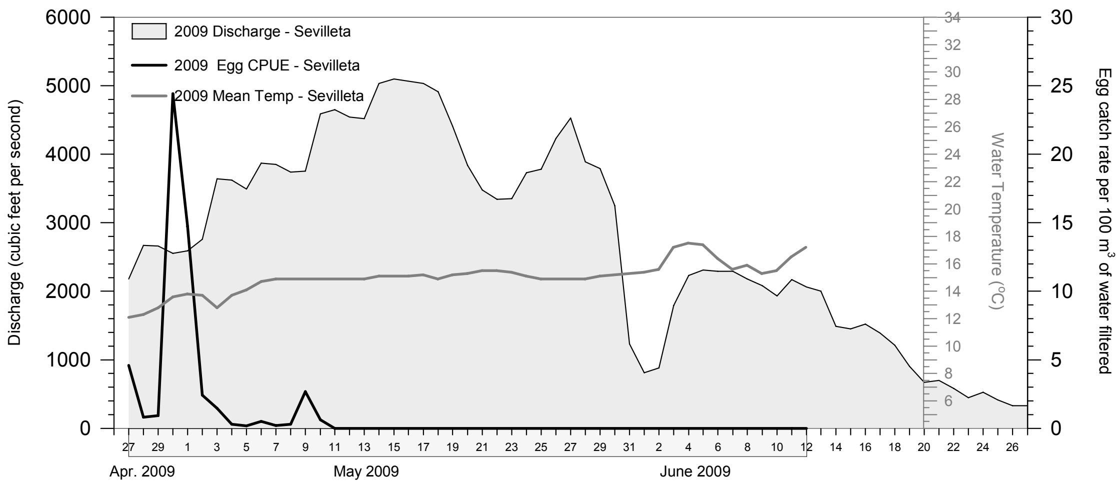
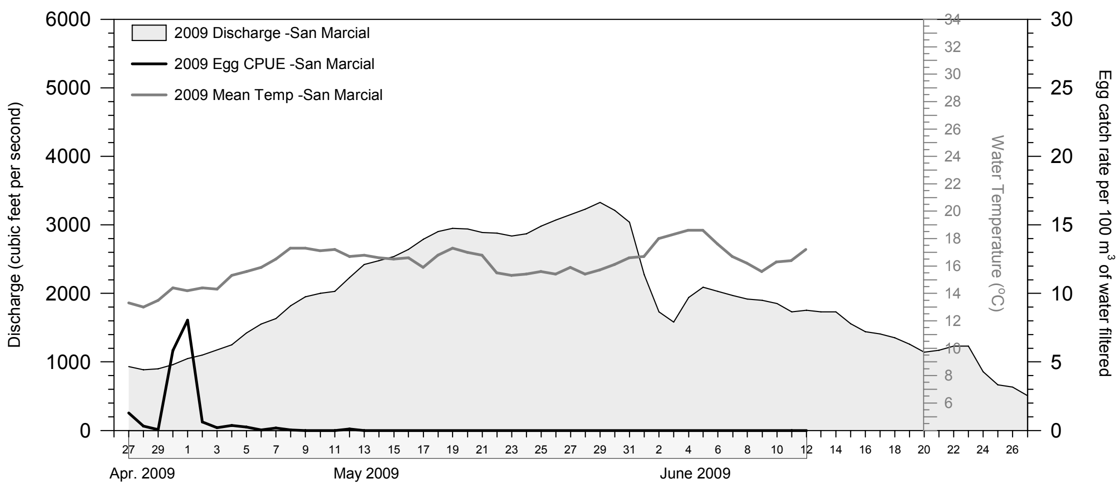
SPATIAL SPAWNING PERIODICITY OF RIO GRANDE SILVERY MINNOW DURING 2009

A MIDDLE RIO GRANDE ENDANGERED SPECIES ACT COLLABORATIVE PROGRAM FUNDED RESEARCH PROJECT





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30 September 2009

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prepared for:

MIDDLE RIO GRANDE ENDANGERED SPECIES ACT COLLABORATIVE PROGRAM

under USBR contract:

Number 03CR408031
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30 September 2009

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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 and has continued annually (except 2005) since 2001. Previous studies 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, were conducted near the downstream-most portion of each of the three accessible river reaches (Angostura, Isleta, and San Acacia). The 2009 study was structured to monitor the spatial and temporal (May-June) reproductive output of Rio Grande silvery minnow in the two downstream-most river reaches (Isleta and San Acacia).

Sampling at both 2009 Rio Grande silvery minnow spawning periodicity study sites was conducted from 27 April through 12 June 2009 (n= 47 days). The cumulative volume of water sampled at the two Rio Grande sites was 263,347 m^3 (213.5 acre-feet). There was a slight increase, from upstream to downstream, in the total volume of water filtered per sampling site. The cumulative volume of water sampled at the Sevilleta Site was 118,555 m^3 and the total amount of water sampled at the San Marcial Site was 144,792 m^3. A cumulative total of 1,489 Rio Grande silvery minnow eggs were collected at the two sites during 2009. The majority (n= 844; 56.7%) of the catch was taken at the Sevilleta Site while the number and cumulative percent of Rio Grande silvery minnow eggs collected at the San Marcial site (n= 645; 43.3%) was slightly lower. Rio Grande silvery minnow eggs were collected on 14 days at the Sevilleta Site and 13 days at the San Marcial Site. On 12 days, Rio Grande silvery minnow eggs were taken concurrently at both the Sevilleta and San Marcial sites. Daily egg catch rates at the Sevilleta Site ranged between 0.18 and 24.42 eggs per 100 m^3 of water sampled (n= 6 and n= 331, respectively) while daily egg catch rates at the San Marcial Site ranged between 0.03 and 8.05 eggs per 100 m^3 of water sampled (n= 1 and n= 281, respectively). During the study, mean daily egg catch rates at the Sevilleta and San Marcial sites were 0.71 and 0.45 eggs per 100 m^3 of water sampled, respectively. The number of eggs estimated to be transported downstream of the Sevilleta Site over the duration of the study was 3,554,295 with a daily maximum of 1,523,783. The number of eggs estimated to be transported downstream of the San Marcial Site over the duration of the study was 436,924 with a daily maximum of 206,707.

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=6.16; p<0.0001) among mean values of catch rate (#/100m^3) for the six years of the study (2002-2004, 2006-2009). The following pair-wise comparisons were significant (p<0.05) over the period of record (2002 vs. 2004, 2006, 2009; 2003 vs. 2007; 2006 vs. 2007; 2007 vs. 2009). The natural log-transformed mean egg catch rate (standarized for discharge) was highest in 2002 (5.86 ±0.89), followed by 2007 (4.77±0.35), 2008 (3.22±1.26), 2003 (2.89±0.51), 2009 (2.56±0.60), 2006 (1.44±0.69), and 2004 (0.96±1.26). Additional statistical analyses for the Isleta Reach were made over the period of time that data were available (2006-2009). Analysis of reproductive output revealed a significant difference (F=8.68; p<0.0001) among mean values of catch rate (#/100m^3) for the four years of the study (2006-2009) in the Isleta Reach. The following pair-wise comparisons were significant (p<0.05) over the period of record in the Isleta Reach (2006 vs. 2007, 2008, 2009). The natural log-transformed mean egg catch rate (standarized for discharge) was highest in 2009 (4.59 ±0.48), followed by 2008 (4.28 ±0.43), 2007 (4.19±0.39), and 2006 (1.97±-0.40) in the Isleta Reach.

Comparisons of the old and new MEC screen efficiencies revealed significant differences between the screen types and also suggested differences in efficiencies based on quantity of instream debris and sampling interval. The mean volume of water sampled per interval at the lower velocity sampling location at the San Marcial site was 89.4±13.2 (N=14) compared to 129.4±13.5 (N=14) at the higher velocity location at the same site for the old screen. In contrast, the mean volume of water per interval sampled at the lower velocity sampling location at the San Marcial site was 137.8±14.9 (N=14) compared to 188.3±11.7 (N=14) at the higher velocity location at the same site for the new screen. For the lower velocity location, t=5.19 and p<0.0001 for the comparison between screens and the new screen was found to be 54.1% more efficient at sampling water than was the old screen over the same time period (one hour intervals). For the higher velocity location, t=5.04 and p<0.0001 for the comparison between screens and the new screen was found to be 45.5% more efficient at sampling water than was the old screen over the same time period (one hour intervals). The mean volume of water sampled per interval at the sampling location at the Sevilleta site was

18.6±1.39 (N=9) for the old screen compared to 22.3±1.1 (N=9) for the new screen. For the Sevilleta site, t=3.90 and p<0.0023 for the comparison between screens and the new screen was found to be 19.9% more efficient at sampling water than was the old screen over the same time period (10 minute intervals).

A comparison of the relationship between the October CPUE (#/100m2) mean log (ln(CPUE+1)) values of Rio Grande silvery minnow densities and natural log-transformed mean egg catch rate (standardized for discharge) at San Marcial using linear regression yielded a non-significant relationship (r^2<0.01; p=0.98) over the study period (2002-2004, 2006-2009). Similarly, a comparison of the relationship between natural log-transformed mean egg catch rate (standardized for discharge) at San Marcial and maximum discharge at USGS Gauge #08358400 (Rio Grande Floodway at San Marcial, NM) using linear regression over the same time period also yielded a non-significant relationship (r^2<0.01; p=0.87). These preliminary findings suggest that the number of eggs produced in the river does not appear to be strongly related to either the maximum discharge (measure of spring runoff) or to the number of individuals that survive to October. It is likely that the physical conditions of the river following spawning (i.e., extended period with elevated flows vs. low flows accompanied by river drying) are much more important than the quantity of eggs in determining the success of annual recruitment. Similarly, it is likely that the number of eggs produced in a given year is related more to the population size in spring as opposed to the strength of the spring runoff. Additional years of data will hopefully further elucidate these subtle relationships and lend insight to the causal mechanisms resulting in successful recruitment of Rio Grande silvery minnow.

Rio Grande silvery minnow appear to have had another good year for spawning, which should translate into increased numbers of reproductively capable females available to spawn in the spring of 2010. 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) combined with summer drying could result in a rapid decline to pre-2005 population levels. The lost of individuals from downstream reaches during river drying events is particularly problematic as these are the areas that most frequently and consistently support the highest densities of Rio Grande silvery minnow (except in years immediately following downstream drying). The future conservation status of Rio Grande silvery minnow appears dependent on ensuring adequate flow and habitat conditions during the spawning and early recruitment phases of this species while also allowing upstream recolonization by individuals transported downstream.

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, armoring, 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. 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 (Dudley and Platania, 2007b). 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, 2000). The 1999 monitoring effort 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) from 1996 to 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 conducted from 2006 to 2008 (Platania and Dudley, 2006, 2007, 2008) 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, 2007a, 2008, 2009). Recent monitoring efforts (Dudley and Platania, 2009) show that the October density of Rio Grande silvery minnow was significantly lower ($p<0.05$) in 2008 compared to 2005. However, the October density of this species was higher ($p<0.05$) in 2008 than in 1996, 2000-2004, and 2006. The San Acacia Reach yielded most of the Rio Grande silvery minnow in October of 2008, followed by the Angostura Reach and Isleta Reach. This was in contrast to population monitoring in October of 2007, when the largest catch rates were recorded in the Angostura and Isleta reaches.

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 2005-2008 (e.g., highest densities in the Angostura Reach during 2006 and 2007, in the Isleta Reach during 2005, and in the San Acacia Reach during 2008). 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 were 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 from 2006 to 2008.

The study conducted herein is at its core a continuation of the systematic 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. 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 to help facilitate the separate efforts. Daily updates on egg catch rates are provided to interested personnel within the Middle Rio Grande Endangered Species Act Collaborative Program (MRGESACP). 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 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. 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. Snow pack runoff and ambient flow conditions in 2004 were sufficient enough that, for the first time in two years, this was not necessary. Artificial flow spikes have not been generated since 2004 for the purpose of inducing spawning. This document presents the results of the 2009 spawn of Rio Grande silvery minnow and compares data collected under the auspices of this study from 2001-2004 and 2006-2009.

