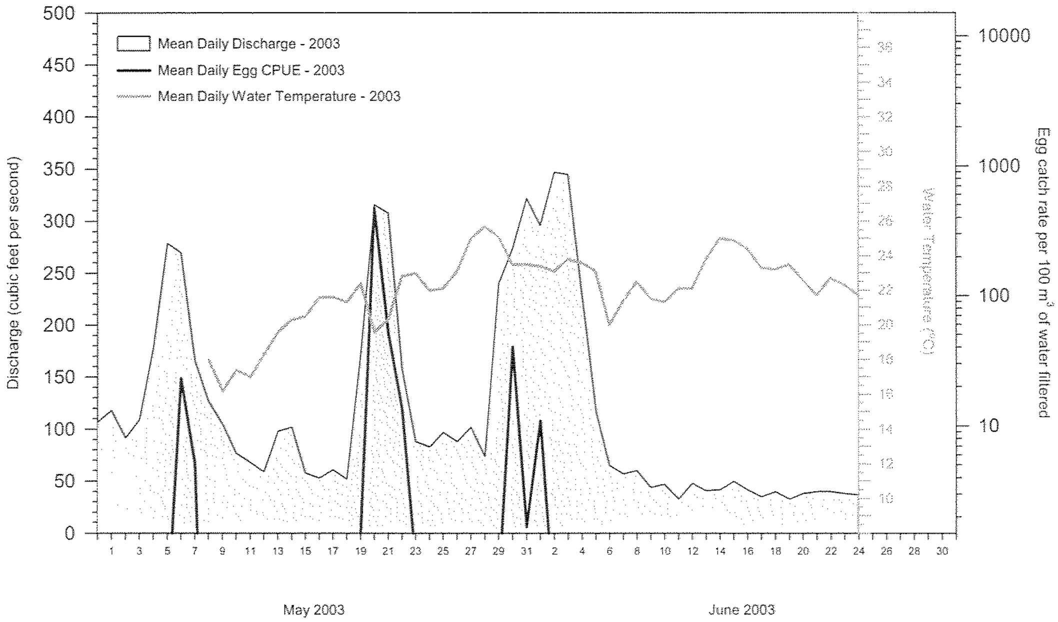
Spawning Periodicity of Rio Grande silvery minnow during 2003

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



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SPAWNING PERIODICITY OF RIO GRANDE SILVERY MINNOW DURING 2003

prepared for:

MIDDLE RIO GRANDE ENDANGERED SPECIES ACT COLLABORATIVE PROGRAM

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EXECUTIVE SUMMARY

The historical Middle Rio Grande fish fauna was reflective of a Great Plains river. At least five cyprinid species that can be characterized as Great Plains river fishes formerly occurred throughout the Middle Rio Grande. Spawning by members of this reproductive guild is associated with high-flow events such as spring runoff or summer rainstorms. Upon release, eggs are about 1.6 mm in diameter but quickly swell (ca. 3.0 mm) and remain suspended in the water column during development. The last remaining member of this reproductive guild in the Rio Grande, New Mexico, is the federally endangered Rio Grande silvery minnow, *Hybognathus amarus*.

Population monitoring studies of Rio Grande silvery minnow catch rates revealed that silvery minnow catch rates have declined about three orders of magnitude from 1993 to 2003. Additionally, relative abundance of this species has declined from about 50% of the total ichthyofaunal community in 1995 to <0.5% in 2003. The number of silvery minnow taken in 2003 was low in all reaches and had declined to the lowest levels ever recorded by September 2003. In 2003, the Angostura Reach yielded the most silvery minnow, followed by the San Acacia Reach, and the Isleta Reach. This was in contrast to previous years of population monitoring where the San Acacia Reach produced the largest catch rates of silvery minnow. Low flow conditions and the diversion of nearly all water at the Isleta Diversion Dam during the summer of 2003 resulted in river drying in downstream reaches and substantial losses of riverine habitat especially in the San Acacia Reach. The affects of the continued decline in the population of silvery minnow were reflected in a significantly reduced 2003 egg catch rate as compared to 2002.

