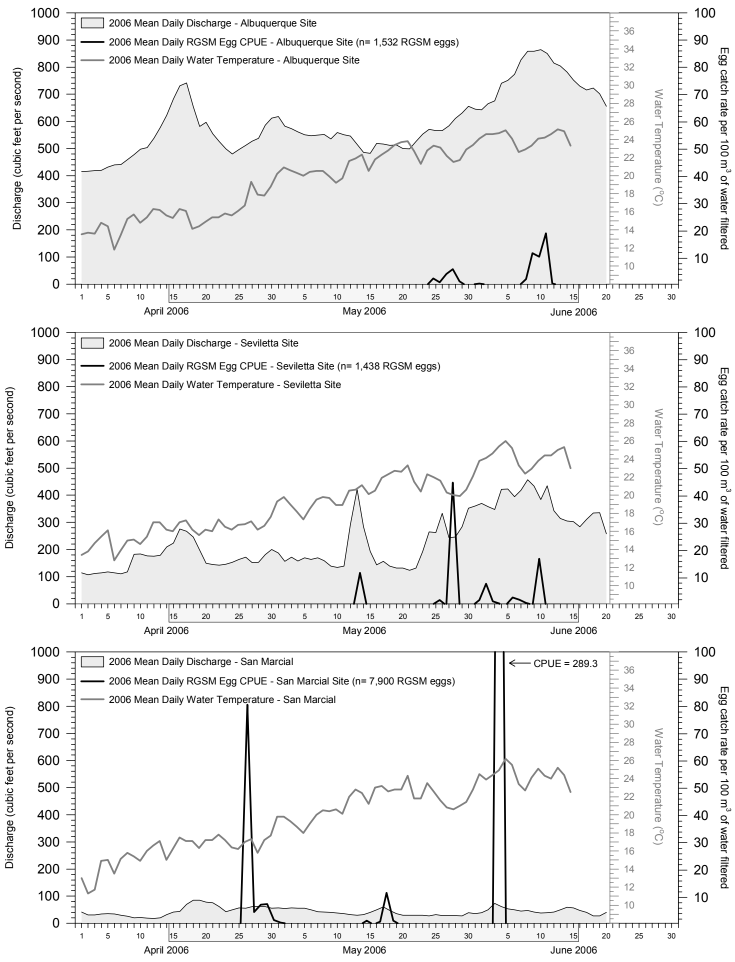
Spatial Spawning Periodicity of Rio Grande silvery minnow during 2006

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



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SPATIAL SPAWNING PERIODICITY OF RIO GRANDE SILVERY MINNOW DURING 2006

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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, 1995; Platania and Altenbach, 1996, 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, 2002a). 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; Smith and Hoagstrom, 1997) and in the Low Flow Conveyance Channel (Smith and Hoagstrom, 1997; 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.

Population monitoring studies of Rio Grande silvery minnow have shown a decline of about three orders of magnitude in the number and catch rate of this species between 1993 and 2003 (Dudley and Platania, 1999, 2000, 2001, 2002; Dudley et al., 2003). Over 90% of the catch of Rio Grande silvery minnow was in the San Acacia Reach of the Middle Rio Grande during 2000-2002 (Dudley and Platania, 2001, 2002) but in 2003, the Angostura Reach yielded the most silvery minnow, followed by the San Acacia Reach, and the Isleta Reach (Dudley et al., 2003). Low flow conditions and the diversion of nearly all water at the Isleta Diversion Dam during summer 2003 resulted in river drying in downstream reaches and substantial losses of riverine habitat especially 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) resulted in a 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. 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 marked modification of subsequent reproductive monitoring protocols beginning in 2005. Unfortunately, delays in funding resulted in postponing this effort from 2005 until 2006.

The study proposed herein is at its core a continuation of the 2002-2004 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, will be assessed using a linear regression model. As in previous years, selected samples of wild eggs collected during this study will also be 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. Long-term monitoring of the reproductive effort of Rio Grande silvery minnow remains extremely necessary for recovery efforts and to facilitate effective management decisions. The 2006 effort is designed to provide insight to success of recent stocking efforts.

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 2006 spawn of Rio Grande silvery minnow and compares data collected under the auspices of this study during 2001-2004, and 2006.

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)

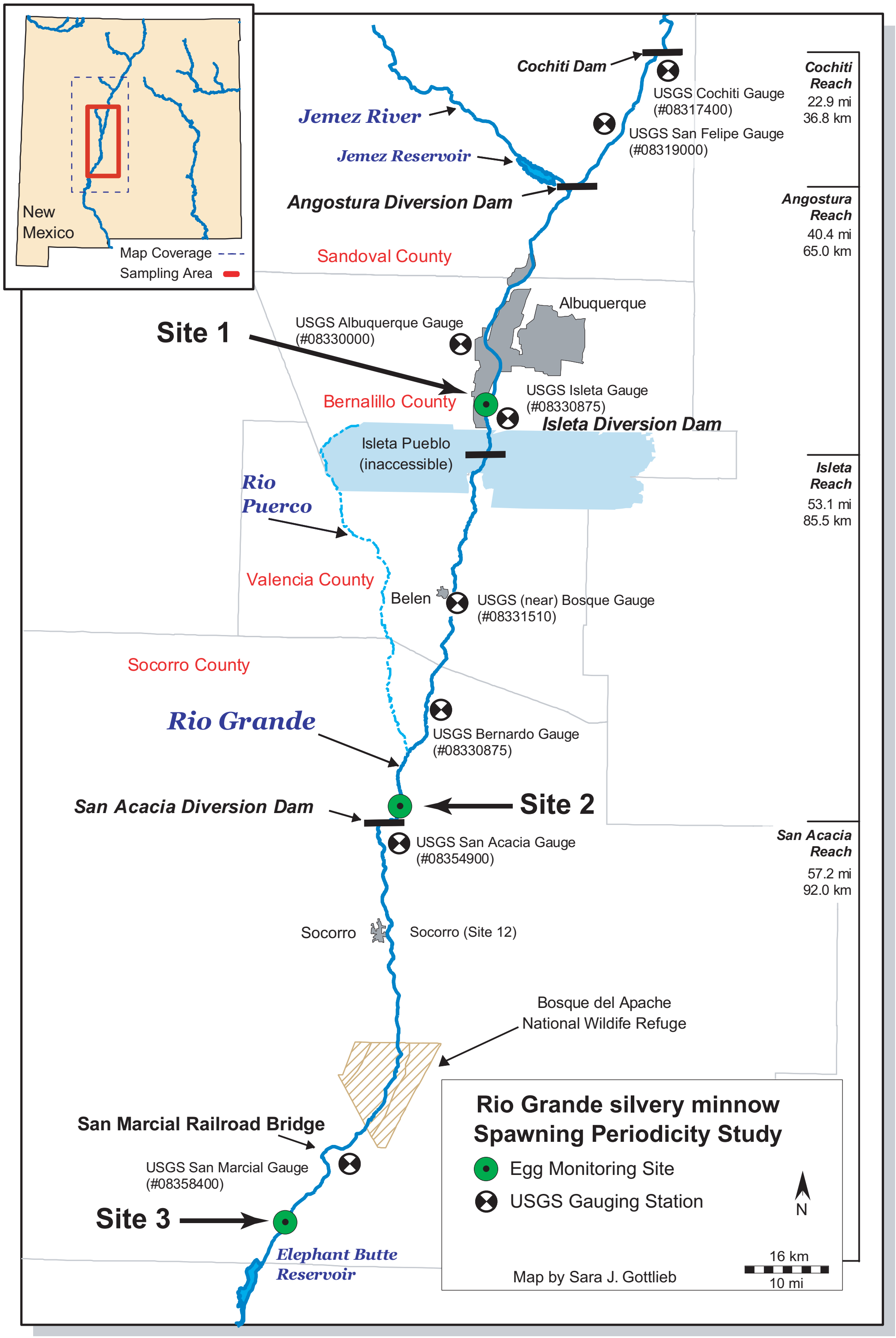

Figure 1. Map of the Middle Rio Grande, New Mexico, and the 2006 study site locations.

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, 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 study was 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 in 2005 was last systematically sampled during the 1999 spatial spawning periodicity study of this species (Platania and Dudley, 2002a), 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 during 2006 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).

Sampling for Rio Grande silvery minnow eggs was conducted daily from 5 May through 4 July 2004. Previous studies (Platania and Dudley 2002a, 2002b, 2002c, 2004) 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 constantly present at the sampling site from 4 May through 4 July 2004.

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 2004.

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 flow in 2002. Mean daily discharge (MDD) during the peak of the spawning period during 2002 (May 17-20) was 282.75 ft^3/s (7.92 m^3/s) compared with 265.67 ft^3/s (7.44 m^3/s) during 2003 (May 19-21). The CPUE values during 2002-2003 were standardized using the formula: CPUE_S = CPUE · (MDD/7.92 m^3/s). The resulting values of the constant (MDD/7.92 m^3/s) were 1.00 in 2002 and 0.94 in 2003.