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 and braided river channel, 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 and 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

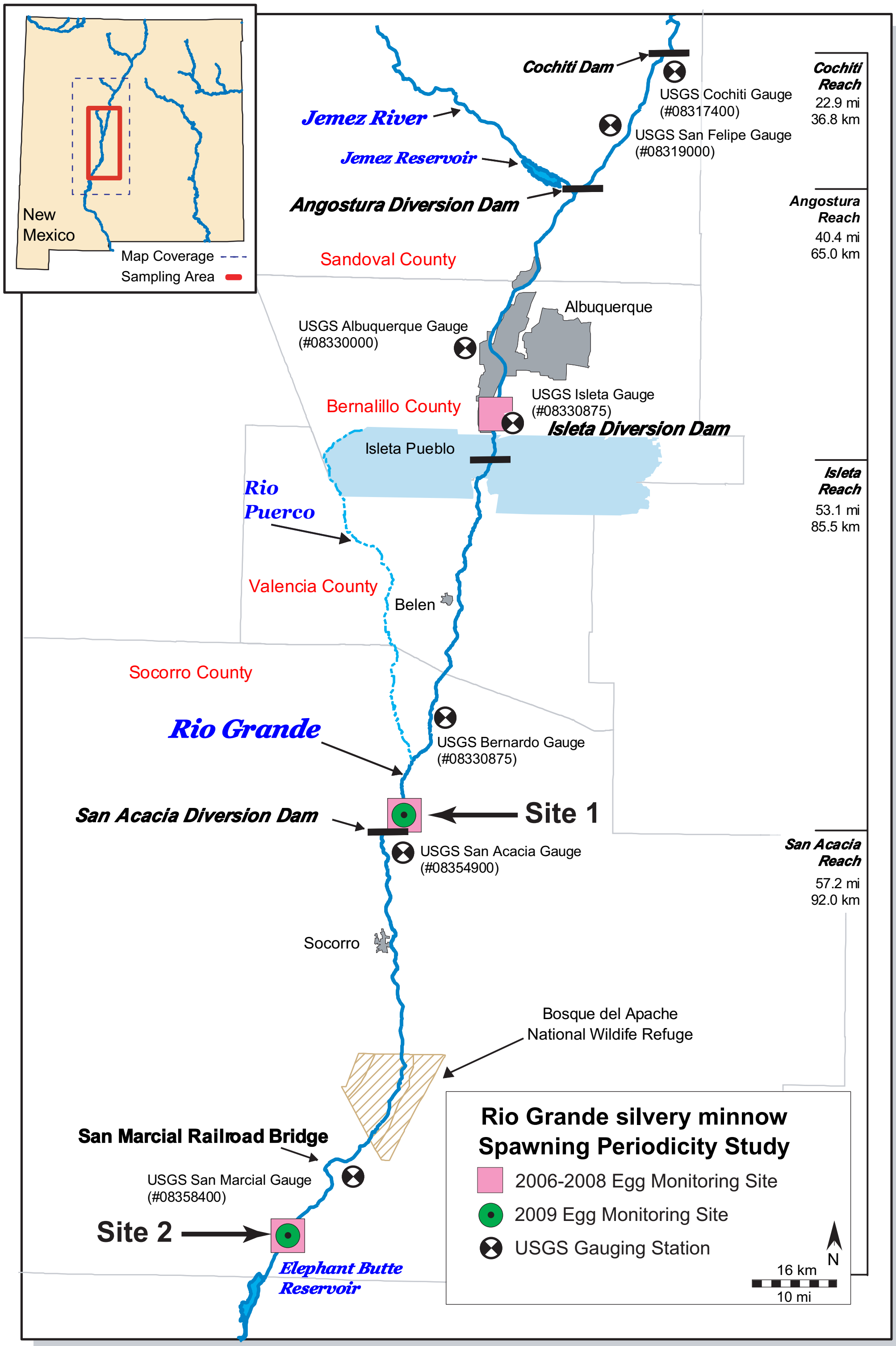

Figure 1. Map of the Middle Rio Grande, New Mexico, and the 2009 study site locations.

San Acacia Reach. In addition to easy accessibility and favorable river conditions (i.e., wide river channel, 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, were conducted near the downstream-most portion of each of the three accessible river reaches (Angostura, Isleta, and San Acacia). The Angostura Reach Site selected for sampling from 2006-2008 was also sampled during the 1999 spatial spawning periodicity study of this species (Platania and Dudley, 2000). This site is within 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). However, the Middle Rio Grande Endangered Species Collaborative Program decided to drop the Angostura Site from sampling in 2009. The Rio Grande-Isleta Reach Site selected for sampling from 2006-2009 is on Sevilleta 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 Sevilleta Site is downstream of U. S. Geological Survey stream gauging station (# 08331510), which is the nearest upstream Isleta Reach gauge. 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). The total number of eggs passing a sampling site in a 24 hour period was estimated by using egg sampling data from the site (over a 6 hour period) and flow data from the nearest upstream USGS gauging station (i.e., (number of eggs collected / (volume of water sampled / volume of water available)) · 4).

Previous studies (Platania and Dudley 2000, 2002, 2003, 2004, 2005, 2006, 2007, 2008) demonstrated May and June as the primary period of silvery minnow reproductive activity. The normal sampling regime in 2009 was comprised of three daily efforts (morning, noon, and afternoon), each of two-hour duration. Eggs were not staged (i.e., determining approximate time from spawning) as this would require substantial laboratory work outside of the current core objectives of this study. Staging eggs would give a general idea of drift time but extrapolating to drift distance would be subject to a series of simplifying assumptions. Also, determining drift distance is a complex modeling exercise of which eggs are only a component (i.e., eggs can be present in the drift for about one day but larvae can be present in the drift for about another three days post-hatching). Three MEC's were operated so as to increase the volume of water sampled per unit of time. Research personnel worked daily at both sampling sites from 27 April through 12 June 2009.

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

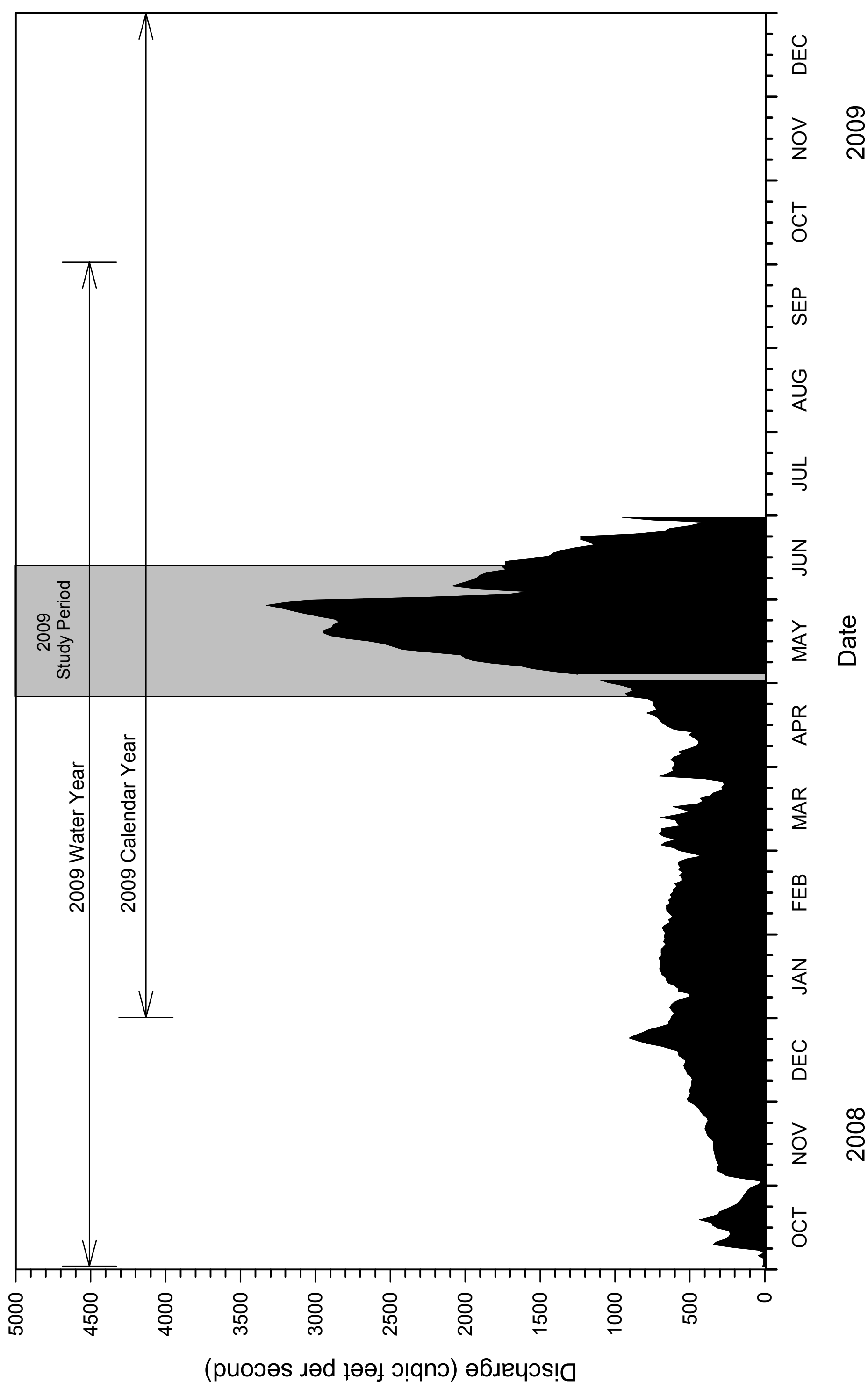

Figure 2. Hydrograph of the Rio Grande, New Mexico, at the San Marcial Gauging Station before, during, and after the 2009 study period.

determination between 2001 and post-2001 studies preclude use of 2001 data for quantitative or statistical comparison with data from subsequent years. There have not been changes in the method for quantitative determination of egg catch rate since 2002.

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]/100 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 2006-2009 egg catch rate time-series distributions were compared with a normal distribution using the Shapiro-Wilk test. To meet normality assumptions, all data were log-transformed ($X' = \ln(X+1)$). Normal quantile plots of empirical data were also examined in reference to Lilliefor's confidence bounds.

The non-zero 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 among 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.

A new screen for the MEC was developed and tested during this study on the authors' own initiative in 2009. A simple window screen material had been used for the MEC since studies began in the Rio Grande in 1999. However, it was recognized that a large amount of the fine particulate debris entering the MEC quickly became impinged on the screen. Frequent cleanings of the screen were required to allow for the more efficient passage of water through the device. These problems led to the development of the new screen (design is proprietary), which was modified to allow the passage of much of the very fine particulate debris but did not allow passage of any drifting eggs. The old and new screens were tested for differences in efficiency by switching the screens at periodic intervals in the same sampling location within the river. At the San Marcial site, screens were switched hourly (over a six hour period) from 27 to 31 May 2009. At the Sevilleta site, screens were switched at ten minute intervals over a four hour period on 13 May 2009. The two different tests were conducted to determine sampling efficiency rates of the new and old screens at different testing intervals and under different conditions (i.e., more instream debris at the San Marcial site than the Sevilleta site). Differences in sampling efficiency rates were tested by using a paired-sample t test to determine if the new screen was more efficient than the old screen (one-tailed hypothesis) for each of the sampling sites. In addition to the tests between old and new screens, the old screen was used consistently at the sampling location closest to shore (generally lowest water velocity) for one MEC while the new screen was used consistently at the two more offshore locations (i.e., three two hour sets per day per site). The spacing between each MEC (as measured perpendicular to flow) was about 1.0 m.

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 are presented in this report as mean, minimum, and maximum daily water temperatures. Data from past spawning periodicity studies are also included for comparative purposes.