There was little difference in flow in the Middle Rio Grande between 2002 and 2003. The severe drought which has enveloped the region since 2000 continued while the dismal 2003 snowpack, in combination with already diminished water reserves in upstream reservoirs, severely limited summer flows in the study area. As occurred in 2002, an artificial flow spike (water released from Cochiti Dam on 14 May) was employed to stimulate spawning by Rio Grande silvery minnow in 2003. Rio Grande silvery minnow eggs associated with this flow spike were first taken at about 20:00 h on 19 May 2003 and were present in each of the samples (n=28) taken during the subsequent 85 h (3.5 days). The 19-21 May 2003 spawn produced 91% (n=12,033) of the total 2003 catch and yielded a cumulative catch rate of 284.3 eggs/100 m^3 of water sampled. The 20 May catch rate was the highest recorded during 2003 and the cumulative catch during that day (n=11,121) was 84% of the 2003 total. The number of silvery minnow eggs collected declined by one-order of magnitude each day from 20-23 May 2003 while the magnitude of the decline in catch rates during this same period, although not as dramatic as number of eggs, was also almost 10-fold between 20-21 May.

The 2003 Rio Grande silvery minnow reproductive effort monitoring program yielded the lowest catch and cumulative catch rate recorded to date. A total of 43,403 m^3 of water was sampled during the 58-day duration of this 2003 project yielding 13,292 Rio Grande silvery minnow eggs. Mean daily catch rates on dates that eggs were collected ranged from 0.02 to 475.6 eggs/100 m^3 of water sampled. The decline in cumulative and maximum egg catch rates between 2002 (2,031 and 14,222 eggs/100 m^3, respectively) and 2003 (59 and 476 eggs/100 m^3, respectively) was significant and is expected to continue in 2004.

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. 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. The ability to efficiently sample even 1% of the entire volume of water that carries these reproductive propagules downstream would require a monumental effort. Future efforts should 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 would allow upstream passage of individuals to reaches from which they were displaced. 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.

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 (Lagasse, 1985). Historically, this section of the river gradually meandered through a wide floodplain in vegetated valley. Extensive braiding of the river as it flowed over the shifting sand substrate was common and flow 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 summer rainstorms (monsoonal events) often caused severe flooding and were important in maintaining perennial flow. Historically, the Middle Rio Grande possessed all of the characteristics distinctive of a Great Plains aquatic ecosystem.

The historical Middle Rio Grande fish fauna was also reflective of a Great Plains River. At least five cyprinid species that can be characterized as Great Plains river fishes formerly occurred in the Middle Rio Grande (Platania and Altenbach, 1998). Of the aforementioned species, speckled chub, *Macrhybopsis aestivalis*, Rio Grande shiner, *Notropis jemezanus*, and Rio Grande bluntnose shiner, *Notropis simus simus,* have been extirpated from the Middle Rio Grande. 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 Great Plains River cyprinid fish fauna fish (Bestgen and Platania, 1991; Platania, 1991).

This group of 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) and 2003 and is scheduled to occur in 2004.

Population monitoring studies of Rio Grande silvery minnow have shown an annual decline in the number and catch rate of this species since 1996 (Dudley and Platania, 1999, 2000, 2001, 2002; Dudley et al., 2003). Currently over 90% of the catch of Rio Grande silvery minnow is in the San Acacia Reach of the Middle Rio Grande (Dudley and Platania, 2001, 2002). Multi-agency efforts in areas of habitat improvement, research, and propagation are underway in an attempt to increase population size and distribution with the ultimate goal being recovery of this species.

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. This document presents the results of the 2003 spawn of Rio Grande silvery minnow during that artificial flow spike and compares data collected under the auspices of this study during 2001-2003.

STUDY AREA

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, 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, meandering 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.

This study was restructured to monitor the reproductive output of Rio Grande silvery minnow in the Middle Rio Grande and secure the largest possible number of eggs for the propagation facilities.

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 rescue eggs destined to drift into Elephant Butte Reservoir where, if hatched, larvae would be subjected to a wide array of nonnative predators. The Rio Grande silvery minnow egg collecting site was located about 10 miles (16 km) downstream of the San Marcial Railroad bridge crossing at River Mile 58.8 (UTM Zone 13: 3716150 Northing; 307846 Easting). This site was located near the downstream-most point in the San Acacia Reach (Figure 1). 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.

