recruitment, which should translate into increased numbers of reproductively capable females available to spawn in the spring of 2009. While the population of Rio Grande silvery minnow appears to have stabilized since 2007, the lack of an adequately high spring runoff (high magnitude over an extended duration) could result in a rapid decline to pre-2005 population levels. The future conservation status of Rio Grande silvery minnow appears dependent on ensuring adequate flow conditions during the spawning and early recruitment phases of this species.

Table 4. Summary of the 2007-2008 Rio Grande silvery minnow population monitoring program fish collections.

SPECIES	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL
HERRINGS													
gizzard shad	--		--		--	7	2	1	--	13	2		25
threadfin shad	--		--		--	--	--	--	--	--	--		--
CARPS AND MINNOWS													
red shiner	4,428		1,714		1,296	2,232	1,477	1,668	1,261	2,058	1,636		17,770
common carp	1		--		--	9	51	364	37	27	41		530
Rio Grande chub	--		--		--	--	--	--	--	--	1		1
Rio Grande silvery minnow	1,145		460		161	294	526	2,978	1,901	1,216	868		9,549
fathead minnow	30		15		4	10	114	503	247	260	114		1,297
bullhead minnow	--		--		--	--	--	--	--	--	--		--
flathead chub	276		54		117	132	124	113	139	185	239		1,379
longnose dace	1		--		22	48	59	40	26	61	29		286
SUCKERS													
river carpsucker	161		27		8	388	41	117	10	15	18		785
white sucker	--		--		2	73	480	482	31	9	12		1,089
smallmouth buffalo	--		--		--	5	6	2	--	--	--		13
BULLHEAD CATFISHES													
black bullhead	--		--		--	--	--	--	--	--	3		3
yellow bullhead	1		--		--	--	--	5	17	13	5		41
blue catfish	--		--		--	--	2	3	--	--	--		
channel catfish	209		20		49	33	19	79	331	569	82		1,391
flathead catfish	--		--		--	--	--	--	1	2	1		4
TROUTS													
rainbow trout	--		--		--	--	--	--	--	--	--		--
brown trout	--		--		--	--	--	--	--	--	--		--
LIVEBEARERS													
western mosquitofish	253		--		14	5	13	613	451	819	745		2,913
TEMPERATE BASSES													
white bass	1		1		--	--	--	2	--	1	--		5
SUNFISHES													
green sunfish	--		--		--	--	--	--	--	--	1		1
bluegill	1		--		--	--	--	--	--	2	--		3
largemouth bass	--		--		--	--	--	14	5	3	3		25
white crappie	1		--		--	--	3	--	1	1	1		7
black crappie	--		--		--	--	--	--	--	--	--		--
PERCHES													
yellow perch	--		--		--	--	--	--	--	--	--		--
bigscale logperch	--		--		--	--	--	--	--	--	--		--
walleye	--		--		--	1	--	--	--	1	--		2
TOTAL	6,508		2,291		1,673	3,237	2,917	6,984	4,458	5,255	3,801		37,124

Table 5. Summary of the monthly catch of Rio Grande silvery minnow, by site and reach, during the 2007-2008 Rio Grande silvery minnow population monitoring program. Numerals in parenthesis, a subset of the total catch, are the number of individual silvery minnow in that sample that were marked with VIE tags (=hatchery reared [stocked] fish).

REACH Site Number Site Name	DEC 2007	JAN 2008	FEB 2008	MAR 2008	APR 2008	MAY 2008	JUN 2008	JUL 2008	AUG 2008	SEP 2008	OCT 2008		TOTAL
ANGOSTURA REACH													
0 Angostura Dam	--		--		--	--	0	0	5	4	2		11
1 Bernalillo	235		--		1	1	9	34	63	35	45		423
2 Rio Rancho	44		4		1	5	50	29	49	42	73		297
3 Central Ave (Abq)	115(1)		20		37	3	30	152	141	31	88		617
4 Rio Bravo (Abq)	130		31		7	1	11	10	13	--	11		214
Angostura Reach Total	524		49		46	10	100	225	271	112	219		1,562
ISLETA REACH													
5 Los Lunas	95		8		28	18	9	126	155	85	32		556
6 Belen	119(1)		49		9	9	8	232	38	56	19		539
7 Jarales	103		37		3	1	28	65	86	17	27		367
8 US Hwy 60 Bernardo	6(1)		112 (12)		2	1	2	122	41	34	11		331
9 South of Bernardo	28(1)		15		--	1	9	603	102	32	1		791
10 North of San Acacia	23		6		--	--	6	244	37	13	21		350
Isleta Reach Total	56		42		42	30	62	1,392	459	237	111		2,934
SAN ACACIA REACH													
10 San Acacia Dam	--		7		55	1	28	46(1)	57	68	140		402
11 S of San Acacia	56(45)		30(9)		9	5(2)	2	397	77	123	12		711
12 Socorro	142(2)		69(3)		4	--	3	96	72	148	56		590
13 North of US Hwy 380	4(2)		4(1)		--	--	0	395	97	47	58		605
14 US Hwy 380	5		20(8)		--	--	1	58	128	242	60		514
15 Bosque del Apache	2		--		--	238	291	69	24	124	69		817
16 San Marcial	16		--		5	--	19	204	376	67	83		770
17 South of San Marcial	16		42		--	10	20	72	325	24	30		539
18 South of San Marcial	6		6		--	--	0	24	15	24	30		105
San Acacia Reach Total	247		178		73	254	364	1,361	1,171	867	538		5,053
MONTHLY TOTALS	1,145		460		161	294	526	2,978	1,901	1,216	868		9,549
	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL

ACKNOWLEDGMENTS

Numerous people from a variety of state and federal agencies collaborated to make this project possible. We thank Bruce L. Christman (ASIR), Adam L. Barkalow (ASIR), Austin L. Fitzgerald (ASIR), Trevor J. Krabenhoff (UNM), John P. Larson (ASIR), Conner C. McBride (ASIR), and Nathan B. Zerbe (ASIR) for undertaking the field work (egg collecting phase) portion. Alexandra M. Snyder (Museum of Southwestern Biology, UNM) assisted in transferring eggs for genetic analysis. This study was funded by the Middle Rio Grande Endangered Species Collaborative Program through a contract administered by the U. S. Bureau of Reclamation, Projects Office, Albuquerque, New Mexico. Gary L. Dean (USBR) assisted with this project on several levels, including assuming contract administration for the USBR.

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