RESULTS

Hydrology during 2009

There was a large difference in flow in the Middle Rio Grande in 2007-2009 as compared to 2001-2004 and 2006 (Figures 3-6). The severe drought that enveloped the study region since 2000 was somewhat interrupted in 2004 due to a moderate snow pack 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. Snow pack runoff in 2005 was larger (greater magnitude and duration) than any of the

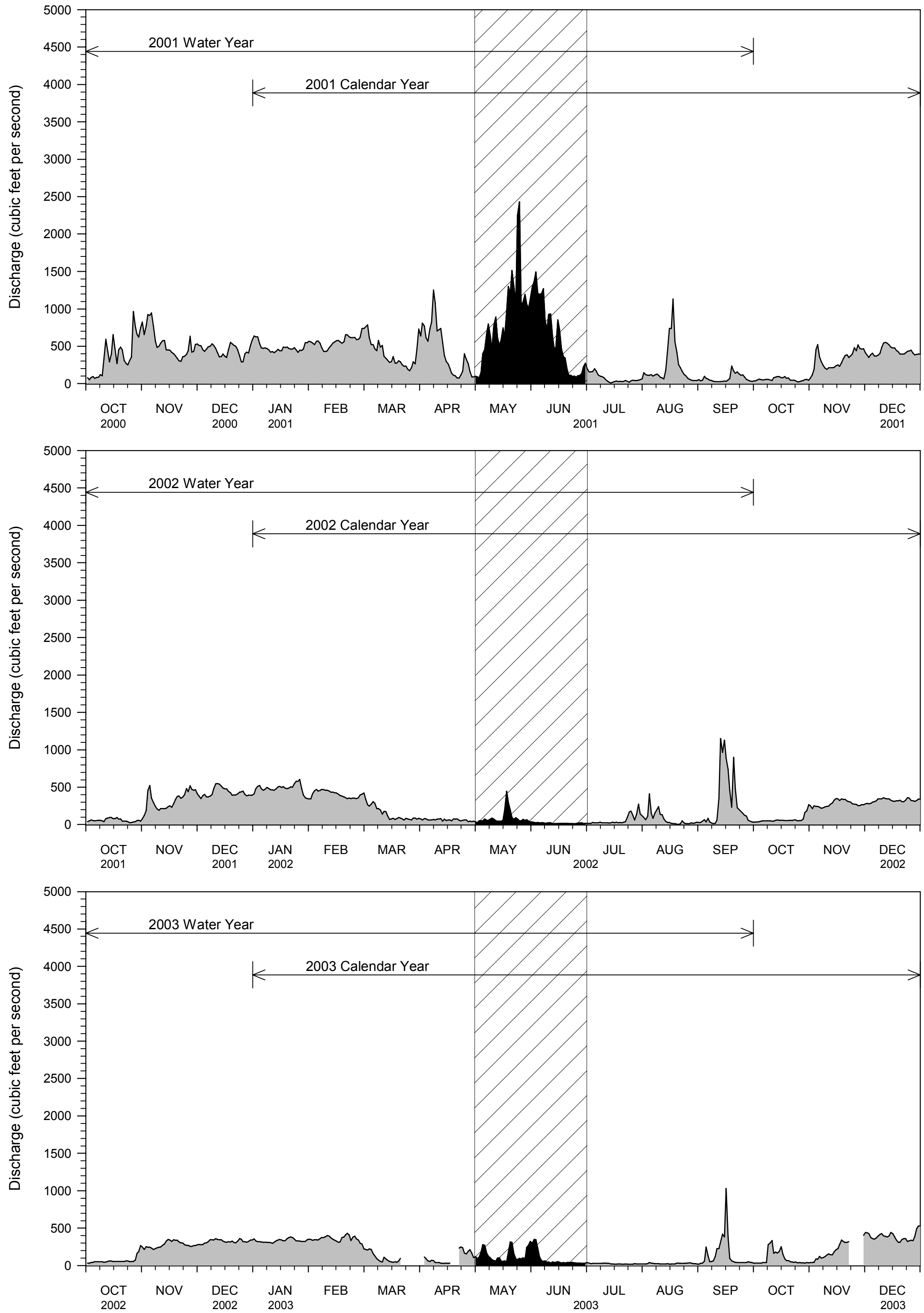

Figure 3. Annual hydrographs of the Rio Grande, New Mexico, at San Marcial before, during, and after the 2001-2003 Rio Grande silvery minnow spawning periodicity study periods. Cross-hatching indicates annual study periods.

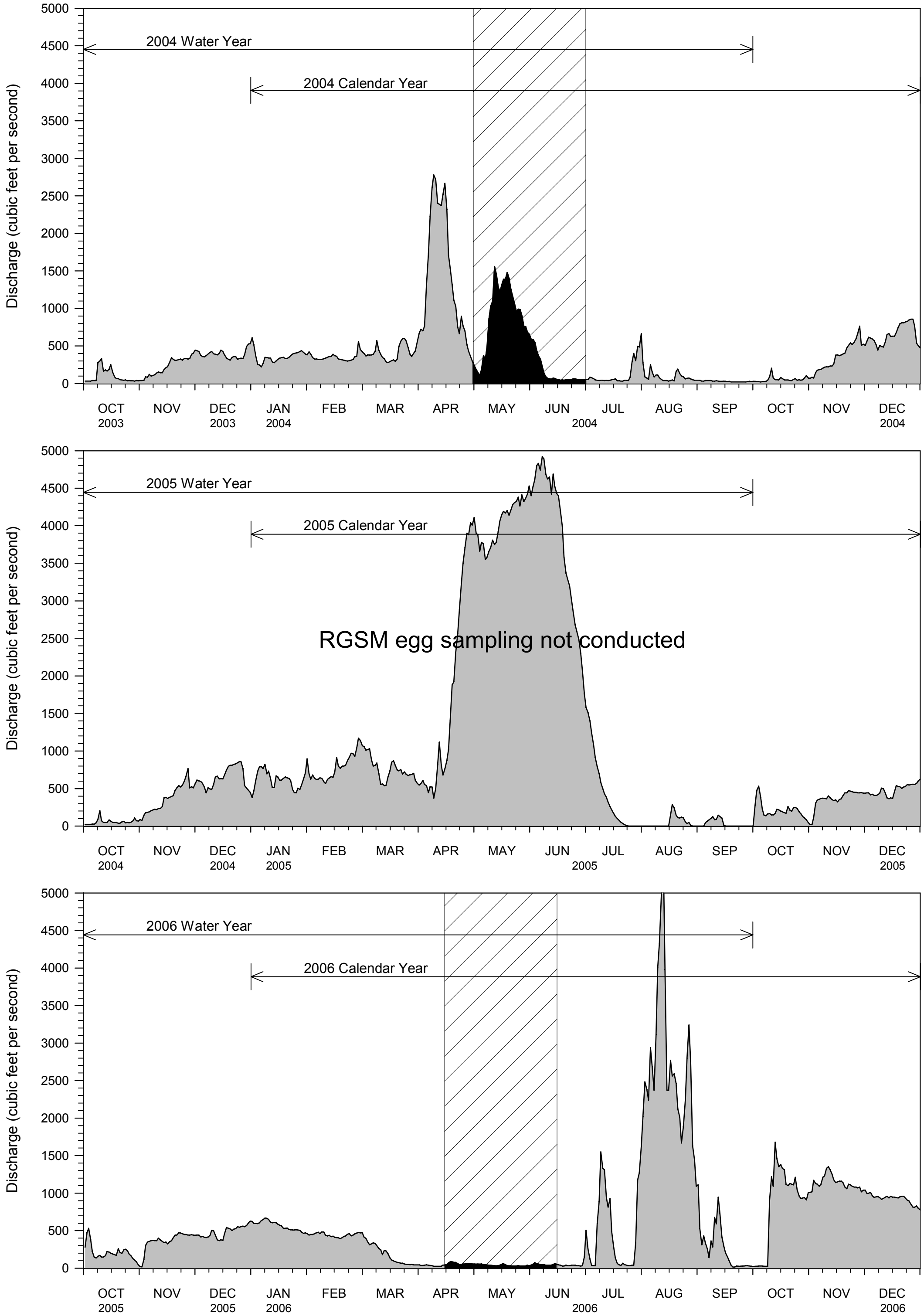

Figure 4. Annual hydrographs of the Rio Grande, New Mexico, at San Marcial before, during, and after the 2004 and 2006 Rio Grande silvery minnow reproductive monitoring study periods. Cross-hatching indicates annual study periods. Sampling was not conducted in 2005.

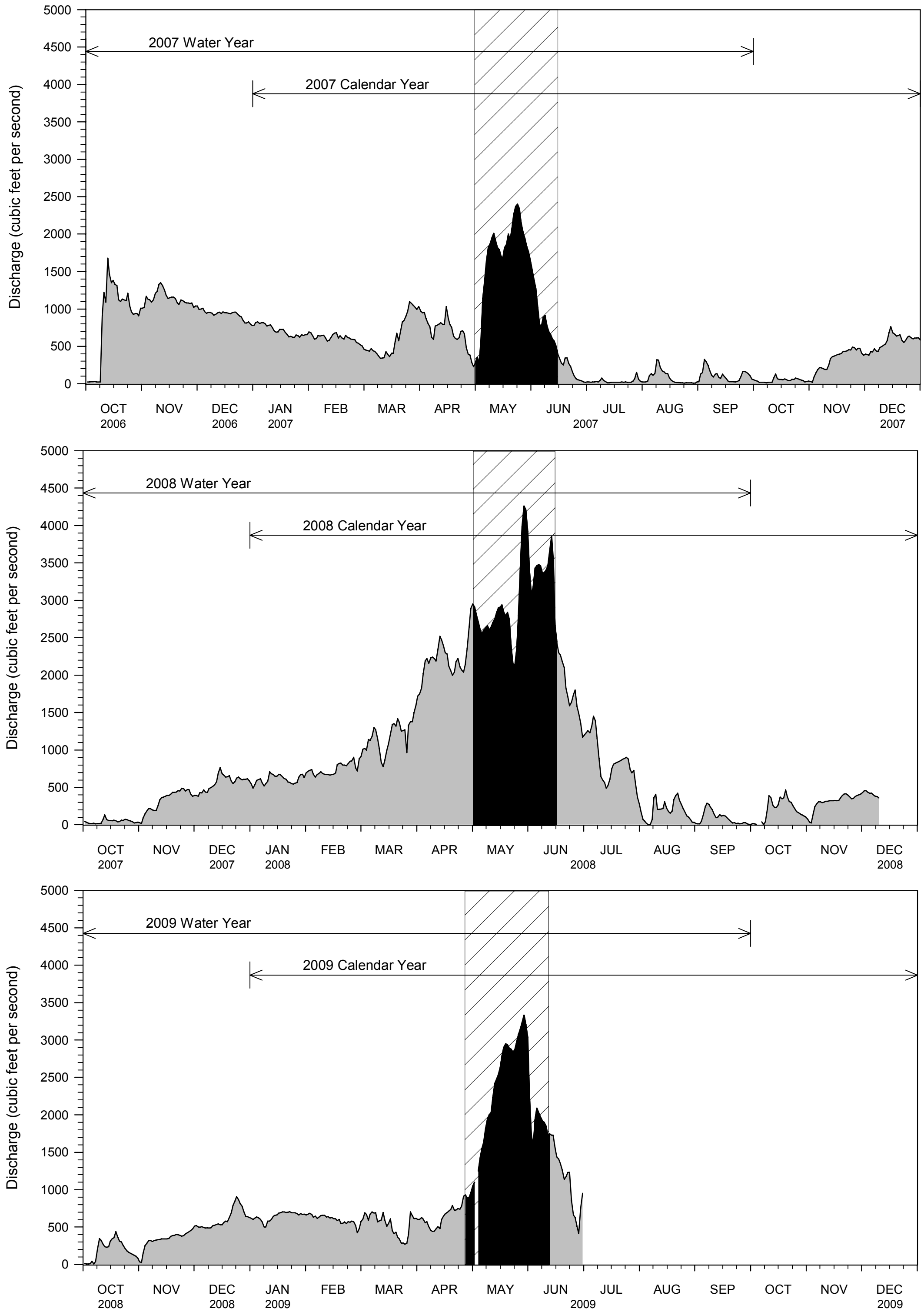

Figure 5. Annual hydrographs of the Rio Grande, New Mexico, at San Marcial before, during, and after the 2007-2009 Rio Grande silvery minnow reproductive monitoring study periods. Cross-hatching indicates annual study periods.