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 1 July 2003. Previous studies (Platania and Dudley 2002a, 2002b, 2002c) demonstrated this (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 (non-peak spawning) so as to increase the volume of water sampled per unit of time. During the period that the principal Rio Grande silvery minnow spawning effort occurred (19-23 May 2003), quantitative sampling of eggs was conducted almost continuously with a single flow-meter equipped MEC. Research personnel were constantly present at the sampling site from 4 May through 1 July 2003.

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. Minor changes, related to egg salvage for propagation (see below), were instituted in 2003. There were no changes in methods for quantitative determination of egg catch rate between 2002 and 2003. The aforementioned differences in egg catch rate determination between 2001 and 2002-2003 preclude use of 2001 data for quantitative or statistical comparison with 2002-2003 data.

In 2003, responsibilities for the egg salvage and reproductive monitoring projects were further refined and defined. Personnel from the BioPark-Albuquerque Aquarium (BioPark) assumed all responsibility for the collection, transportation, and processing of eggs collected for propagation activities. In addition, they (BioPark) were also responsible for developing and instituting a procedure, within the scope of the egg salvage project, to determine the number of eggs retained during that project. Egg catch rate data from the Rio Grande silvery minnow reproductive monitoring effort were not used to determine the cumulative catch of the eggs under the salvage effort. As occurred in 2002, a subset of live eggs collected during the 2003 project was provided to Dr. Thomas F. Turner (UNM-MSB) for a study on aspects of the population/conservation genetics of Rio Grande silvery minnow.

On most occasions during 2001-2003, collected eggs could be easily counted and retained for the propagation program (i.e., catch of <500 eggs per hour). However, enumeration of eggs during peak spawning (especially 2002) was not possible and it was during that period that an accurate determination of the egg/volume of water sampled catch rate was essential. Under those circumstances (peak spawn), eggs were retained and preserved for subsequent enumeration in the laboratory. As occurred in 2001-2002, a subset of live eggs collected during the 2003 project was