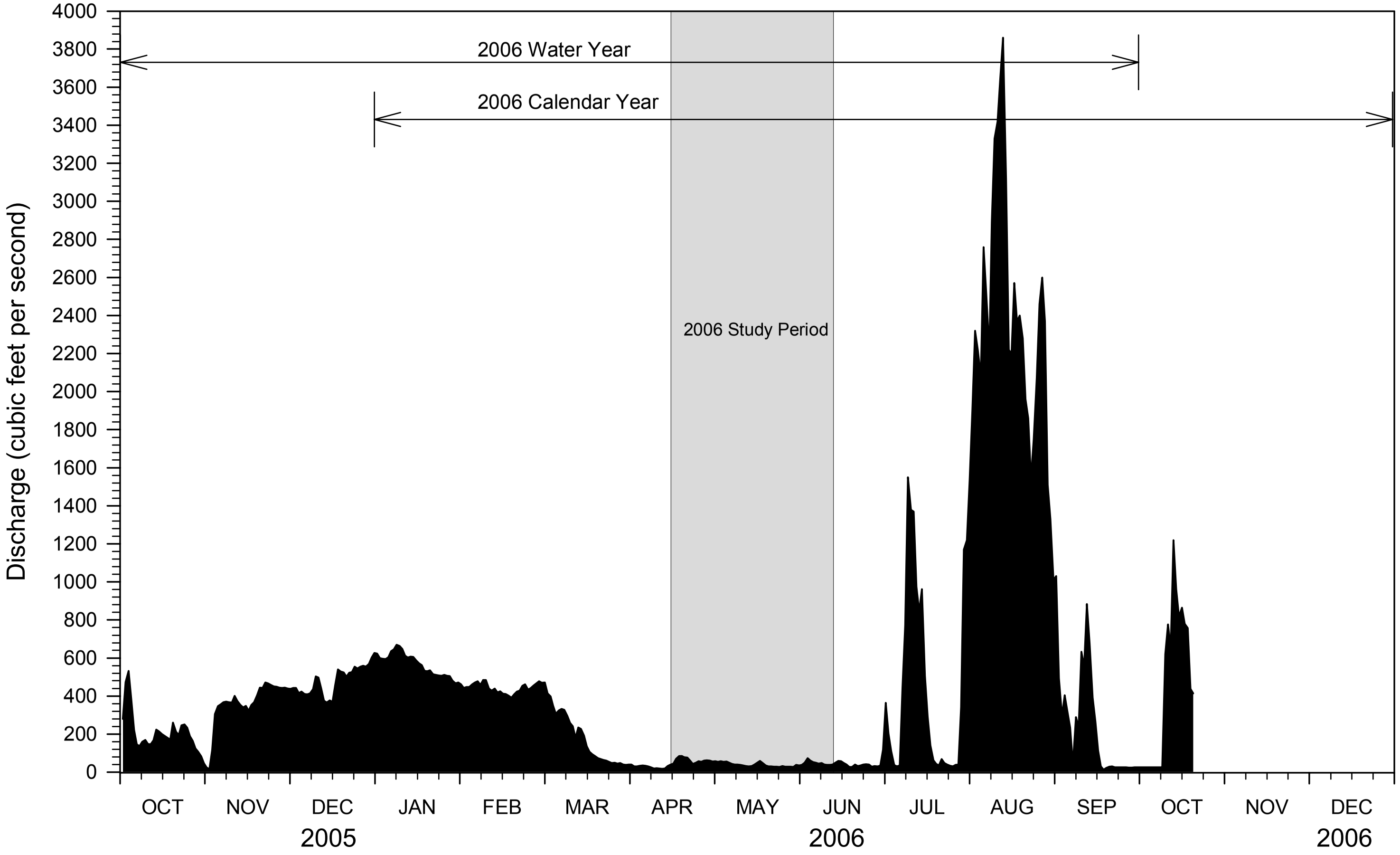

Figure 2. Hydrograph of the Rio Grande, New Mexico, at the San Marcial Gauging Station before, during, and after the 2006 study period.

The CPUE_S values were compared between years to determine general differences in spawning magnitude. Overall annual spawning magnitude was calculated by determining the area under a graph of CPUE (y-axis) by time (x-axis). Detailed data (i.e., hourly) during peak spawning events allow more accurate determination of changes in spawning magnitude over relatively short time periods. The Kolomogorov-Smirnov goodness of fit test was used to detect significant inter-annual differences in catch rate distributions during peak spawning events. Differences in inter-annual spawning magnitude based on mean catch rates, and standardized for flow magnitude, was assessed using a linear regression model (Sokal and Rohlf, 1995).

Shape of the time-series distribution of egg catch rates between years (2002-2003) was compared using a Kolomogorov-Smirnov goodness of fit test (=K-S analysis). This statistical procedure compares percent differences (D) in cumulative frequency of the independent variable between two distributions. Large differences between distributions (e.g., differences in location, dispersion, skewness) produce a significant difference based on the calculated value of D. This procedure was used because there was reason to suspect differences between sampling years. Linear regression analysis utilized catch rate as the dependent variable and year as the independent variable. The rigor of these comparisons was somewhat limited as Rio Grande silvery minnow reproductive effort monitoring data comprise four years; only two (2002-2003) of which can be used for comparative purposes (lack of catch data in 2004). The statistical strength of comparisons performed through linear regression analysis will increase annually given that the sample size (i.e., number of eggs taken) is sufficient. Likewise the absence of flow spikes and concurrent spawning peaks during the study period affect annual comparisons.

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 2006

There was a large difference in flow in the Middle Rio Grande in 2006 as compared to 2001-2005 (Figures 3, 4, 5, 6). 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 27June) 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.

Mean daily discharge in the Rio Grande at the Isleta Lakes Gauge (USGS Gauge 08330875) from 1 April through 20 June 2006 ranged between 415 and 854 cfs (mean value= 597 cfs). From 1-17 April 2006, discharge rose from 415 to 742 cfs, falling to 480 cfs on 24 April 2006. During the following 30 days, flow fluctuated between 500 and 600 cfs before rising to its peak (854 cfs; 10 June) near the end of the study period. Rainstorm events that began soon after the cessation of the study more than doubled discharge (27 June: 1,200 cfs, 28 June 1,710 cfs) at the Albuquerque Site.

Base flow in the Rio Grande at the near Bosque Farms Gauge (USGS Gauge 08331160) during April, May, and most of June 2006 was generally between 100 and 300 cfs. Mean daily discharge at the Isleta Reach study site (Seviletta) for the period 1 April-20 June 2006 was 230 cfs which is less than half that recorded at the Albuquerque Site. Maximum mean daily discharge during the aforementioned period was 457 cfs (8 June 2006). From 12-14 May 2006, there was a small spike in flow as mean daily discharge rose from 138 to 292 cfs (11-12 May) and peaking at 422 cfs (13 May) before declining to 193 cfs (15 May). A late June 2006 rainstorm event raised discharge from 294 cfs (26 June) to 2,040 cfs on 28 June.

Discharge in the Rio Grande at the San Marcial Railroad Bridge Crossing (USGS Gauge 08358400) during the 2006 water year (prior to 1 July) closely mirrored that of the 2002 water year (October 2001 through June 2002). Discharge in the Rio Grande at San Marcial generally remained <600 cfs from well before the end of previous irrigation season (1 November 2005) through June

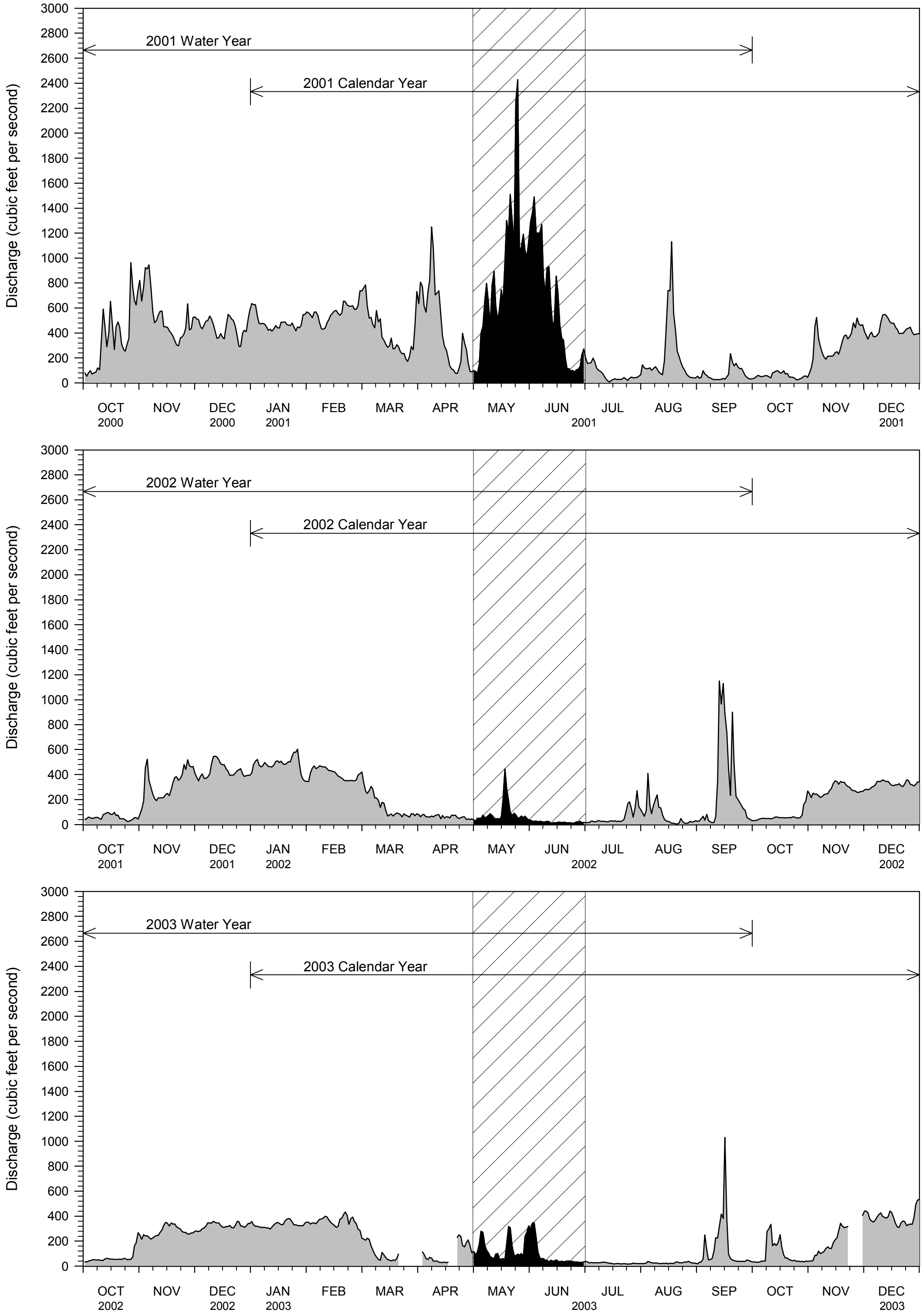

Figure 3. Annual hydrographs of the Rio Grande, New Mexico, at San Marcial before, during, and after the 2001-03 Rio Grande silvery minnow spawning periodicity study periods. Cross-hatching indicates annual study periods.