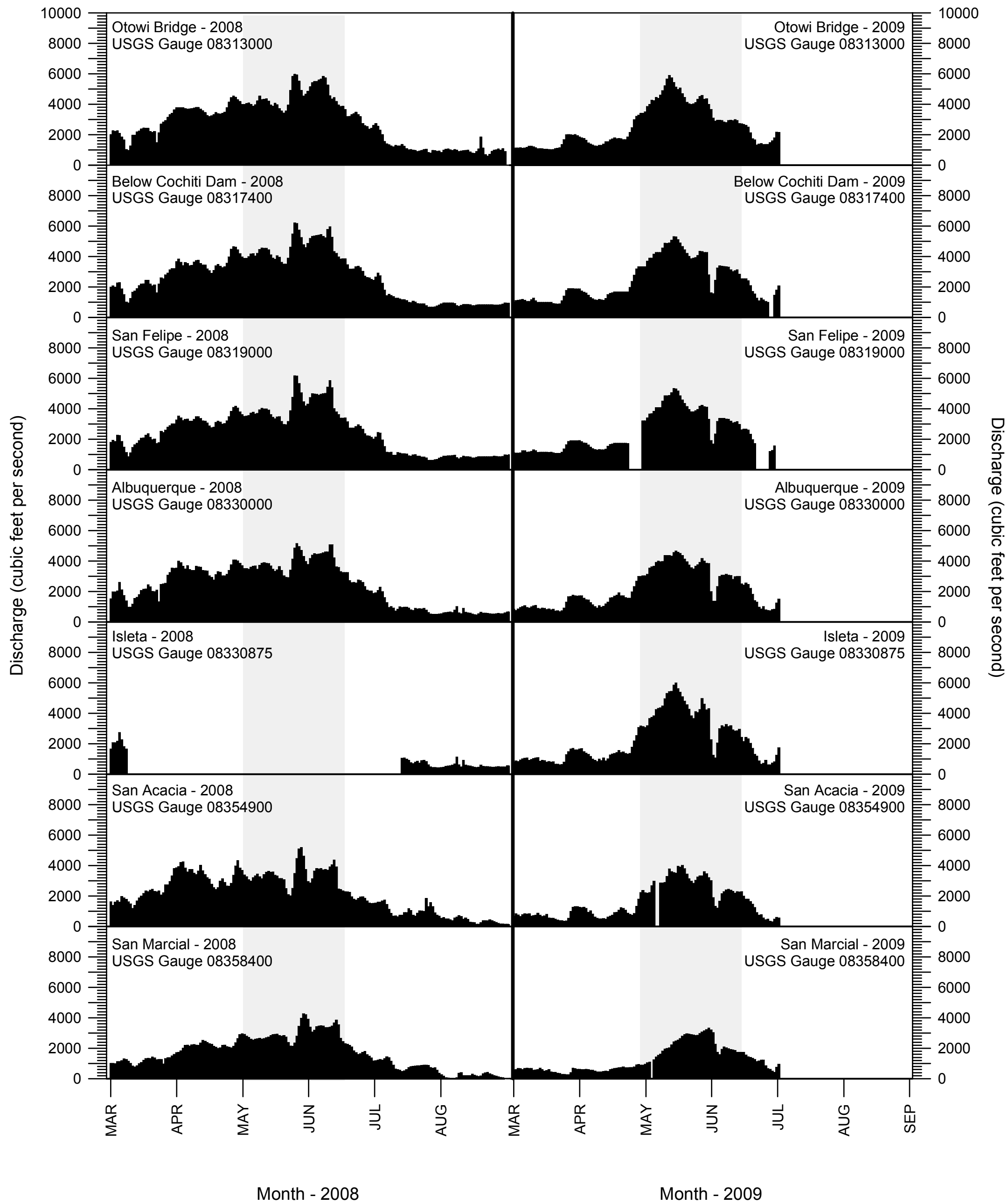

Figure 6. Rio Grande discharge from March through August 2008 and March through June 2009 at seven U. S. Geological Survey Gauge Stations (see Figure 1). The Otowi Bridge gauge site is about 25.5 river miles upstream of Cochiti Dam, not covered with the area of Figure 1, and provided for reference. Discharge data are provisional and may change.

previous four study years (egg sampling was not conducted in 2005). Conversely, flow in the Rio Grande during 2006 (prior to 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 from 2007 to 2009, as compared with 2006, and there was an extended period of time during May and June when flows exceeded 2,000 cfs at the State Hwy 346 Near Bosque Gauge (USGS Gauge 08331510).

Base flow in the Rio Grande at the State Hwy 346 Near Bosque Gauge (USGS Gauge 08331510) during May and early June 2009 was generally between 2,500 and 5,000 cfs (Figure 7). Mean daily discharge at the Isleta Reach Site (Sevilleta) for the period 1 April through 30 June 2009 was 2,094.9 cfs (SD=1,465.4). From 24 April to 14 May, there was a substantial spike in flow as mean daily discharge rose from 901 to over 5,000 cfs; flows then declined rapidly until 2 June (882 cfs) when a second smaller peak began. There was a final steady decline in flow for the month (2,310 cfs [5 June] to 326 cfs [26 June]).

Discharge in the Rio Grande at the San Marcial Railroad Bridge Crossing (USGS Gauge 08358400) during the 2009 water year closely mirrored that of the State Hwy 346 Near Bosque Gauge (except at a reduced magnitude). From 1 April to 30 June 2009, daily discharge in the Rio Grande at the San Marcial Gauge ranged from 413 to 3,330 cfs (mean value= 1,511.2 cfs, SD=883.7). Mean daily discharge at the San Marcial Site was over 500 cfs lower than flows recorded at the Isleta Reach gauge. Flows peaked on 29 May and then declined to a lower plateau of about 2,000 cfs until mid-June; flows during the latter half of June declined to a low of 413 cfs (28 June).

Water temperature

There was little difference (ca. 1-2°C) in mean daily water temperatures at the two sites during the beginning of this study (Figure 8). There was a steady increase in mean daily water temperature at all sites from about 18°C on 1 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 (early June). The San Marcial Site reached a mean daily water temperature of 20°C on 30 May while the Sevilleta Site did not reach this temperature until 3 June 2009. By mid-June, mean daily water temperatures were about 21°C at the Sevilleta and San Marcial sites.

More important and informative than the mean daily water temperatures were maximum daily water temperatures. Maximum water temperatures were 21.5°C at the Sevilleta Site and 22.6°C at the San Marcial Site. Maximum daily water temperature exceeded 20°C on six occasions at the Sevilleta Site and on 27 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 Sevilleta Site. However, the temperature logger at the Sevilleta Site appears to have been partially or fully buried from about 8 May to about 2 June (i.e., minimum and maximum temperatures were nearly equivalent). This was likely caused by shifts in sediments within the river channel.

Mean water temperatures during May and early June varied considerably from 2007-2009 (Figure 9). 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 (2006-2009). Most of the differences in mean temperature among years occurred during early May and were likely caused by subtle annual differences in ambient conditions during that month.

2009 Rio Grande silvery minnow spatial spawning periodicity studies

Sampling at both 2009 Rio Grande silvery minnow spawning periodicity study sites was conducted from 27 April through 12 June 2009 (n= 47 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 the two Rio Grande sites was 259,522 m^3 (210.4 acre-feet). There was a slight increase, from upstream to downstream, in the total volume of water filtered per sampling site (Table 1). The cumulative volume of water sampled at the Sevilleta Site was 118,555 m^3 and the total amount of water sampled at the San Marcial Site was 140,967 m^3.

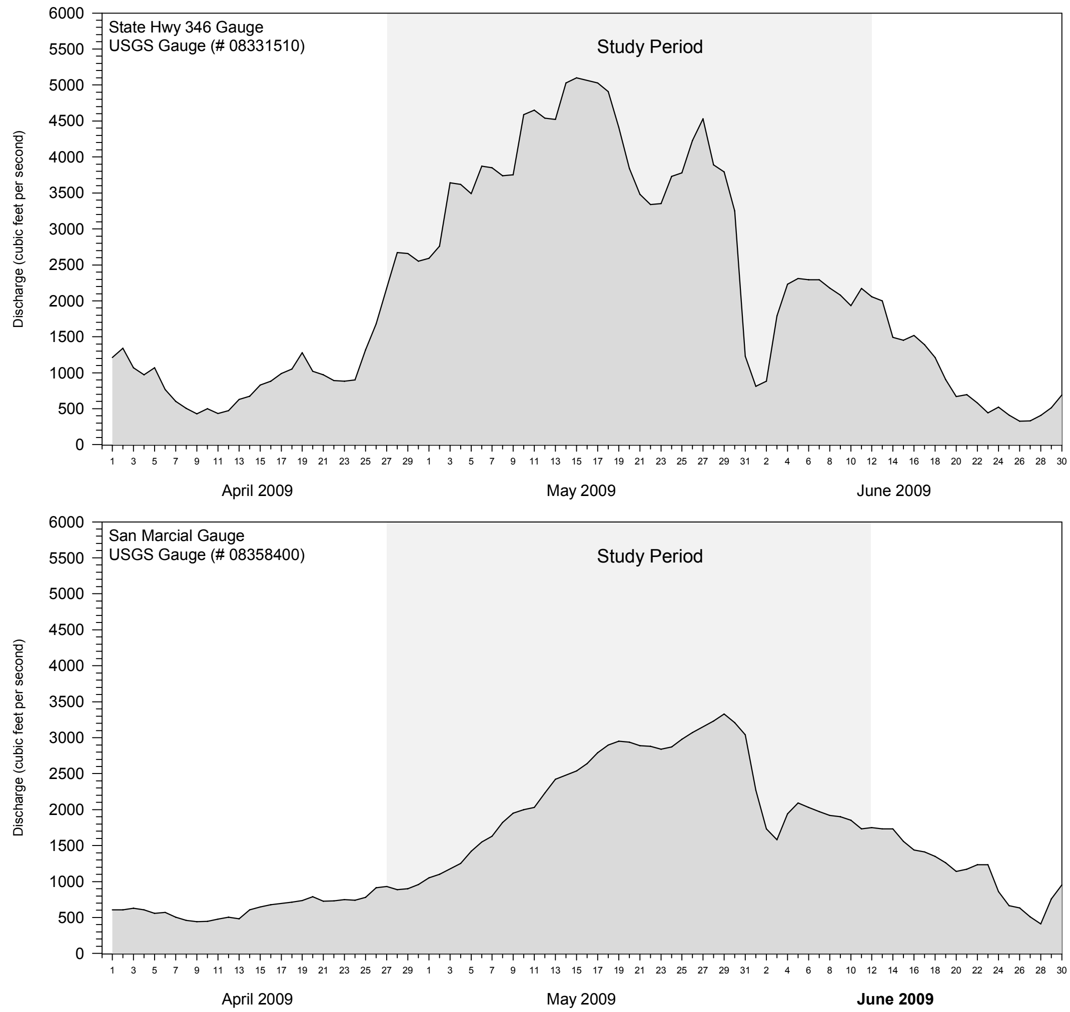

Figure 7. April-June 2009 hydrographs (dark gray) of the Rio Grande, New Mexico, from State Hwy. 346 and San Marcial gauges. The 2009 study period is highlighted in light gray.