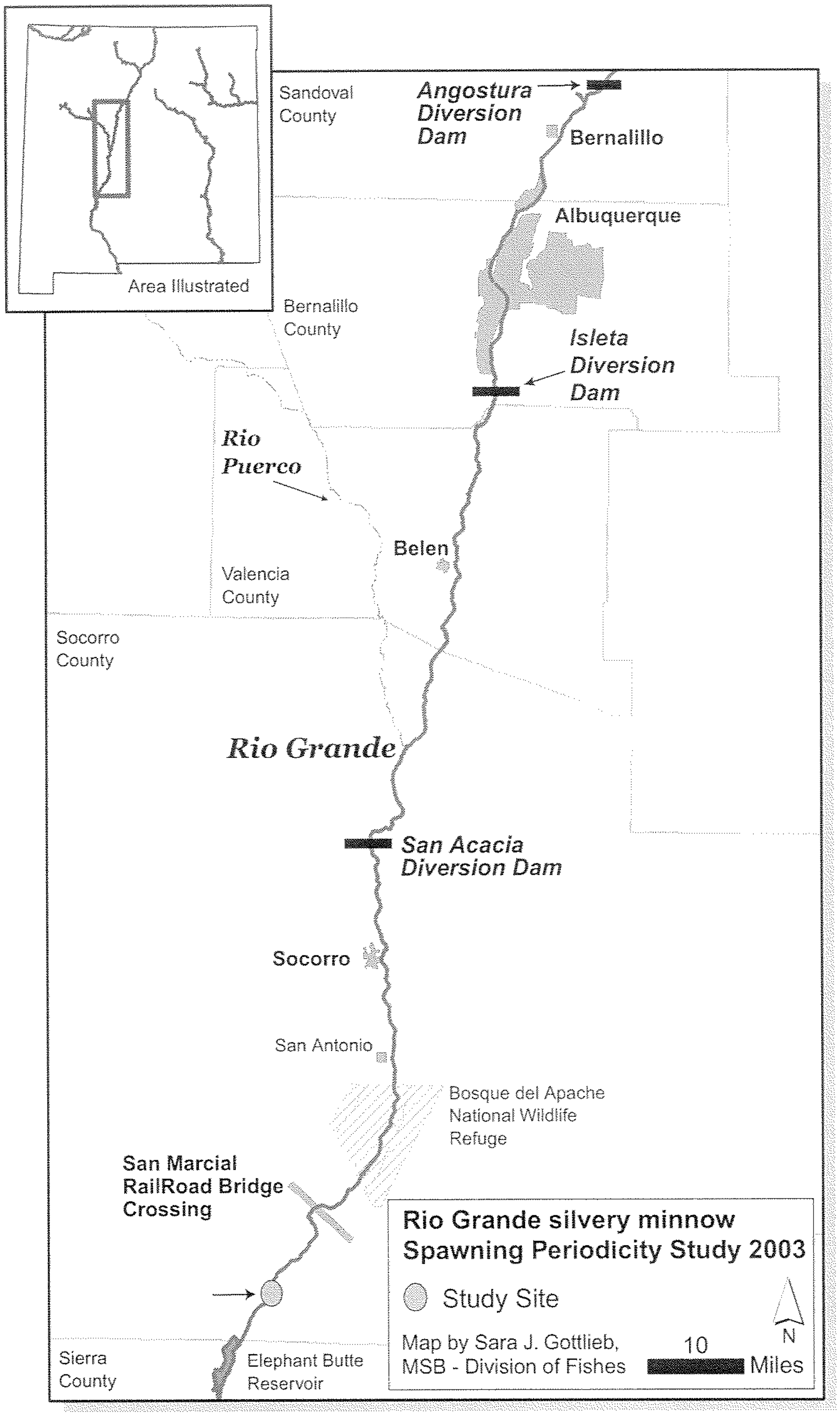


Figure 1. Map of the Middle Rio Grande, New Mexico, and the study site location.

provided to Dr. Thomas F. Turner (UNM-MSB) for a study on aspects of the population/conservation genetics of Rio Grande silvery minnow.

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 conditions 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.

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 three years; only two (2002-2003) of which can be used for comparative purposes. The statistical strength of comparisons performed through linear regression analysis will increase annually.

Water temperature was recorded by two temperature logging devices deployed at the study site on 8 May 2003 and programmed to record hourly water temperature. The second temperature logger was redundant and deployed to compensate in the case of the potential loss of data due to electronic failure in the primary unit. Both data loggers were retrieved on 1 July 2003 and information downloaded. 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. Mean daily discharge data for this study were acquired from the U.S. Geological Survey river gauge at the San Marcial Railroad Bridge crossing over the Rio Grande (gauge # 08358400) and are presented in cubic feet per second (cfs).

Reporting of research activities (qualitative results) of the Rio Grande silvery minnow reproductive effort monitoring study was accomplished by posting a summary of daily activity on the U. S. Bureau of Reclamation maintained "*Rio Grande silvery minnow Spawning Periodicity Study 2003*" world-wide-web page (URL: http://msb-fish.unm.edu/rgsm2003/Egg_Salvage/index.html). An e-mail list serve was established through this web site as a means of keeping those individuals interested in the project informed of river conditions, project updates, and putative silvery minnow spawning period. This outlet provided an extremely effective means of communication, information dissemination, and public outreach. The web page contained a brief summary of the project scope, goals, and schedule of activities, photographs of the sampling site and sampling efforts, a 7.5' USGS topographic map indicating the collection locality, and served as an achieve of e-mail correspondence. Finally, the spawning periodicity study web page contained links that allowed the reader to obtain USGS flow data for the San Marcial Railroad Bridge Crossing, San Marcial, New Mexico site, copies of the 1999, 2001, and 2002 reports on spawning periodicity of Rio Grande silvery minnow (in pdf format), and access to the 2003 Rio Grande silvery minnow population monitoring research page (and its associated links).

RESULTS

Hydrology during 2003 and the artificial flow spike

There was little difference in flow in the Middle Rio Grande between 2002 and 2003. The severe drought which enveloped the region since 2000 continued while the dismal 2003 snowpack, in combination with already diminished water reserves in upstream reservoirs, severely limited summer flows in the study area (Figure 2). Discharge in the Rio Grande at San Marcial Railroad Bridge Crossing (USGS Gauge 08358400) generally remained <400 cfs from well before the end of previous irrigation season (1 November 2002) throughout the calendar year. There were more peak flow events in the Rio Grande from March-early June 2003 (n=4) than had occurred during that same period in 2002 (n=1). None of the 2003 flow spikes were >400 cfs (as recorded at San Marcial Railroad Bridge Crossing) and all were the result of increased discharge from Cochiti Dam. The three flow spikes in May 2003 helped maintain discharge >50 cfs throughout the month with mean daily flow being >150 cfs on 11 days in May 2003.