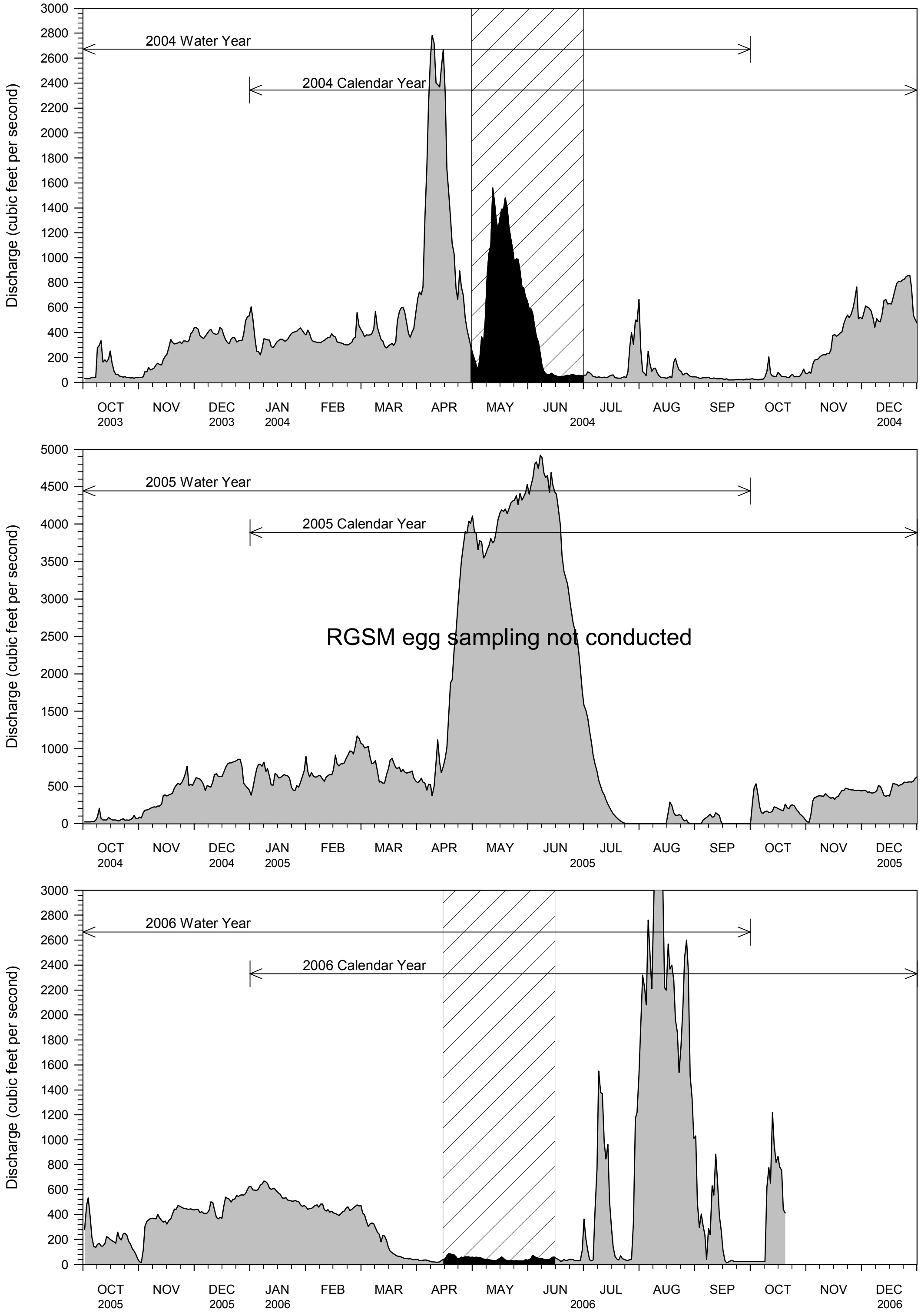

Figure 4. Annual hydrographs of the Rio Grande, New Mexico, at San Marcial before, during, and after the 2004 and 2006 Rio Grande silvery minnow reproductive monitoring study periods. Cross-hatching indicates annual study periods. (Sampling not conducted during 2005).

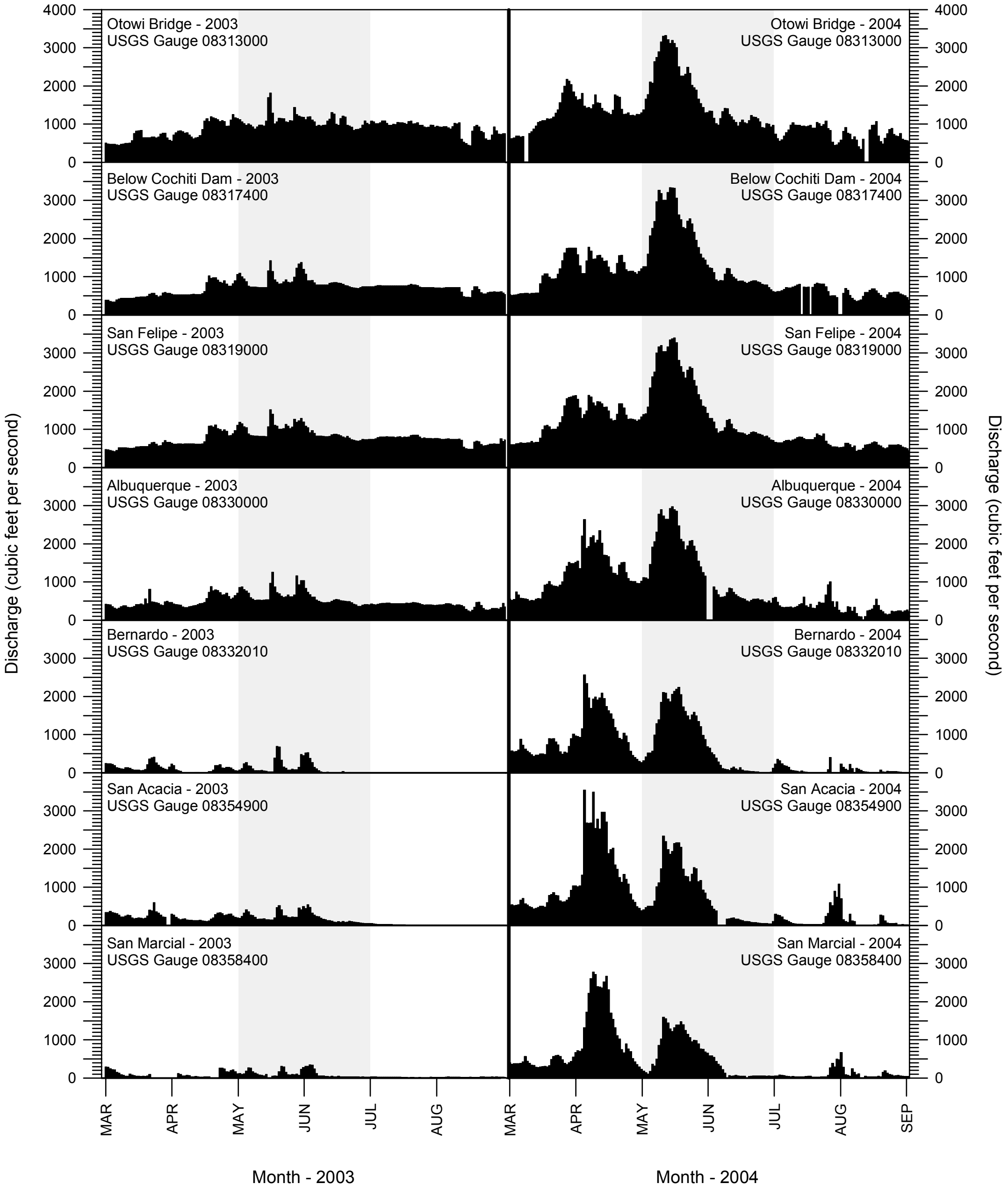

Figure 5. Rio Grande discharge from March through August 2003 and 2004 at seven U. S. Geological Survey Gauge Stations (see Figure 1). The Otowi Bridge gauge site is about 25.5 river miles upstream of Cochiti Dam, not covered with the area of Figure 1, and provided for reference. Discharge data are provisional and subject to change.

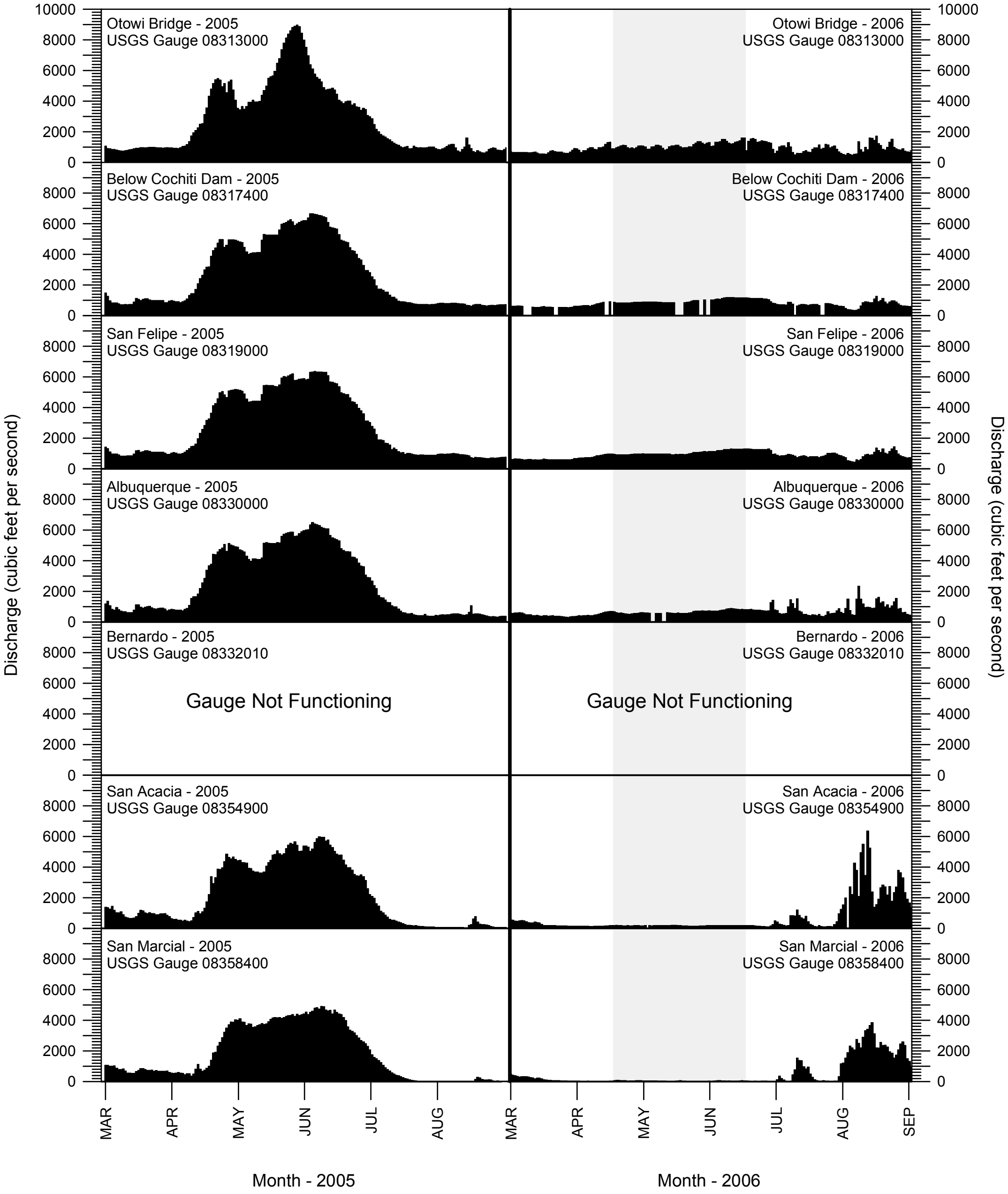

Figure 6. Rio Grande discharge from March through August 2005 and 2006 at seven U. S. Geological Survey Gauge Stations (see Figure 1). The Otowi Bridge gauge site is about 25.5 river miles upstream of Cochiti Dam, not covered with the area of Figure 1, and provided for reference. Discharge data are provisional and subject to change.