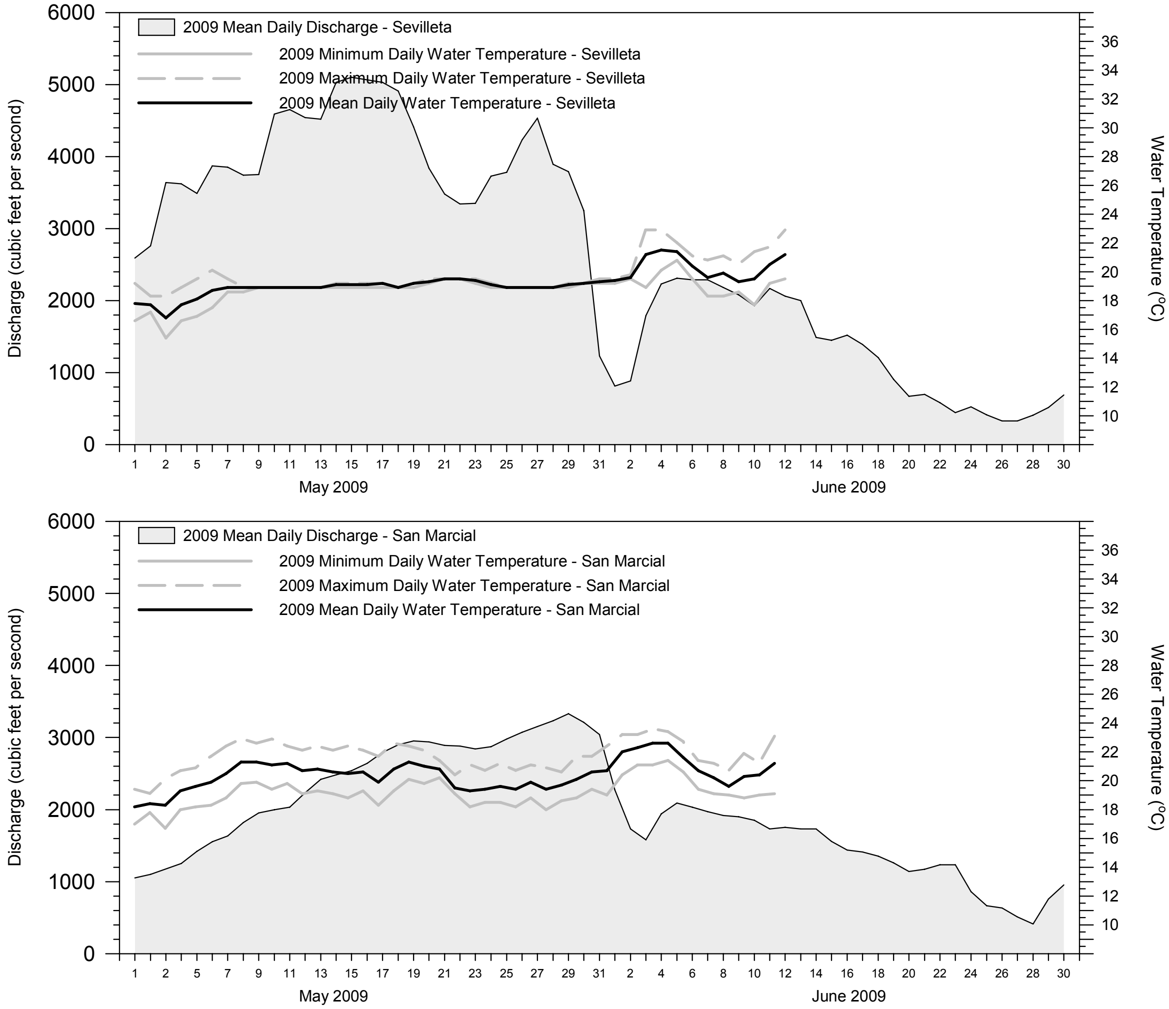

Figure 8. Daily water temperatures (mean, minimum, and maximum) at the 2009 Rio Grande silvery minnow spawning periodicity sampling sites. Approximate mean daily discharge in the Rio Grande at each sampling site is highlighted in light gray.

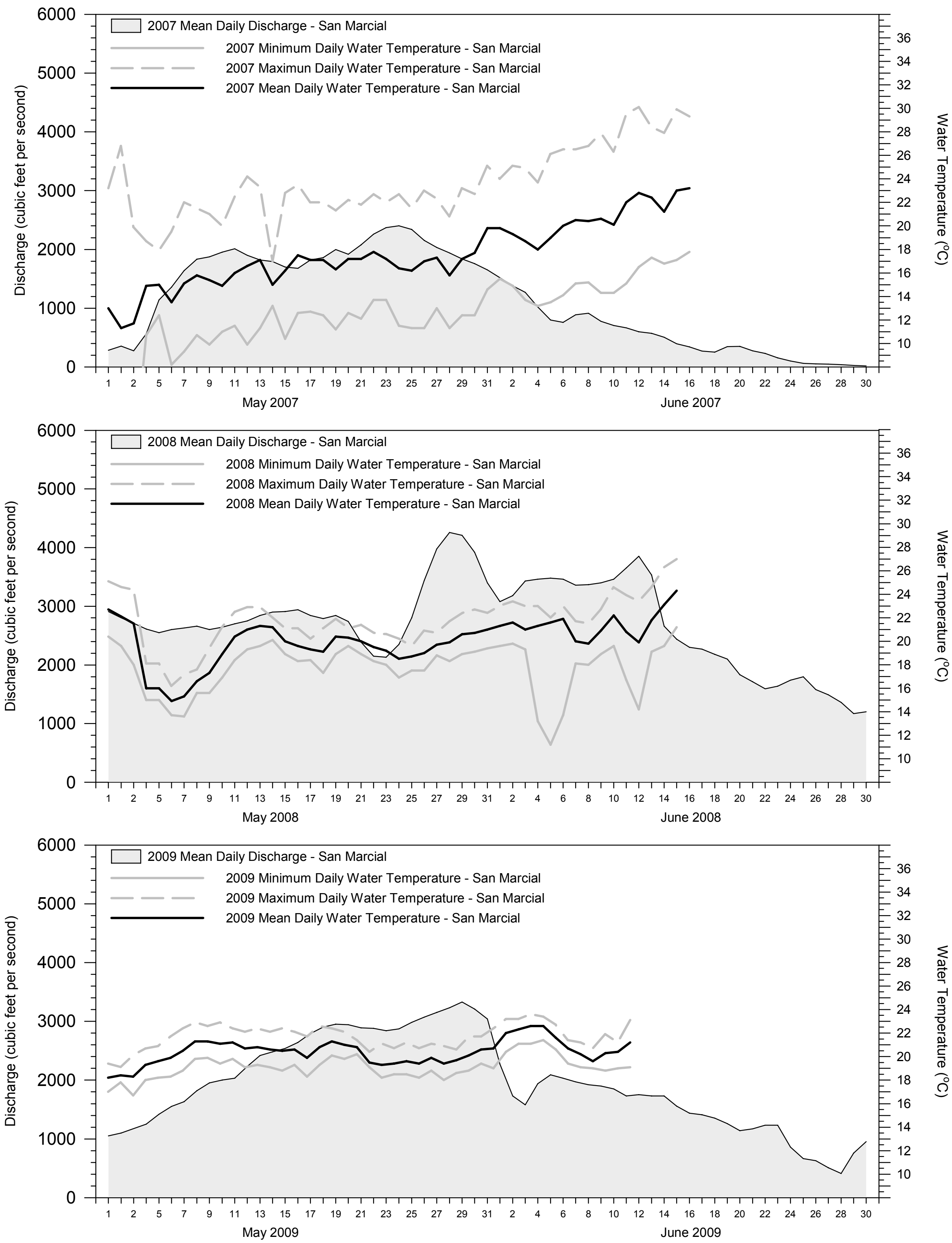

Figure 9. Comparison of the 2007-2009 daily water temperatures (mean, minimum, and maximum) at the San Marcial-Rio Grande silvery minnow spawning periodicity sampling site. Approximate mean daily discharge in the Rio Grande at San Marcial is highlighted in light gray.

A cumulative total of 1,489 Rio Grande silvery minnow eggs were collected at the two sites during 2009 (Table 2). The majority (n= 844; 56.7%) of the catch was taken at the Sevilleta Site while the number and cumulative percent of Rio Grande silvery minnow eggs collected at the San Marcial site (n= 645; 43.3%) was slightly lower. Rio Grande silvery minnow eggs were collected on 14 days at the Sevilleta Site and 13 days at the San Marcial Site. On 12 days, Rio Grande silvery minnow eggs were taken concurrently at both the Sevilleta and San Marcial sites.

The volume of water sampled at both the Sevilleta and Corral sampling sites constituted only a small fraction of the total volume available (nearly three orders of magnitude lower) over each daily six hour sampling period (Table 3). The number of eggs estimated to be transported downstream of the Sevilleta Site over the duration of the study was 3,554,295 with a daily maximum of 1,523,783. The number of eggs estimated to be transported downstream of the San Marcial Site over the duration of the study was 436,924 with a daily maximum of 206,707.

Dates of egg collection ranged from 27 April to 10 May (14 days) at the Sevilleta Site and 27 April to 12 May (16 days) at the San Marcial Site. Daily egg catch rates at the Sevilleta Site ranged between 0.18 and 24.42 eggs per 100 m^3 of water sampled (n= 6 and n= 331, respectively) while daily egg catch rates at the San Marcial Site ranged between 0.03 and 8.05 eggs per 100 m^3 of water sampled (n= 1 and n= 281, respectively). During the study, mean daily egg catch rates at the Sevilleta and San Marcial sites were 0.71 and 0.45 eggs per 100 m^3 of water sampled, respectively (Figure 10).

Comparison of 2002-2004 and 2006-2009 studies

There were several similarities apparent regarding Rio Grande silvery minnow reproduction during 2002-2004 and 2006-2009 (Table 4). Based on the results of data taken from all years of the project, there was an apparently extended duration of spawning (April-July). However, spawning consistently occurred during the early to middle portion of May over the period of record. In 2009, spawning at the San Marcial Site occurred in late April and early May with the peak being on 1 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 occurred 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. Spawning started on 27 April 2009 (first day of project) at the Sevilleta Site and at the San Marcial Site.

Mean daily water temperatures during the initial and peak spawning events were relatively similar across years (Figures 11-13). 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 Sevilleta 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 ranged between 20.0 and 21.3°C at the San Marcial Site during peak spawning [13-15 May] in 2007. 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. In 2009, mean daily water temperatures during spawning ranged between 16.1 and 18.9°C at the Sevilleta Site and between 17.0 and 21.3°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=6.16; p<0.0001) among mean values of catch rate (#/100m^3) for

Table 1. Summary of 2009 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:	Sevilleta	844	0.71	118,555	47	27 April 09	12 June 09
Rio Grande:	San Marcial	645	0.45	140,967	47	27 April 09	12 June 09

[1] Value based on number of Rio Grande silvery minnow eggs collected per 100 m^3 of water sampled for all sampling days.

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

LOCATION : RIVER MILE :	**SEVILLETA** **RM 121.0**	**SAN MARCIAL** **RM 58.8**
27-April-09	50	60
28-April-09	10	11
29-April-09	10	2
30-April-09	331	226
01-May-09	209	281
02-May-09	40	24
03-May-09	57	7
04-May-09	8	15
05-May-09	6	8
06-May-09	16	1
07-May-09	6	6
08-May-09	9	1
09-May-09	74	0
10-May-08	18	0
12-May-08	0	3
TOTALS	**844**	**645**
%	**56.7**	**43.3**

Table 3. Volume of water sampled (6 hours), volume of water available (6 hours), and number of Rio Grande silvery minnow eggs estimated to be transported downstream of sampling location (24 hours) by date and site. Table does not include dates that eggs ***were not*** collected at either site.

Data Type: / Location:	Volume Sampled (ft³) Sevilleta	Volume Sampled (ft³) San Marcial	Volume Available (ft³) Sevilleta	Volume Available (ft³) San Marcial	Eggs Transported Sevilleta	Eggs Transported San Marcial
27-April-09	38,547	165,613	47,088,000	20,088,000	244,315	29,111
28-April-09	43,478	128,944	57,672,000	19,072,800	53,058	6,508
29-April-09	38,842	137,109	57,456,000	19,375,200	59,168	1,130
30-April-09	47,858	136,932	55,080,000	20,736,000	1,523,783	136,895
01-May-09	50,118	123,326	55,944,000	22,680,000	933,178	206,707
02-May-09	58,586	138,923	59,616,000	23,760,000	162,812	16,419
03-May-09	139,219	129,286	78,624,000	25,380,000	128,763	5,497
04-May-09	95,058	146,874	78,192,000	27,000,000	26,322	11,030
05-May-09	119,302	122,050	75,384,000	30,672,000	15,165	8,042
06-May-09	112,153	95,163	83,592,000	33,480,000	47,702	1,407
07-May-09	105,827	114,902	83,160,000	35,208,000	18,860	7,354
08-May-09	105,232	109,008	80,784,000	39,312,000	27,636	1,443
09-May-09	97,982	116,384	81,000,000	42,120,000	244,697	0
10-May-09	103,701	73,620	99,144,000	43,200,000	68,836	0
12-May-09	101,397	107,411	98,064,000	48,168,000	0	5,381
Totals	**1,257,300**	**1,845,545**	**1,090,800,000**	**450,252,000**	**3,554,295**	**436,924**
%	**40.5**	**59.5**	**70.8**	**29.2**	**89.1**	**10.9**

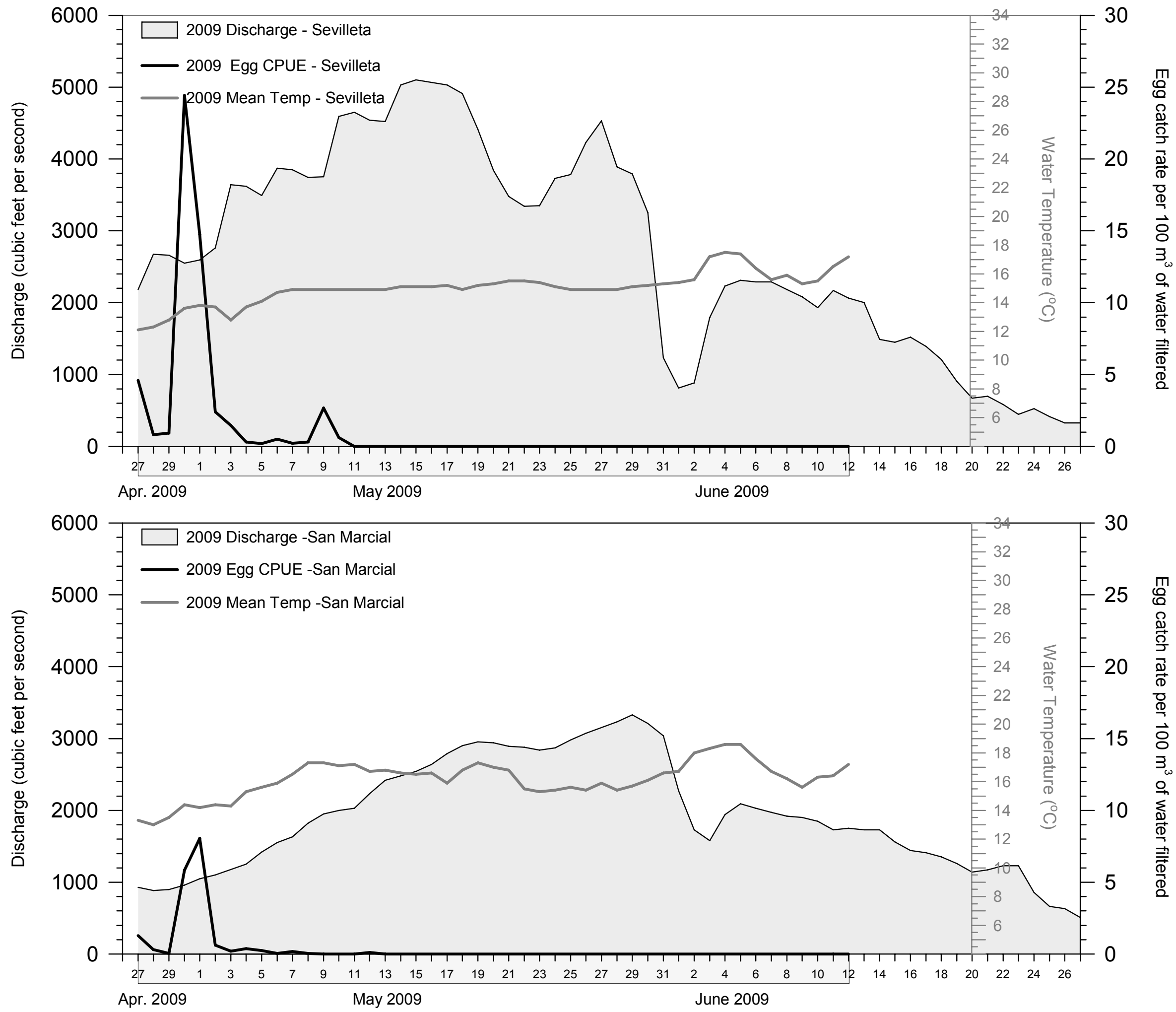

Figure 10. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2009 Rio Grande silvery minnow spawning periodicity study period (sampling period is highlighted in gray along the abscissa axis).

Table 4. Catch rates of Rio Grande silvery minnow eggs by year, site, and category (mean daily, maximum daily, and maximum sample).

Sampling Information Year: Site			Mean Daily Catch Rate[1] (# / 100 m³)	Maximum Daily Catch Rate (# / 100 m³)	Maximum Sample Catch Rate (# / 100 m³)
2002	Rio Grande:	San Marcial	1,622.04	14,222.00	96,558.00
2003	Rio Grande:	San Marcial	34.85	476.00	1,027.00
2004	Rio Grande:	San Marcial	0.07	0.09	0.22
2005			Not Sampled	Not Sampled	Not Sampled
2006	Rio Grande:	Albuquerque	3.47	19.15	22.64
2006	Rio Grande:	Sevilleta	4.50	44.88	53.82
2006	Rio Grande:	San Marcial	30.81	289.33	621.97
2007	Rio Grande:	Albuquerque	0.34	0.94	1.43
2007	Rio Grande:	Sevilleta	13.00	147.13	158.56
2007	Rio Grande:	San Marcial	11.55	106.12	201.55
2008	Rio Grande:	Albuquerque	0.32	1.33	2.65
2008	Rio Grande:	Sevilleta	5.70	76.87	136.31
2008	Rio Grande:	San Marcial	1.76	5.10	7.67
2009	Rio Grande:	Sevilleta	3.86	24.42	38.72
2009	Rio Grande:	San Marcial	1.33	8.05	8.57

[1] Catch rate determinations in this table are not corrected for discharge and only incorporate daily sample totals that contained Rio Grande silvery minnow eggs.

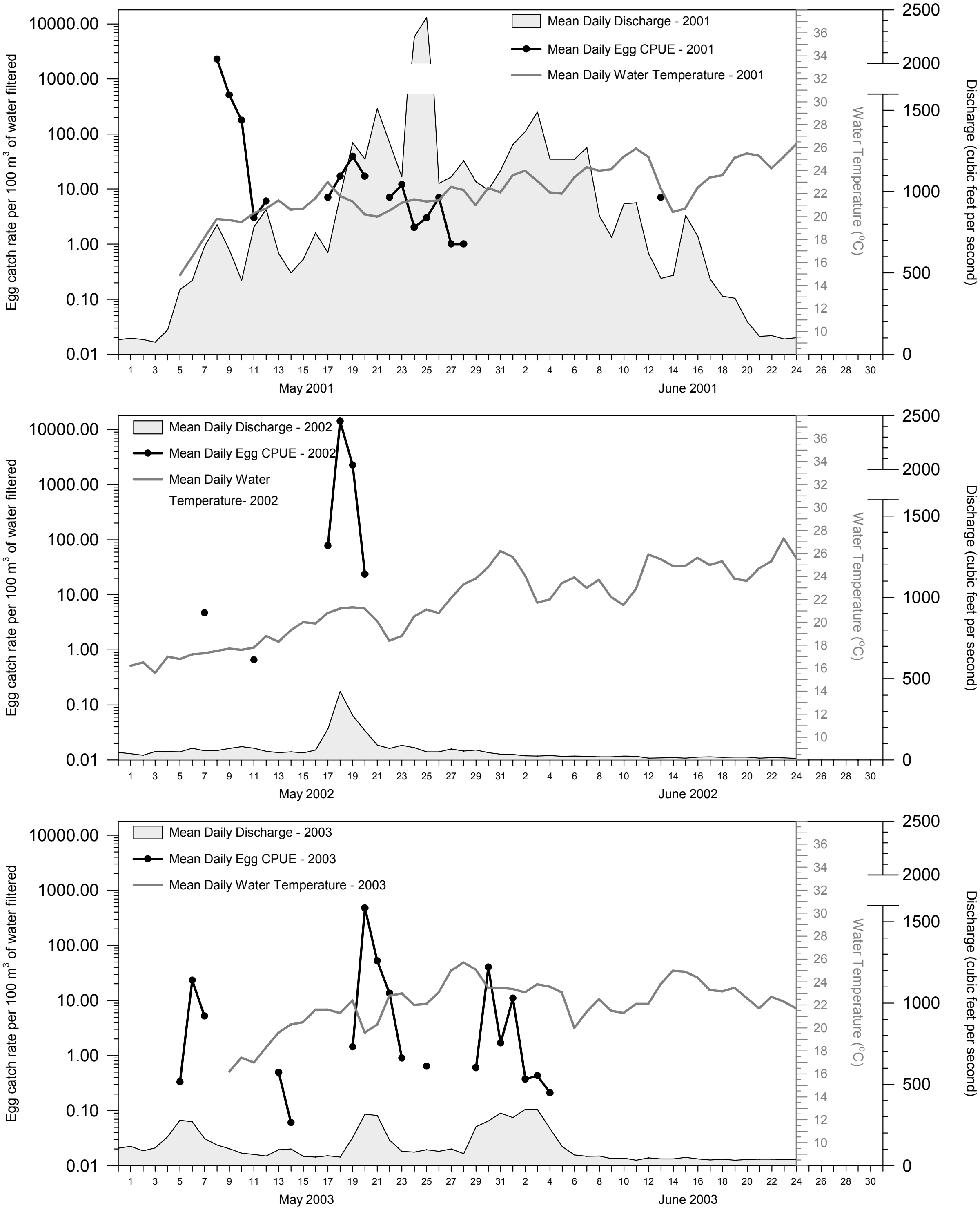

Figure 11. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2001-2003 Rio Grande silvery minnow spawning periodicity study periods at San Marcial. Note that the Y-axis for egg catch rate is a log-scale.

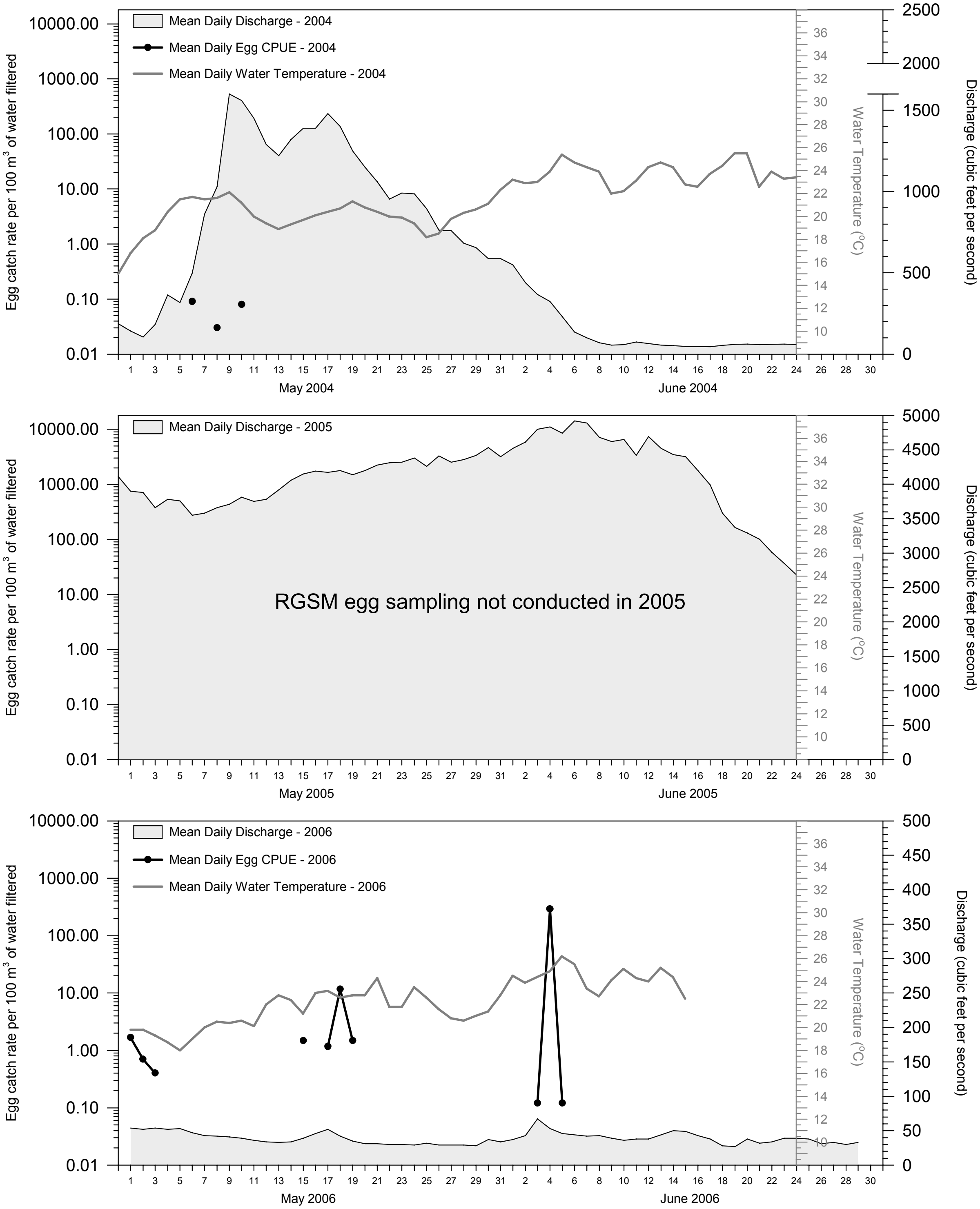

Figure 12. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2004 and 2006 Rio Grande silvery minnow spawning periodicity study periods at San Marcial. Note that the Y-axis for egg catch rate is a log-scale. Sampling was not conducted in 2005.