2006. From 1 April-20 June 2006 mean daily discharge in the Rio Grande at the San Marcial Gauge ranged from 18 to 85 cfs. Mean daily discharge for this period at the San Marcial Site was only 43 cfs or less than one-fifth that in the Isleta Reach and one-fourteenth that in the Albuquerque Reach. The late June rainstorm event that impacted the Albuquerque and Isleta reaches arrived as a much reduced flow (peak 364 cfs) at San Marcial on 1 July 2006 (Figure 7).

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 usually generated the lowest water temperatures with only one date (19 April 2006) registering a water temperature <10°C. Mean daily water temperature at the study site rose steadily at all sites from about 15.0°C on 15 April to about 20°C in early to mid-May (Figure 8). The Albuquerque Site was the first to consistently generate mean daily water temperatures of 20°C or more. The San Marcial Site reached a mean daily water temperature of 20°C on 7 May while the Seviletta Site did not reach this temperature until 12 May 2006. At the end of May, mean daily water temperatures were about 23°C at all three sites.

More important and informative than the mean daily water temperatures were maximum daily water temperatures. Maximum water temperatures were 28.6°C at the Albuquerque study site, 30.2°C at the Seviletta Site, and 33.3°C at the San Marcial Site. Maximum daily water temperature exceeded 30°C on only one occasion (5 June 2006) at the Seviletta Site and 15 times at the San Marcial Site. The first occasion that maximum water temperature exceeded 30°C at the San Marcial Site was13 May. Every day from 30 May through 6 June maximum water temperature at the San Marcial Site exceeded 30°C. During those dates, mean daily water temperature was about 24°C not only at the San Marcial Site but also at the other two sampling locations. It is likely that low flow at the San Marcial Site contributed greatly to the high maximum water temperatures. Water temperatures in excess of 30°C were recorded at the San Marcial study site on 11 dates in 2004 (13 June-2 July 2004) compared with 10 days during the study period in 2003, and 29 days in 2002 (Figure 9).

2006 Rio Grande silvery minnow spatial spawning periodicity studies

Sampling at each of the three 2006 Rio Grande silvery minnow spawning periodicity study sites was conducted from 15 April through 15 June 2006 (n= 63 days). A bosque wildfire in the vicinity of San Marcial bosque erupted on Thursday, 4 May 2006 and necessitated evacuation of the San Marical sampling station through Sunday, 7 May 2006. Daily sampling at the San Marcial site was reinitiated 8 May 2006 and continued through the tenure of this study. 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.

The cumulative volume of water sampled at these three Rio Grande sites was about 344,076 m3 (279 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 (126 acre-feet) was 45% of the study total (over twice that filtered at the San Marcial Site) while the total amount of water sampled at the Seviletta Site (92 acre-feet) was 33% of the study total. In 2004, 95,682 m3 of water was sampled (during 61 days) at the San Marcial Site or about 26% more than was sampled in 2006 (during 59 days). These differences in volume sampled reflect, in part, higher mean daily discharge at the San Marcial Site during the 2004 (528 cfs) study period as compared with 2006 (47 cfs).

A cumulative total of 10,915 Rio Grande silvery minnow eggs were collected at the three sites during 2006. The vast majority (n= 7,900; 72.4%) of the catch was taken at the San Marcial Site while the number and cumulative percent of Rio Grande silvery minnow eggs collected at the Albuquerque (n= 1,532; 14.0%) and Seviletta sites (n= 1,483; 13.6%) were almost identical. Rio Grande silvery minnow eggs were collected on 18 days at the Albuquerque Site, 21 days at the Seviletta Site, and 15 days at the San Marcial Site. On 12 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 five dates. There was only one date (3 June 2006) that Rio Grande silvery minnow eggs were collected at all three sites. Besides the 3 June 2006 sample, there were no other dates that eggs were collected at both the Albuquerque and San Marical sites.

Dates of egg collection ranged from 26 April through 5 June (41 days) at the San Marcial Site, 2 May through 13 June (43 days) at the Seviletta Site, and 26 April through 5 June (24 days) at the Albuquerque Site. Spawining (as indicated by the collection of eggs) by Rio Grande silvery minnow in the Albuquerque Reach occurred 28 days after spawning near San Marcial and 22 days

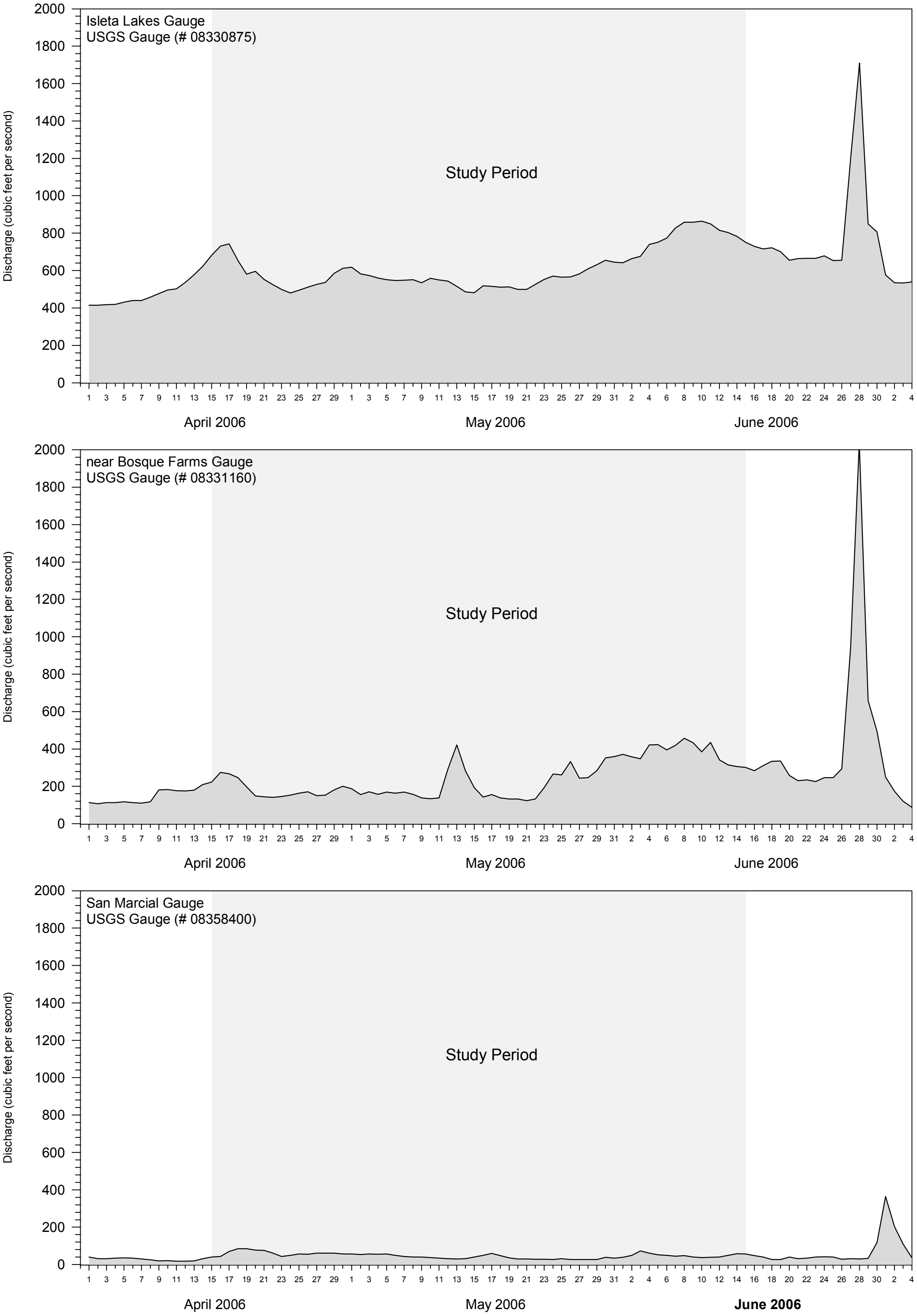

Figure 7. April-June 2006 hydrographs (dark gray) of the Rio Grande, New Mexico, from Isleta, Bosque Farms, and San Marcial gauges. The 2006 study period is highlighted in light gray.