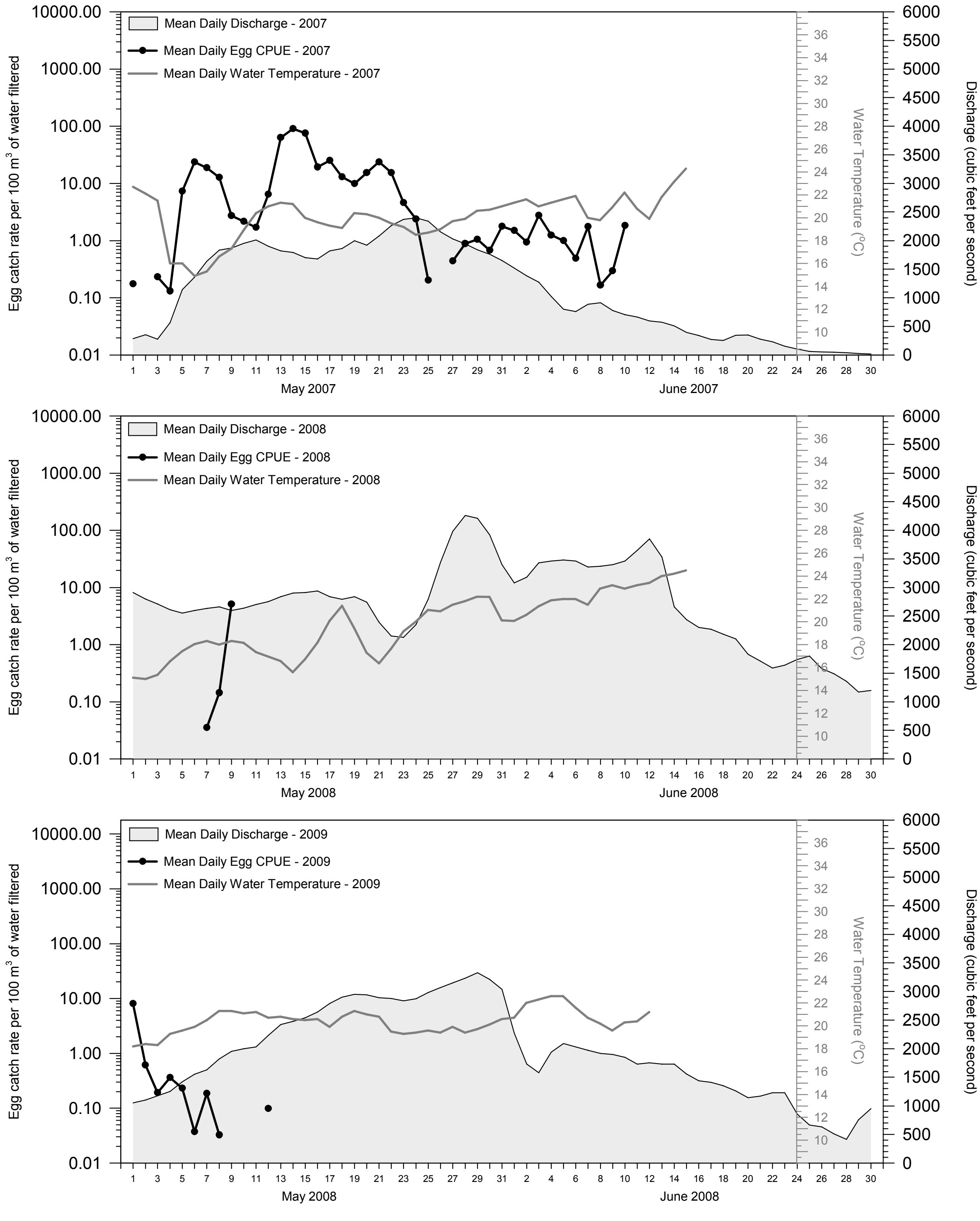

Figure 13. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2007-2009 Rio Grande silvery minnow spawning periodicity study periods at San Marcial. Note that the Y-axis for egg catch rate is a log-scale.

the six years of the study (2002-2004, 2006-2009). The following pair-wise comparisons were significant (p<0.05) over the period of record (2002 vs. 2004, 2006, 2009; 2003 vs. 2007; 2006 vs. 2007; 2007 vs. 2009). The natural log-transformed mean egg catch rate (standardized for discharge) was highest in 2002 (5.86 ±0.89), followed by 2007 (4.77±0.35), 2008 (3.22±1.26), 2003 (2.89±0.51), 2009 (2.56±0.60), 2006 (1.44±0.69), and 2004 (0.96±1.26). Additional statistical analyses for the Isleta Reach were made over the period of time that data were available (2006-2009). Analysis of reproductive output revealed a significant difference (F=8.68; p<0.0001) among mean values of catch rate (#/100m^3) for the four years of the study (2006-2009) in the Isleta Reach. The following pair-wise comparisons were significant (p<0.05) over the period of record (2006 vs. 2007, 2008, 2009) in the Isleta Reach. The natural log-transformed mean egg catch rate (standardized for discharge) was highest in 2009 (4.59 ±0.48), followed by 2008 (4.28 ±0.43), 2007 (4.19±0.39), and 2006 (1.97±-0.40) in the Isleta Reach.

A comparison of the relationship between the October CPUE (#/100m2) mean log (ln(CPUE+1)) values of Rio Grande silvery minnow densities and natural log-transformed mean egg catch rate (standardized for discharge) at San Marcial using linear regression yielded a non-significant relationship (r^2<0.01; p=0.98) over the study period (2002-2004, 2006-2009). A comparison of the relationship between natural log-transformed mean egg catch rate (standardized for discharge) at San Marcial and maximum discharge at USGS Gauge #08330000 (Rio Grande at Albuquerque, NM) using linear regression over the same time period yielded a non-significant relationship (r^2=0.01; p=0.84). Similarly, a comparison of the relationship between natural log-transformed mean egg catch rate (standardized for discharge) at San Marcial and maximum discharge at USGS Gauge #08358400 (Rio Grande Floodway at San Marcial, NM) using linear regression over the same time period also yielded a non-significant relationship (r^2<0.01; p=0.87).

Comparison of 2001-2004 and 2006-2009 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 (maximum) throughout the study period than during previous or subsequent years (Figures 14 and 15). The highest May maximum daily water temperatures during the 2001-2004 and 2006-2009 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 to 2009 maximum daily water temperatures were relatively lower (e.g., <24°C from 5 May until 2 June 2009). 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, and 2007 to 2009 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.

Comparison of MEC Screens

Comparisons of the old and new MEC screen efficiencies revealed significant differences between the screen types and also suggested differences in efficiencies based on quantity of instream debris and sampling interval. The mean volume of water sampled per interval at the lower velocity sampling location at the San Marcial site was 89.4±13.2 (N=14) compared to 129.4±13.5 (N=14) at the higher velocity location at the same site for the old screen. In contrast, the mean volume of water per interval sampled at the lower velocity sampling location at the San Marcial site was 137.8±14.9 (N=14) compared to 188.3±11.7 (N=14) at the higher velocity location at the same site for the new screen. For the lower velocity location, t=5.19 and p<0.0001 for the comparison between screens and the new screen was found to be 54.1% more efficient at sampling water than was the old screen over the same time period (one hour intervals). For the higher velocity location, t=5.04 and p<0.0001 for the comparison between screens and the new screen was found to be 45.5% more efficient at sampling water than was the old screen over the same time period (one hour intervals). The mean volume of water sampled per interval at the sampling location at the Sevilleta site was 18.6±1.39 (N=9) for the old screen compared to 22.3±1.1 (N=9) for the new screen. For the Sevilleta site, t=3.90 and p<0.0023 for the comparison between screens and the new screen was found to be 19.9% more efficient at sampling water than was the old screen over the same time period (10 minute intervals).

We also recorded volumes of water sampled using the new and old screen MEC's for our regular two hour sets at both sampling sites. This was not a statistical comparison because of

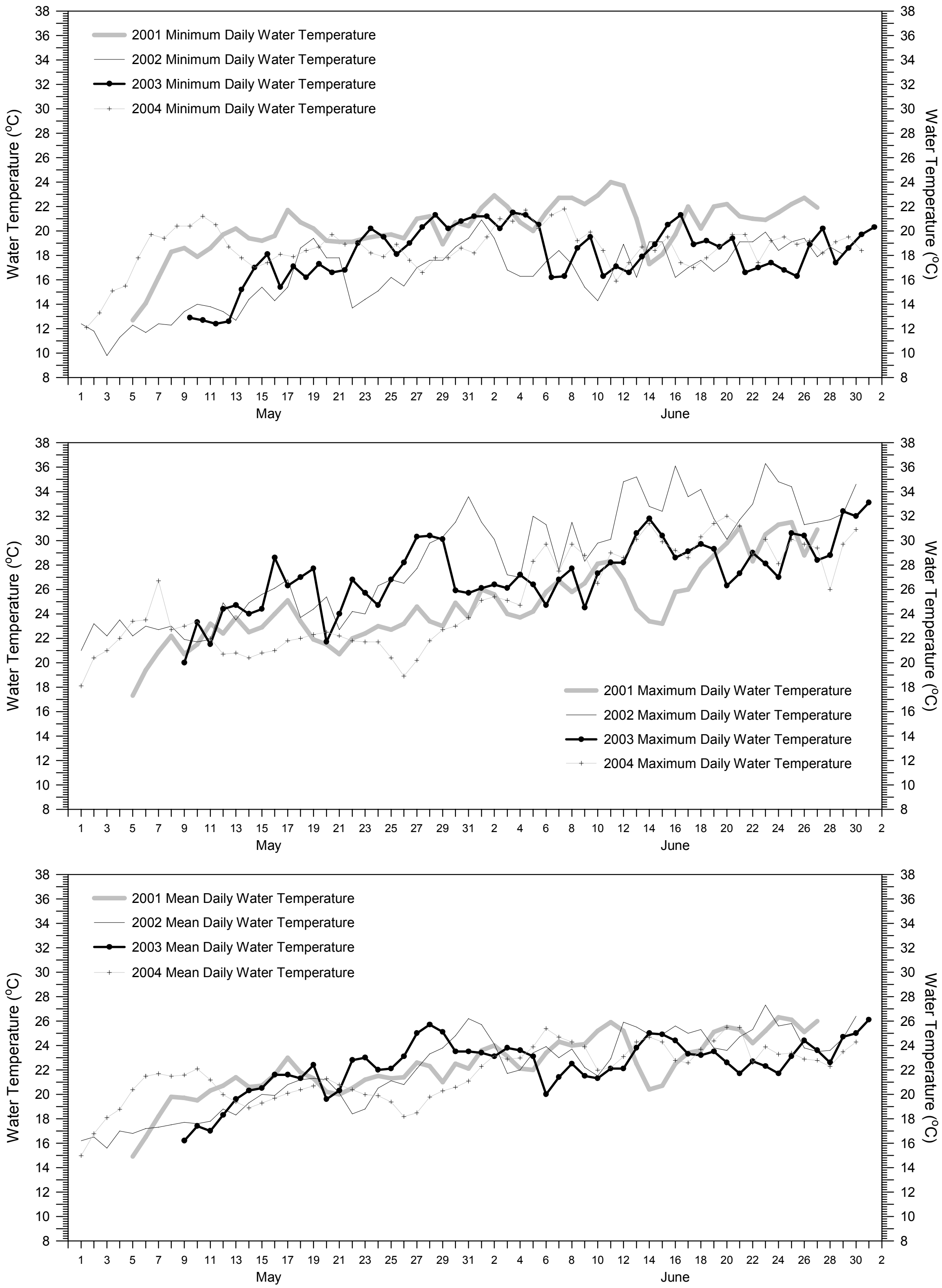

Figure 14. Annual minimum, maximum, and mean daily water temperatures at the San Marcial site during the 2001-2004 Rio Grande silvery minnow spawning periodicity study periods.