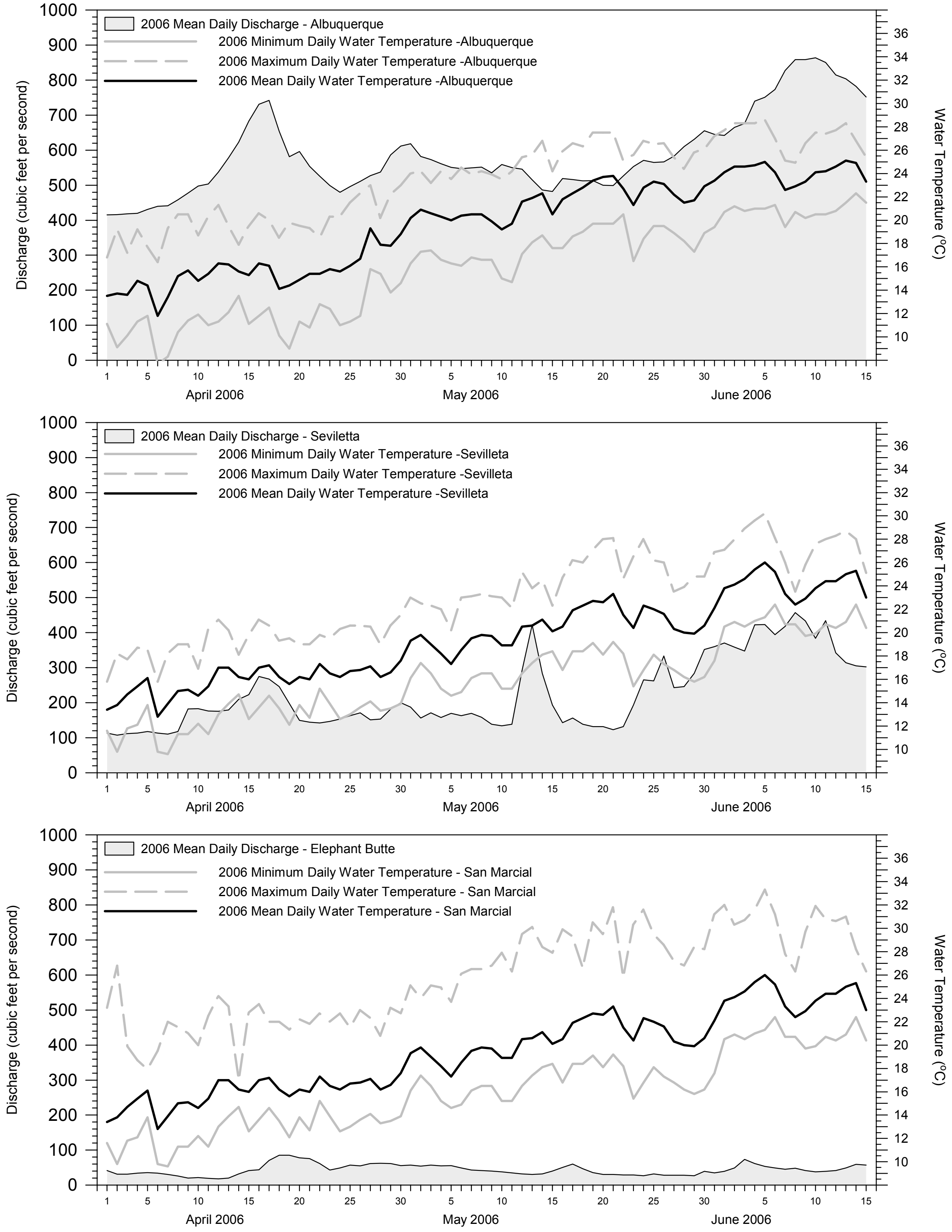

Figure 8. Daily water temperatures (mean, minimum, and maximum) at the 2006 Rio Grande silvery minnow spawning periodicity sampling sites (1 April - 15 June 2006). Approximate mean daily discharge in the Rio Grande at each sampling site is highlighted in light gray.

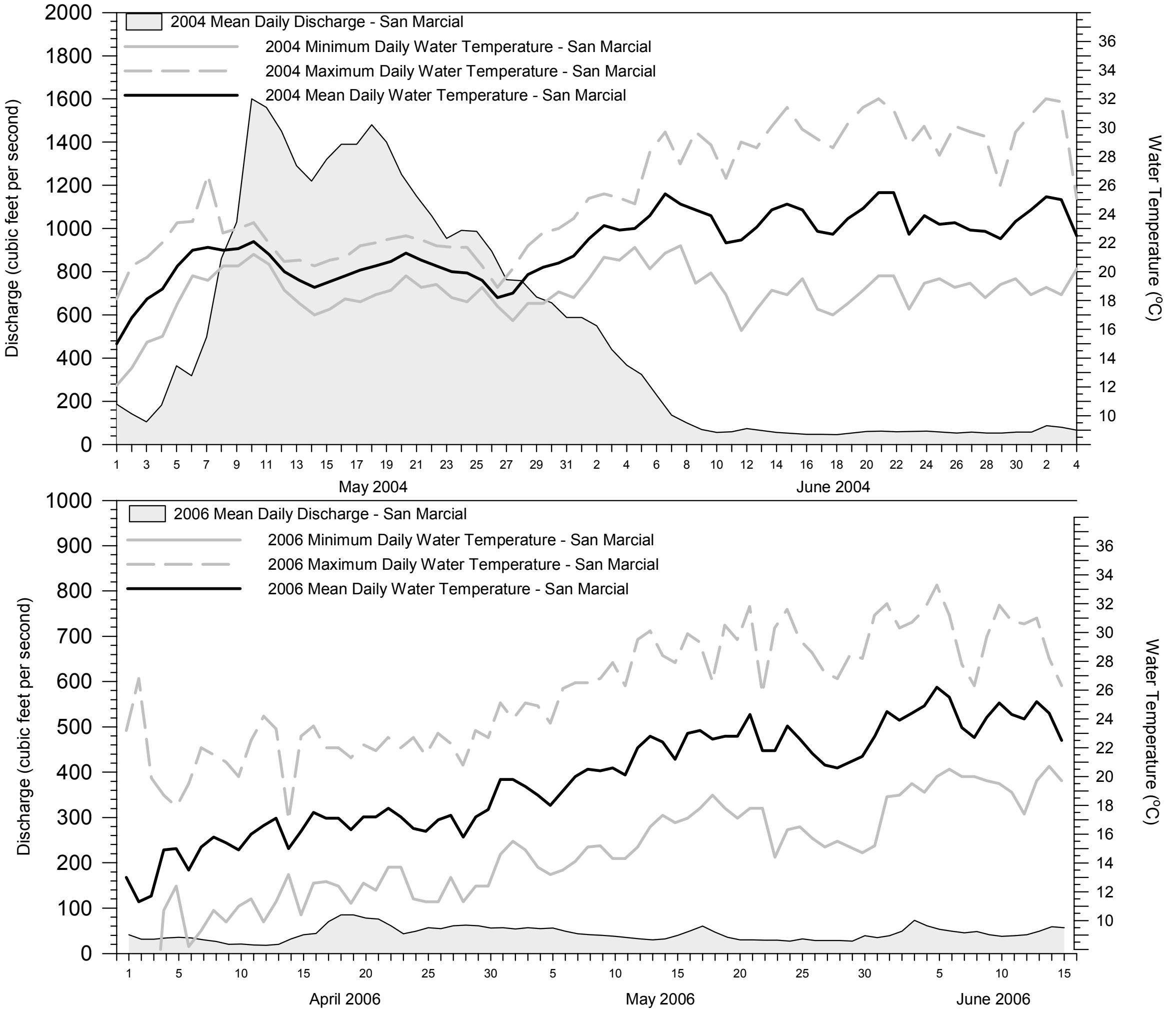

Figure 9. Comparison of the 2004 and 2006 daily water temperatures (mean, minimum, and maximum) at the San Marcial-Rio Grande silvery minnow spawning periodicity sampling site. Approximate mean daily discharge in the Rio Grande at San Marcial is highlighted in light gray.

Table 1. Summary of 2004 and 2006 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	1,532	0.99	154,886	63	15 April 06	15 June 06
Rio Grande:	Sevilletta	1,483	1.31	113,246	63	15 April 06	15 June 06
Rio Grande:	San Marcial	7,900	10.40	75,943	59 [2]	15 April 06	15 June 06
Rio Grande:	San Marcial	5	0.0592	95,682	61	05 May 04	04 July 04

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

[2] = A widlfire fire (4 May 2006) in the bosque near San Marcial resulted in closure of the bosque and precluded sampling 4-7 May 2006.

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 0.05 and 19.15 eggs per 100 m^3 of water sampled (n= 1 and n= 405, respectively). Cumulative egg catch rate at the Albuquerque Site during the 18 days that eggs were taken was 3.21 eggs per 100 m3 of water sampled versus 0.99 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 37.96 and 38.37 eggs per 100 m^3 of water sampled, respectively (Figure 10).

The presence of Rio Grande silvery minnow eggs in the Albuquerque Reach during 2006 was first documented on 23 May. Eggs were collected at the Albuquerque Site on 18 of the remaining 23 days of the study. From 25-29 May, 433 eggs or 28% of the total Albuquerque Site catch was taken while from 8-12 June, 1,041 eggs or 68% of the total Albuquerque Site catch was taken. Silvery minnow eggs at the Seviletta Site were present in almost all daily samples from 25 May through 13 June. Those 20 sampling dates yielded 1,380 eggs or 93% of the total Seviletta Site egg catch. Catch rate at that site during that period ranged from 0.05 to 44.88 eggs per 100 m^3 of water sampled

Rio Grande silvery minnow egg sampling at the San Marcial Site resulted in three discrete periods of during which eggs were taken. The first period at this site that yielded eggs was 26 April-3 May (eight days). Eggs were collected during each of those dates with a total of 1,892 eggs (range= 5 to 1,616) taken accounting for 23.9% of the total San Marcial Site catch. From 15-19 May 2006, 296 Rio Grande silvery minnow eggs were taken yielding 3.7% of the total site catch. The vast majority (n= 5,709 72.3%) of the total San Marcial Site catch was taken on 4 June 2006. Only two eggs were taken on the previous day and one on the next day at the San Marcial Site. Egg catch rate on 4 June 2006 was 289.33 eggs per 100 m^3 of water sampled which was the highest for both the site and study.

2004 Rio Grande silvery minnow egg collections

A total of 95,682 m^3 of water was sampled during the 61-day duration of the 2004 project but only five Rio Grande silvery minnow eggs were taken. Mean daily catch rates on dates that eggs were collected ranged from 0.08 to 0.22 eggs/100 m^3 of water sampled with the mean daily cumulative catch rate on these dates being 0.06 eggs/100 m^3 of water sampled.

Rio Grande silvery minnow eggs were collected in three separate samples during 2004. The first eggs were collected on 7 May 2004 at 1500 h while mean daily discharge in the river was about 498 cfs. That sample produced two Rio Grande silvery minnow eggs in the 917 m^3 of water filtered during the specific effort. On 9 May 2004, a single Rio Grande silvery minnow egg was taken during the morning sampling effort (0745-0945 h) in the 1,196 m^3 of water filtered. Mean daily discharge in the river on 9 May 2004 was 1,030 cfs or over twice that recorded on 7 May 2004 (date of first egg collection). The final Rio Grande silvery minnow eggs taken during this 2004 project were collected between 1530-1730 h on 11 May. Two eggs were present in the 912 m^3 of water filtered. Mean daily discharge on 11 May 2004 had risen to 1,560 cfs. No additional Rio Grande silvery minnow eggs were collected in the 79,143 m^3 of water filtered during the subsequent 54 days of the 2004 study. The volume of water sampled from 12 May 2004 through 4 July 2004 was almost twice (1.8 times) that sampled during the 2003 Rio Grande silvery minnow egg sampling effort.