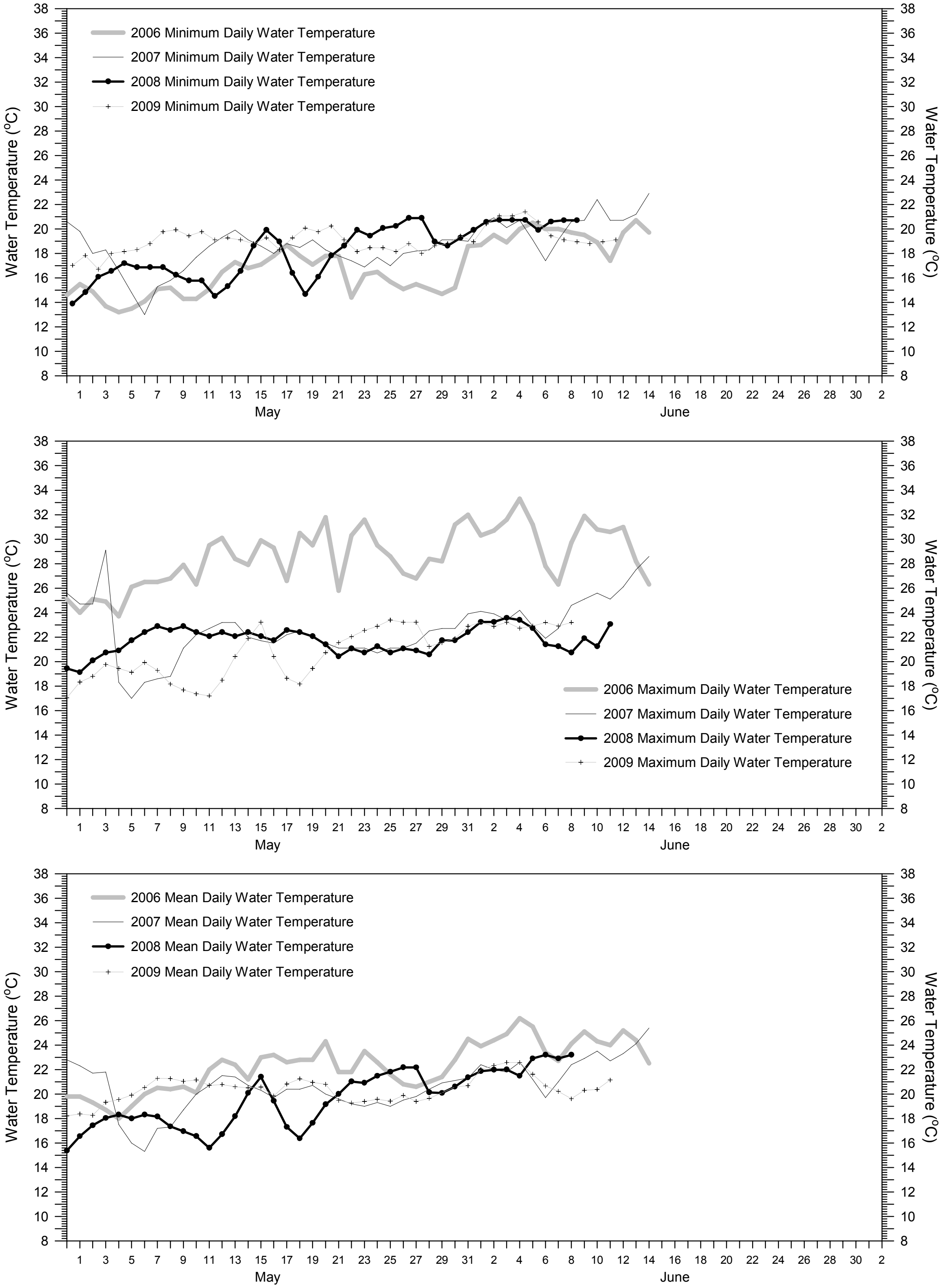

Figure 15. Annual minimum, maximum, and mean daily water temperatures at the San Marcial site during the 2006-2009 Rio Grande silvery minnow spawning periodicity study periods.

known differences in water velocities among locations where the old and new screen MEC's were set in the river channel (i.e., higher velocities at the MEC sets with the new screens). The new screen MEC's (N=2) were found to sample a substantially larger amount of water than did the old screen MEC (N=1) at both sampling sites (91,270 m^3 vs. 27,285 m^3 at the Sevilleta Site and 115,090 m^3 vs. 25,877 m^3 at the San Marcial Site).

DISCUSSION

As rivers have become increasingly fragmented, an important factor limiting the recolonization of upstream reaches and imperiling pelagic spawning cyprinids is the downstream transport of reproductive products below barriers or displacement into highly degraded downstream riverine habitats and reservoirs (Dudley and Platania, 2007b). 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; Dudley and Platania, 2007b). 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 conservation status of Rio Grande silvery minnow.

In addition to the problems created by river fragmentation, habitat simplification (caused by flow regulation, bank armoring etc.) 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 reduced egg retention in upper reaches of the Middle Rio Grande. Arroyos and backwaters 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; Pease et al., 2006). Additionally, it has been suggested that nursery habitat (i.e., areas typified by shallow depths and minimal water velocities) 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 increase retention of Rio Grande silvery minnow eggs upstream. However, successful recruitment of individuals from the larval to the juvenile stage requires an extended time period (ca. six weeks); nursery habitats should ideally be wetted throughout this critical phase of development. 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 growth and survival 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 (or providing alternative fish passage) 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.

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 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 embryos become pigmented very early in development. Conversely, the eggs of Rio Grande silvery minnow are clear, nonadhesive, smooth, large, and the embryos lack discernible pigment.

Spawning of Rio Grande silvery minnow and other members in its reproductive guild (Platania and Altenbach, 1998) appears 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 challenge for resource managers. While the simplest solution would appear to be collecting eggs from downstream localities and transporting them to rearing facilities, this method has only short term importance. 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 would require a substantial effort.

Efforts were made in 2009 to estimate the number of eggs transported downstream of each sampling site based on the total number of eggs collected, volume of water sampled, volume of water available to be sampled, and duration of sampling. This approach required several simplifying assumptions including 1) eggs were approximately evenly distributed within the volume of water passing the sampling site, 2) eggs collected during a six hour period of sampling in a given day approximately represented the rate at which eggs were transported downstream of the site during that day, and 3) the volume of water at the nearest upstream USGS station approximately represented the volume of water passing the sampling the site. Even with modest violations of these assumptions, the number of eggs estimated to be transported downstream of sampling sites would still likely be quite high (i.e., several million over the course of the 2009 study). These results indicate a substantial downstream transport of drifting eggs at the two sampling sites in the Middle Rio Grande despite the seemingly low numbers collected in individual MECs.

Population trends lend support to the observation that substantial numbers of eggs (and presumably larvae) are being transported downstream every year. In 2009, large numbers of larval Rio Grande silvery minnow were collected along the shoreline in MECs several weeks following the peak spawning events (unpubl. data). In support of these observations, the highest densities of juvenile Rio Grande silvery minnow are most frequently found in the southern reaches of the Middle Rio Grande (Dudley and Platania, 2009). Recent population monitoring surveys (September 2009) show the vast majority (73.4%) of the population is located in the San Acacia Reach.

Despite the seemingly large number of Rio Grande silvery minnow propagules transported downstream every year, some portion do remain upstream. It is likely that the proportion of individuals retained and successfully recruited upstream is related to the complexity of instream habitat conditions and the availability of nursery habitat. Years with elevated and extended spring runoff conditions appear to create the favorable habitat conditions required for the successful recruitment of early life stages of Rio Grande silvery minnow (Dudley and Platania, 2009).

Additional effort was expended in 2009 to determine the sampling efficiencies of two screen types (old and new) with the goal of ultimately increasing the volume of water sampled over the same time interval. The new screen was found to be more efficient (range=19.9% to 54.1%) than the old screen for all tests at the two sampling sites. While differences in sampling efficiencies between screens were similar at the San Marcial site at relatively lower and higher velocities, the sampling efficiency differences were not as pronounced at the Sevilleta site. It is possible that some combination of the more frequent sampling intervals and relatively lower amount of instream debris at the Sevilleta site accounted for these differences. Also, more frequent sampling intervals ensured that differences in water velocities during the day were minimized between matched pairs; coefficients of variation were notably higher at the San Marcial site (range=35.1 to 55.0) than at the Sevilleta site (range=14.3 to 21.6). Lower debris loads at the Sevilleta site likely contributed to the less pronounced differences between screens since the old screen didn't become clogged with debris as quickly as it did at the San Marcial site. At both sites, the new screen appeared to be more effective in sampling more water over a given time period compared to the old screen and this improvement appeared to be most pronounced when higher amounts of instream debris were present in the river. We also recorded the volume of water sampled using the new and old screens during our regular two hour sets at each site and found that the new screen consistently sampled more water than the old screen. However, the new screen MEC's were also consistently set in areas that had higher water velocity (i.e., farther from shore than the old screen MEC) so these results are not as indicative as those of the controlled tests.

The years with relatively higher daily egg catch rates (2001, 2002, 2003, and 2006) were generally years (with the exception of 2001) where the autumnal population of Rio Grande silvery minnow declined substantially as compared to the previous October. In contrast, the years with relatively lower daily egg catch rates (2004, 2007, 2008, and 2009) were generally years (with the exception of 2004) where the autumnal population of Rio Grande silvery minnow either increased substantially or remained stable as compared to the previous October. However, when egg catch rates for the different years were corrected for discharge and log-transformed for analysis, these apparent relationships were found to have no statistical support. Similarly, there were no significant relationships between these corrected egg catch rates and the maximum discharge at several USGS gauging stations. These preliminary findings suggest that the number of eggs produced in the river does not appear to be strongly related to either the maximum discharge (measure of spring runoff) or to the number of individuals that survive to October. It is likely that the physical conditions of the river following spawning (i.e., extended period with elevated flows vs. low flows accompanied by river drying) are much more important than the quantity of eggs in determining the success of annual recruitment. Similarly, it is likely that the number of eggs produced in a given year is related more to the population size in spring as opposed to the strength of the spring runoff. Additional years of data will hopefully further elucidate these subtle relationships and lend insight to the causal mechanisms resulting in successful recruitment of Rio Grande silvery minnow.

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 been 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.

Despite the apparently low number of propagules in 2004, there was an improved spring runoff (as compared with 2002 or 2003) and populations increased notably by October of 2004. Populations continued to rebound notably during 2005 and maintained relatively high levels (as compared to 2002-2003) from 2005-2008 (Dudley and Platania, 2009). The 2008 population monitoring effort during October yielded 868 Rio Grande silvery minnow that comprised 23% of the total fish catch. Those values were notably higher than those recorded from 2000-2004. The high snow pack runoff and elevated discharge that stimulates spawning by Rio Grande silvery minnow resulted in a modest spawning effort during the 2009 study period. Summer monsoonal rainstorms that began in late June and early July contributed considerable water to the Middle Rio Grande and helped maintain flow throughout the study area. However, the effect of these storms (and elevated discharges) on Rio Grande silvery minnow reproduction was not quantified because the study was terminated on 12 June 2009. Rio Grande silvery minnow appear to have had another good year for spawning and recruitment in 2009, which could translate into increased numbers of reproductively capable females available to spawn in the spring of 2010.

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) combined with summer drying could result in a rapid decline to pre-2005 population levels. The loss of individuals from downstream reaches during river drying events is particularly problematic as these are the areas that most frequently and consistently support the highest densities of Rio Grande silvery minnow (except in years immediately following downstream drying). The future conservation status of Rio Grande silvery minnow appears dependent on ensuring adequate flow and habitat conditions during the spawning and early recruitment phases of this species while also allowing upstream recolonization by individuals transported downstream.

ACKNOWLEDGMENTS

Numerous people from a variety of state and federal agencies collaborated to make this project possible. We thank Adam L. Barkalow (ASIR), W. Howard Brandenburg (ASIR), Michael A. Farrington (ASIR), Jennifer L. Hester (ASIR), Trevor J. Krabbenhoft (UNM), and Lee E. Renfro (ASIR) for assistance with 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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