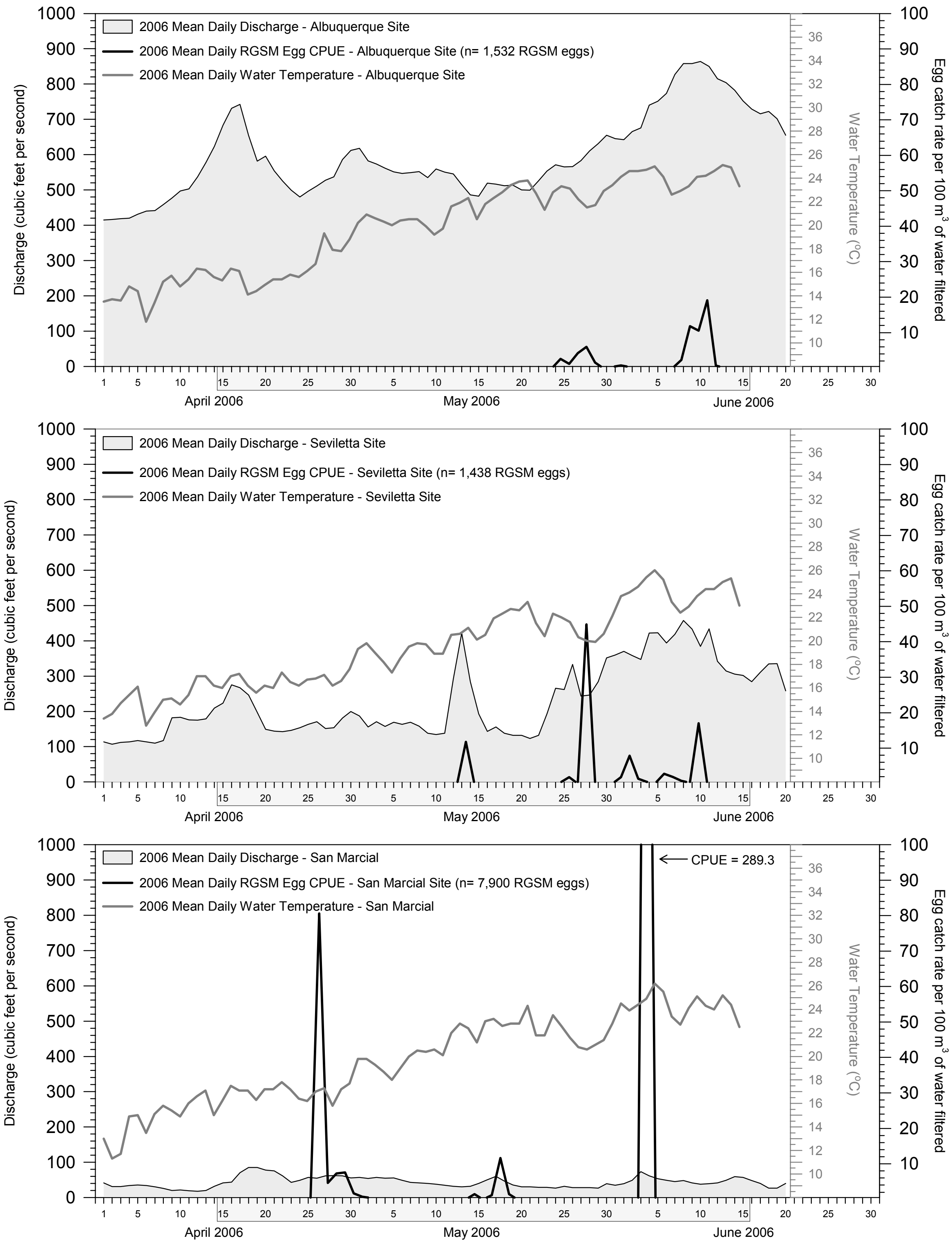

Figure 10. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2006 Rio Grande silvery minnow spawning periodicity study period (sampling period is highlighted in gray along the abscissa axis).

COMPARISON OF 2001-2004, 2006 RESULTS

The marked decline in catch of Rio Grande silvery minnow eggs observed in the 2004 spawning periodicity study was expected given the continued reduction in population levels of this species. 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.

Perhaps more important than the small number of silvery minnow collected from January through April 2004 was their longitudinal distribution. About 90% (n=93) of silvery minnow collected during the 2004 population monitoring study were taken in the Angostura Reach. The Isleta Reach produced 7% (n=7) of the silvery minnow catch while the San Acacia Reach, formerly the region of greatest abundance of this species, yielded only three Rio Grande silvery minnow. The low abundance level of this species in the two downstream-most reaches of the Middle Rio Grande (Isleta and San Acacia), which total about 110 river miles, is the primary reason for the lack of eggs during the 2004 Rio Grande silvery minnow spawning periodicity sampling effort.

The 2004 egg sampling effort, when combined with similar systematic studies (i.e., Low Flow Conveyance Channel Study) versus purely observational reports, provide potential insight to specific aspects of egg drift dynamics in the Rio Grande. These data indicate that the timing of the 2004 spawning by Rio Grande silvery minnow was the same at both the upper (Low Flow Conveyance Channel Study) and lower boundaries (2004 Spawning Periodicity) of the San Acacia Reach. Rio Grande silvery minnow eggs were collected on 7, 9, and 12 May during the former study and 7, 9, and 11 May in the latter investigation. That silvery minnow eggs not were subsequently collected during the remainder of either study further supports the belief that the 2004 spawn occurred during the same brief period.

The collection of numerous young-of-year Rio Grande silvery minnow in the Angostura and Isleta reaches in May (n= 501;n= 449 Angostura; n= 52 Isleta) and June (n= 310; n= 233 Angostura; n= 77 Isleta) provide documentation of May spawning by silvery minnow in the Angostura Reach. The dearth of eggs collected during the 2004 spawning periodicity study and number of larval silvery minnow in the Angostura and Isleta reaches in May and June 2004 strongly suggest that the majority of products of the spawn in the Angostura Reach hatched prior to reaching the downstream sampling site. If this assumption is true, it would follow that eggs collected at the 2004 sampling site were produced in the San Acacia Reach. The absence of reach specific 2004 Rio Grande silvery minnow egg sampling stations precludes additional meaningful extrapolation of these data.

While flow in the river during the five-year study period (2001-2004, 2006) was relatively low, the drought conditions during 2002-2003 were more extreme than that of 2001. The greatest between years differences were generally from March through June which is the period normally associated with spring runoff in the Middle Rio Grande. The greatest similarities in hydrologic conditions in the Middle Rio Grande, especially in the vicinity of the study area, were between 2002 and 2003. Discharge during the previous autumn and winter of each of the three years was consistently low but declined gradually from about 600 cfs in 200-01 to about 400 cfs in 2002-03.

Prior to 2004, the last spring snowmelt runoff, albeit relatively small and of short duration, occurred in April-June 2001. The principal spring 2002-2003 flow events in the study area were the result of releases of reservoir storage with only one flow spike during April-June 2002 and four present during that same period in 2003. The magnitude of the flow spikes were relatively similar between the two years with the peak of the 2002 event (420 cfs) being about 100 cfs larger than of 2003. Conversely, flow in the study area during 2001 was generally >600 cfs throughout May and June with peak discharges >2,000 cfs. There were several 200-400 cfs flow events during July and August 2002 but none in 2003. The largest flow events during both 2002 and 2003 occurred in September, resulted in mean daily discharges >1,000 cfs, and were the result of localized rainstorms. In 2001, the largest post-runoff event was mid-August and it too was >1,000 cfs and the result of rainstorm. During all four years, baseflows in the study area of the Rio Grande returned during late October or early November.

There are several similarities apparent regarding Rio Grande silvery minnow reproduction during 2001-2004, and 2006 (Figure 11 and 12). Spawning occurred during early May each sampling year. 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. During 2001, flow was relatively high (i.e., > 500 cfs) from early May through late June and spawning occurred as late as 13 June. Likewise, in 2003, water levels remained elevated (ca. 300 cfs) into early June and spawning was recorded on 4 June 2003. The single major flow spike during 2002 was of short duration (4-5 days), had dissipated by 22 May, and resulted in silvery minnow eggs only through 20 May. In 2004, eggs were collected from 7-11 May at the study site for this project and 7-12 May at the Low Flow Conveyance Channel study sites.

The apparent length of the spawning season is likely misleading as the annual level of reproduction by Rio Grande silvery minnow has been marked by short duration spawning events (2-3 days) that generally result in collection of the vast majority of the total reproductive output. In 2001 and 2002, over 98% of the total annual sample of propagules was obtained during these 2-3 day events while in 2003, this value was 91%. The cumulative catch of eggs during periods other than the peak spawning event often do not yield as many eggs are present in a single peak spawning sample. These data continue to document that, despite the ability of members of the population to reproduce over an extended spawning season, the overwhelming majority of spawning by this species occurs during a very short period in response to increasing flow.

Prior to 2004, the 2003 effort had yielded the lowest catch and cumulative catch rate. In addition, catch rates during the principal 2003 spawning spike were also markedly lower than the first two years of this investigation. The magnitude of decline in the 2003 egg catch rate values become even more considerable in light of the fact that the 2001 samples were obtained during flow conditions that were 3-4 times greater in magnitude than those present in 2003. The most valid comparison of Rio Grande silvery minnow egg catch rates was between 2002 and 2003 as maximum mean daily discharge in the study area during both sampling efforts were relatively similar (300-400 cfs) which also allowed for extremely efficiency sampling. Conversely, the virtual absence of Rio Grande silvery minnow eggs from the 2004 samples translated into catch rates that were 2.3 to 3.5 orders of magnitude smaller than recorded during 2003.

Table 2. Rio Grande silvery minnow spawning periodicity study summary information on annual egg catch rates during 2001-2006.

	MEAN ANNUAL CATCH RATE[1]	MAXIMUM DAILY CATCH RATE	MAXIMUM SAMPLE CATCH RATE	FLOW SPIKE MEAN CATCH RATE[2]
2001	251	510	2,878	536
2002	2,031	14,222	96,558	3,367
2003	59	476	1,027	221
2004	0.17	0.09	0.22	NA
2005	NS	NS	NS	NS
2006 - Albuq.	**3.5**	**19.2**	**22.6**	**5.7**
2006 - Sevilleta	**94.7**	**44.9**	**53.8**	**44.9**
2006 - San Marcial	**404.3**	**289.3**	**622.0**	**289.3**

[1] Catch rate determinations only incorporate samples that contained Rio Grande silvery minnow eggs.

[2] Catch rate is determined from the flow spike event that produced the majority of the total annual catch.

The 2002-2003 cumulative frequency distributions of egg catch rates were examined for differences using egg catch rates (CPUE) calculated at three-hour intervals during the maximum spawning period (ca. three days). This could not be done for 2004 because of the paucity of eggs taken. The 2002-2003 CPUE values during the maximum spawning period exceeded 100 eggs/100 m^3 for about 58 hours in 2002 and 26 hours in 2003. Results of Kolomogorov-Smirnov goodness of fit analysis revealed a significant difference ($p<0.001$) in catch rate of Rio Grande silvery minnow eggs between the two sampling years (2002 and 2003) with the maximum value of D being 0.6842. The area under egg catch rate time-series curves (2002 and 2003) was determined using the trapezoidal rule for equally spaced X (time) values. The calculated area was 158,374.2 in 2002 but had dropped to 3,756.4 by 2003.

Assumptions of normality in annual Rio Grande silvery minnow egg catch rates were evaluated using the Shapiro-Wilk W test. This statistical procedure has been shown to be excellent when testing for departures from a normal distribution. Critical values of W are calculated and significant differences are assessed using a goodness-of-fit procedure. The 2002 and 2003 egg catch rate time-

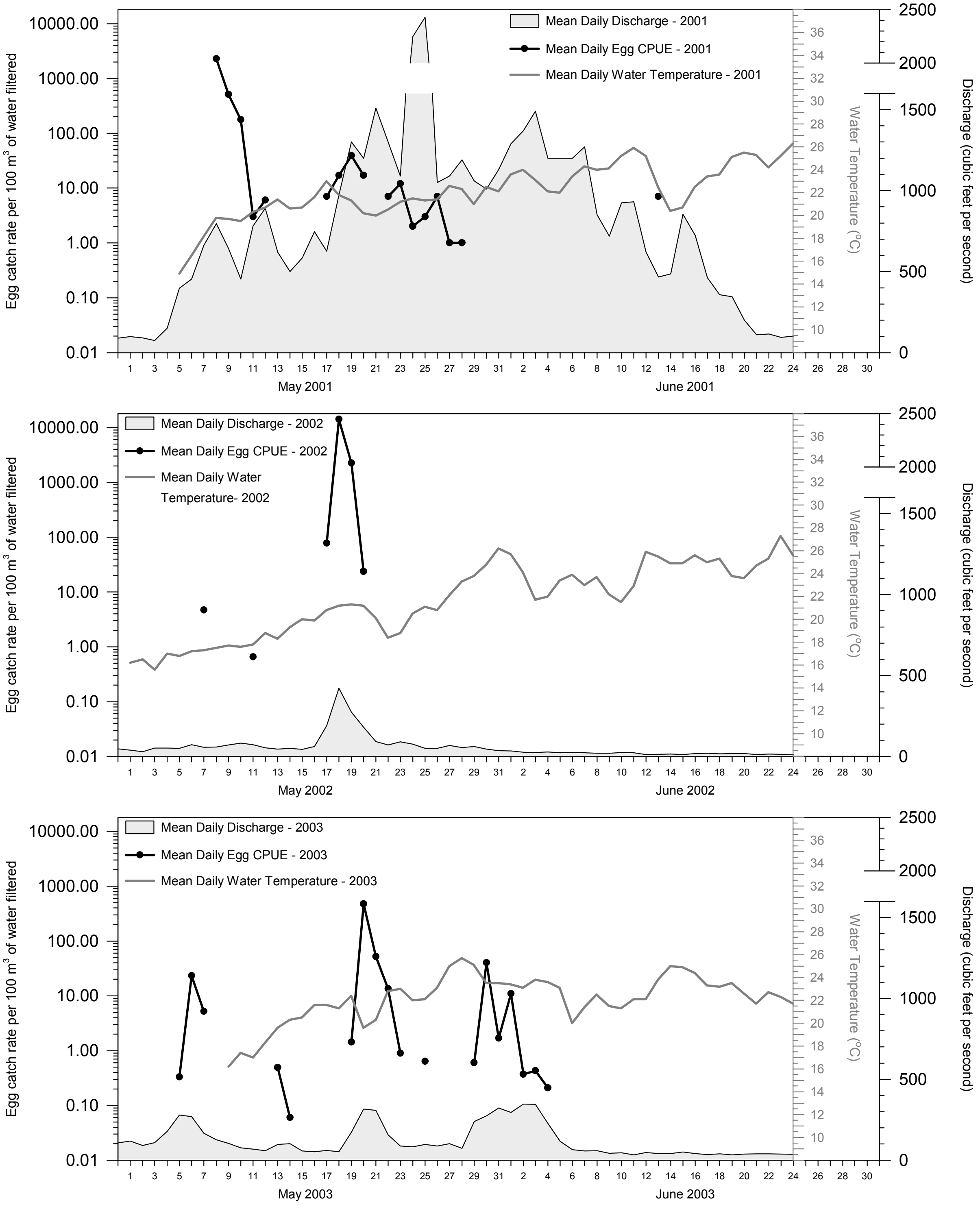

Figure 11. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2001-03 Rio Grande silvery minnow spawning periodicity study periods at San Marcial. Note that the Y-axis for egg catch rate is a log-scale.

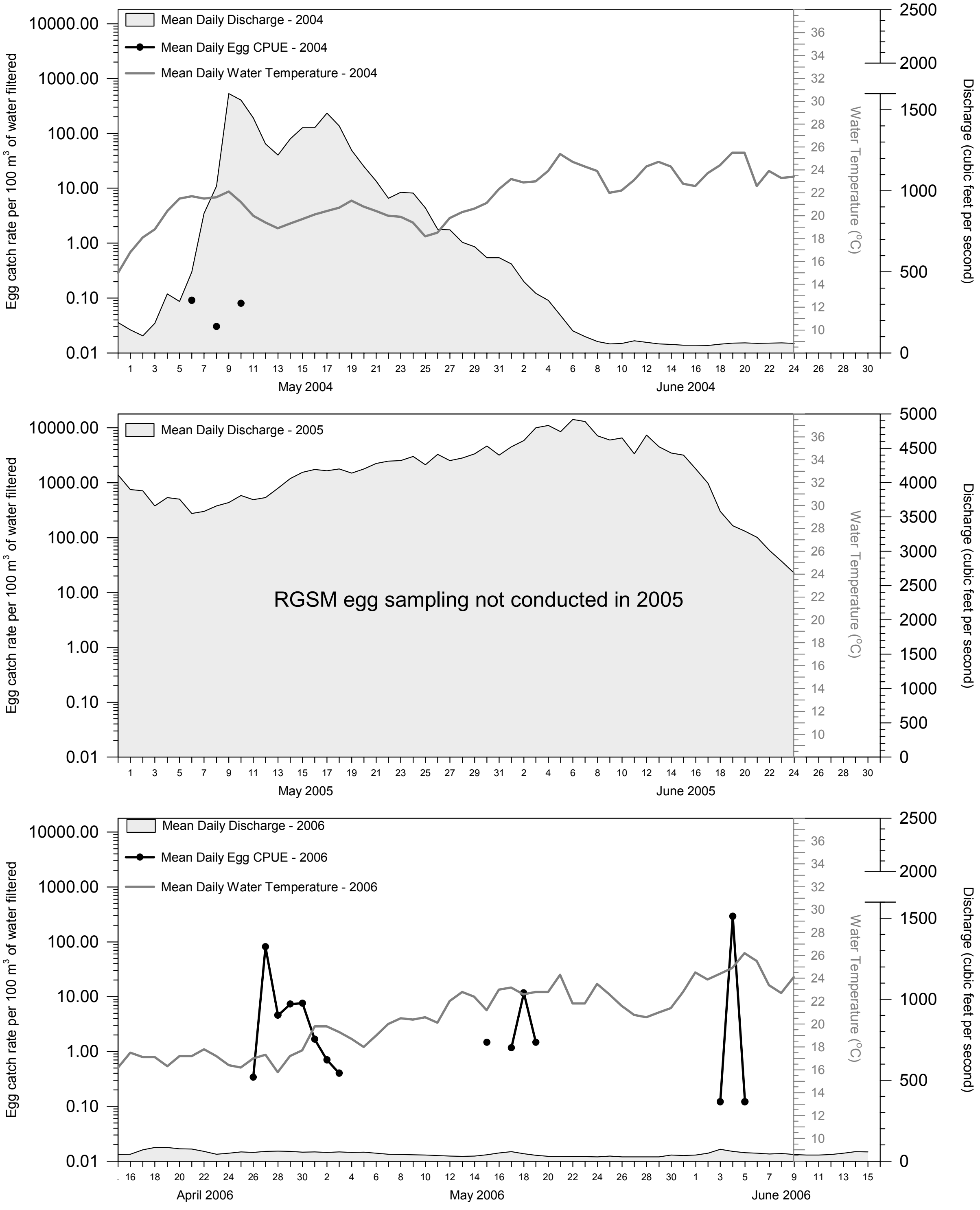

Figure 11. Mean daily discharge, mean daily egg catch rate, and mean daily water temperature during the 2003-06 Rio Grande silvery minnow spawning periodicity study periods at San Marcial. Note that the Y-axis for egg catch rate is a log-scale.

Table 3. Summary of the monthly 2005-2006 Rio Grande silvery minnow population monitoring program fish collections.

SPECIES	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
		2005					2006						
HERRINGS													
gizzard shad	—	—	—	—	—	—	1	3	56	—	—		60
CARPS AND MINNOWS													
red shiner	389	465	106	41	80	53	405	766	5,661	2,327	1,629	NA	11,922
common carp	47	62	12	13	17	5	10	217	975	36	13	NA	1,407
Rio Grande chub	—	—	—	—	—	—	—	—	—	—	—	NA	0
Rio Grande silvery minnow	3,899	3.570	2,819	3,375	1,620	1,148	1,404	654	920	463	160	NA	20,032
fathead minnow	107	94	29	13	13	11	13	1,282	2,935	874	69	NA	5,440
bullhead minnow	1	—	10	—	1	—	—	—	—	—	—	NA	12
flathead chub	57	105	28	24	8	17	25	132	413	301	155	NA	1,265
longnose dace	32	28	—	6	2	4	3	67	93	46	119	NA	400
SUCKERS													
river carpsucker	2	10	3	5	5	2	8	158	1,243	189	11	NA	1,636
white sucker	2	5	3	—	—	1	1	760	1,276	32	8	NA	2,044
smallmouth buffalo	—	—	—	—	—	—	—	3	39	—	—	NA	42
BULLHEAD CATFISHES													
black bullhead	5	—	—	—	—	—	—	—	—	—	—	NA	5
yellow bullhead	48	3	—	1	7	—	—	2	1	12	—	NA	74
channel catfish	6	214	33	—	6	25	23	12	16	461	268	NA	1,064
flathead catfish	—	—	—	—	—	—	—	—	—	—	—	NA	0
TROUTS													
rainbow trout	—	—	—	—	—	—	—	—	—	—	—	NA	0
brown trout	—	—	—	—	—	—	—	—	—	—	—	NA	0
LIVEBEARERS													
western mosquitofish	821	305	18	6	5	8	7	91	399	277	106	NA	2,043
TEMPERATE BASSES													
white bass	3	4	1	—	1	2	5	1	2	—	—	NA	19
SUNFISHES													
green sunfish	—	—	—	—	—	—	—	—	—	4	—	NA	4
bluegill	—	—	—	—	—	—	1	—	—	—	—	NA	1
largemouth bass	6	3	—	—	—	1	—	—	1	1	—	NA	12
white crappie	—	1	—	1	1	—	—	1	3	—	—	NA	7
black crappie	—	—	—	—	—	—	—	—	—	—	—	NA	0
PERCHES													
yellow perch	2	3	—	—	—	—	—	—	—	—	—	NA	5
bigscale logperch	—	—	—	—	—	—	1	—	—	—	—	NA	1
walleye	—	—	—	—	—	—	—	—	25	2	—	NA	27
TOTAL	5,427	4,872	3,062	3,485	1,766	1,277	1,907	4,105	14,058	5,025	2,538		47,522

Table 4. Summary of the monthly catch of Rio Grande silvery minnow, by site and reach, during the 2005-2006 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	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
			2005					2006						
ANGOSTURA REACH														
0	Angostura Dam	3	—	—	—	—	—	—	—	—	10	0	NA	13
1	Bernalillo	19	130	—	—	—	1	—	1	2	6	9	NA	168
2	Rio Rancho	99	252	—	—	2	3	36	17(3)	27(3)	11(2)	15(4)	NA	462
3	Central Ave (Abq)	14	8	23	3	15(2)	4	5	—	1	34	38	NA	145
4	Rio Bravo (Abq)	20	21	2	—	3	2	6	8(1)	—	3	1	NA	66
	Angostura Reach Total	155	411	25	3	20	10	47	26	30	64	63	NA	854
ISLETA REACH														
5	Los Lunas	414	202	119	12	2	142	13	71	4	21	3	NA	1,003
6	Belen	278	324	48	32	8	16	5	116	17	62	0	NA	906
7	Jarales	1,218	414	1,615	1,994	32	21(1)	4	7	409	41	19	NA	5,780
8	US Hwy 60 Bernardo	317	24	62	8	13	26	2	9	6	21	5	NA	493
9	South of Bernardo	128	205	267	45	1	8	3	3	1	122	45	NA	828
9.5	North of San Acacia	90	60(4)	11	14(1)	9	62	1	—	27	1	3	NA	278
	Isleta Reach Total	2,445	1,229	2,122	2,105	65	281	28	206	464	268	75	NA	9,288
SAN ACACIA REACH														
10	San Acacia Dam	75	38	9	—	27(1)	26	83(1)	139	102	44	1	NA	544
11	S of San Acacia	40	111	74	6	8(1)	56(1)	204(1)	50(1)	17	5	1	NA	572
12	Socorro	270	413(2)	90	382(2)	481(2)	60	597(1)	141(1)	97	8	0	NA	2,539
13	North of US Hwy 380	172	263	72	78(1)	15	439	127	34	21	13	14	NA	1,248
14	US Hwy 380	258	874(1)	85	163	51	38	286	33	34	37	0	NA	1,859
15	Bosque del Apache	424	146	328	447	873	139	13	13	52	3	0	NA	2,438
16	San Marcial	15	18	1	132	37	63	13	10	93	0	3	NA	386
17	South of San Marcial	21	38	10	21	35	23	3	1	6	1	3	NA	162
18	South of San Marcial	24	29	3	38	8	19	3	1	4	20	0	NA	149
	San Acacia Reach Total	1,299	1,931	672	1,267	1,535	863	1,329	422	426	131	22	NA	9,897
	MONTHLY TOTALS	3,899	3,571	2,819	3,375	1,620	1,154	1,404	654	920	463	160	NA	20,039
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL

series distributions were compared with a normal distribution using the Shapiro-Wilk W test. Calculated values of W were higher for the 2003 data set compared with the 2002 data set (W=0.807 and W=0.636) indicating larger departure from normality in the 2002 data set. Values of W for both data sets were significant (p<0.01).

To correct for this difference, data were log-transformed ($X' = \ln(X+1)$). Normal quantile plots of empirical data for 2002 and 2003 were also examined in reference to Lilliefor's confidence bounds. No systematic departure from normality was observed. Resulting values of *W* using log-transformed data were 0.931 and 0.927 (non-significant) for 2002 and 2003, respectively, indicating that parametric statistical analysis was appropriate.

Comparing the two independent samples was accomplished using the t-distribution test. This statistical procedure (also known as the Student's t test) was used to detect differences between two samples based on assumptions of normality and homogeneity of variances. Differences between sample means were evaluated based on the critical value of t based on sample size. Differences between the 2002 and 2003 egg catch rate data sets (log-transformed) were analyzed using the t-distribution. Analysis of the reproductive output curves revealed that the 2002 egg catch rate was significantly higher (t=3.62; p<0.001) than the 2003 catch rate. The log-transformed mean egg catch rate was notably higher in 2002 than in 2003 (3.17 ±0.26 and 1.95±0.20, respectively).

Mean daily water temperatures during the initial and peak spawning events were relatively similar across years. 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.

Comparison of 2001-2006 water temperatures at the study site during May and June demonstrate relatively few differences in mean daily water temperatures across this period (Figure 13). Mean, minimum, and maximum daily water temperatures in early May 2004 (1-10 May) were generally higher than previously recorded. Outside of this period (1-10 May 2004), the highest minimum daily water temperatures were still recorded in 2001 with the lowest minimum temperatures occurring during 2002. Likewise, the highest maximum daily water temperatures were in 2002 with the lowest maximum daily water temperatures generally in 2001 or 2004. 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 and 2004 served to ameliorate water temperatures and minimize diel variation. Conversely, the very low flow conditions present in 2002, especially post-flow spike, typically resulted in daily temperature fluctuations of about 14°C. 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.

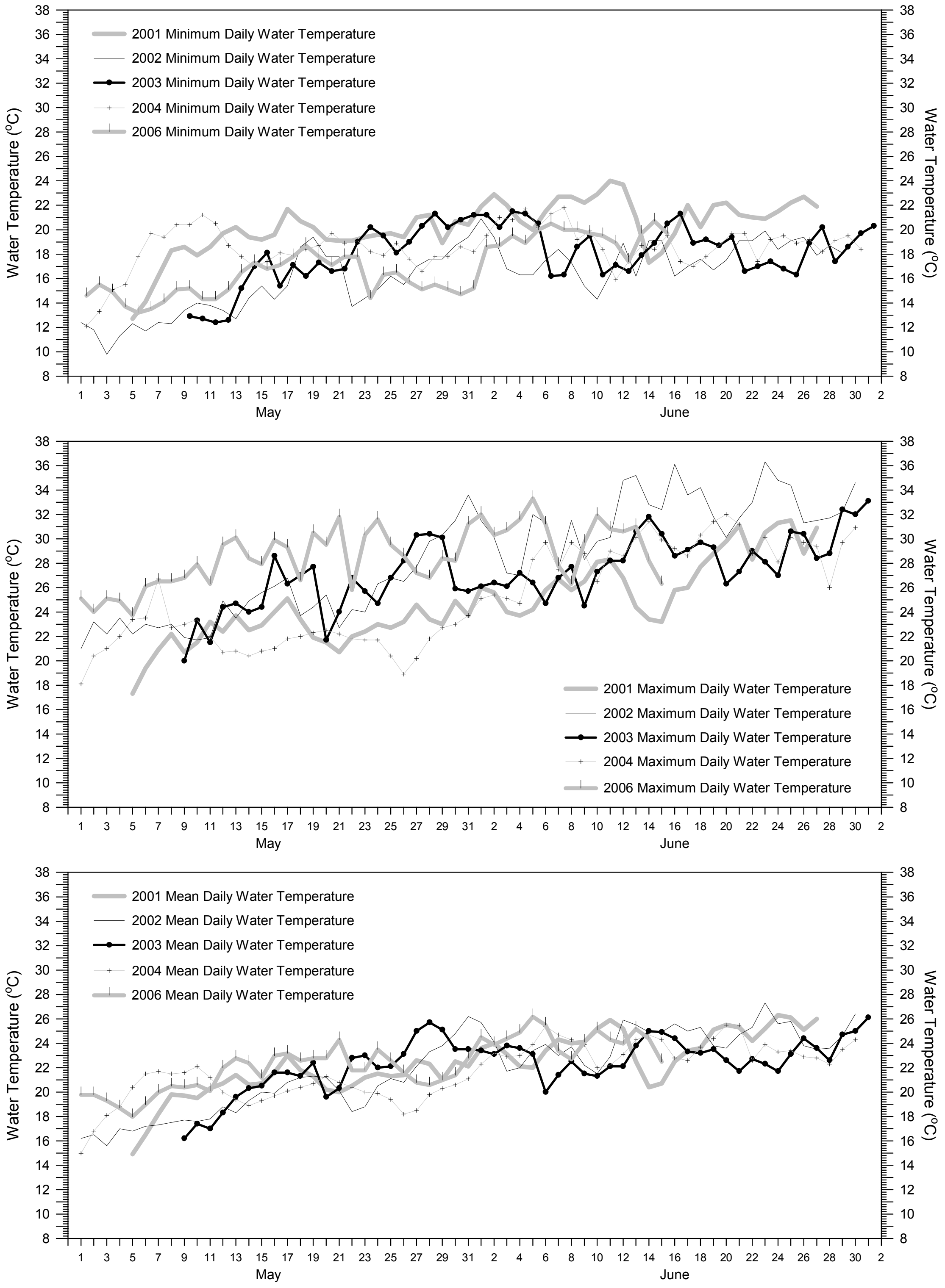

Figure 13. Comparisons of annual minimum, maximum, and mean daily water temperatures during the 2001-04 and 2006 Rio Grande silvery minnow spawning periodicity study periods.

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 et al., 2004) 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.

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 Rio Grande 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. In 1999, 2001, 2002, and 2003 the peak spawning event by Rio Grande silvery minnow occurred soon after the initiation of runoff (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.

Future efforts should also focus on reducing the deleterious effects that changes in river connectivity, flow patterns, and habitat heterogeneity have on the downstream displacement of Rio Grande silvery minnow eggs and larvae. Eliminating diversion structures as barriers would allow upstream passage of individuals to reaches from which they were displaced. Repopulating upstream reaches of the Middle Rio Grande through natural recolonization would greatly aid in the recovery of this species. Efforts to improve degraded riverine habitats could include returning the flow regime to a more historical pattern (i.e., allowing passage of large flow events) and removing or relocating structures that inhibit the lateral movement of the Rio Grande (e.g., jetty-jacks, levees, and water conveyance ditches). The long-term recovery of Rio Grande silvery minnow will depend on taking management actions that attempt to restore the natural processes of this river.

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