The four increases in flow that originated from Cochiti Dam and were realized at San Marcial Railroad Bridge occurred between 16 April and 31 May 2003 (Figure 3). The flow increases were about four-six days in duration and represented increases in discharge ranging from about 40-100%. The peaks occurred at two-week intervals with the first on 17 April and last on 29 May 2003. The first increase in flow from Cochiti Dam arrived at the study site prior to the initiation of this study.

The 1 May flow spike arrived at San Marcial Railroad Bridge on 4 May and maintained elevated flows of about 270 cfs at that site during 5-6 May 2003. Discharge in the San Acacia Reach of the Rio Grande returned to "normal" baseflow by 9 May and remained that way for about one-week (Figure 4). The artificial flow spike that stimulated spawning by Rio Grande silvery minnow was the third in the series of four initiated at Cochiti Dam. Releases from Cochiti Reservoir for this flow event began on 14 May 2003 and continued for three days. Mean daily discharge at Cochiti Dam increased from 716 cfs on 13 May 2003 to 1,160 cfs on 14 May 2003, and peaked at 1,430 on 15 May 2003. Cochiti Dam discharge declined from 1,140 to 864 cfs during the next three days (16-18 May) and generally remained between 800-900 cfs through 25 May 2003. The third flow spike arrived at San Marcial on 19 May, peaked at about 300 cfs on 20-21 May, and returned to baseflow conditions on 23 May 2003 (Figure 5).

The final May 2003 flow spike started on 26 May 2003 when mean daily discharge at Cochiti Dam rose to about 1,000 cfs and peaked at about 1,400 cfs (29 May) before returning to pre-spike levels (800-900 cfs) on 1 June 2003. Water from this event arrived at the San Acacia Reach on 28 May and at the San Marcial Railroad Bridge on 29 May 2003. This was the longest duration and highest flow event during the study period with elevated discharge recorded from 29 May through 5 June and mean daily flows of 347 and 345 cfs on 2-3 June 2003, respectively.

Rio Grande silvery minnow egg collections

A total of 43,403 m^3 of water was sampled during the 58-day duration of this 2003 project yielding 13,292 Rio Grande silvery minnow eggs. Mean daily catch rates on dates that eggs were collected ranged from 0.02 to 475.6 eggs/100 m^3 of water sampled. The mean daily catch rate for the duration of the study was 30.6 eggs/100 m^3 of water sampled. However, this former value has little biological meaning as it includes dates on which no eggs were collected (n=40). The mean daily catch rate of eggs on dates when at least one egg was collected (59.3 eggs/100 m^3 of water sampled; n=18) was about half of that on which >10 eggs were collected (103.4 eggs/100 m^3 of water sampled; n=9).

Rio Grande silvery minnow eggs were first collected on 5 May 2003 at 1500 h. This spawning event was lasted three days (5-7 May 2003) and yielded catch rates from 0.7 to 23.1 eggs/100 m^3 of water sampled. The cumulative catch rate for the first spawning event was 15.6 eggs/100 m^3 with the three-day egg catch (n=899) being about 6.5% of the total 2003 catch. The 5-7 May spawning event corresponded with an increase in flow that began on 4 May 2003, peaked at ca. 280 cfs on 5-6 May, and had returned to pre-spike levels by 9 May 2003. Between 10-18 May 2003, a cumulative total of seven Rio Grande silvery minnow eggs were taken, in two separate collections (13-14 May 2003).

An increase in discharge at the site was noted at 1200 h on 19 May 2003 which indicated the arrival of the 14 May-Cochiti Dam initiated flow spike. The absence of Rio Grande silvery minnow eggs, despite sampling from 0830-1915 (19 May 2003), suggested a delayed response between initiation of spawning and arrival of the flow spike. Eggs associated with this flow spike were first taken at about 20:00 h on 19 May 2003 and were present in each of the samples (n=28) taken during the subsequent 85 h (3.5 days).

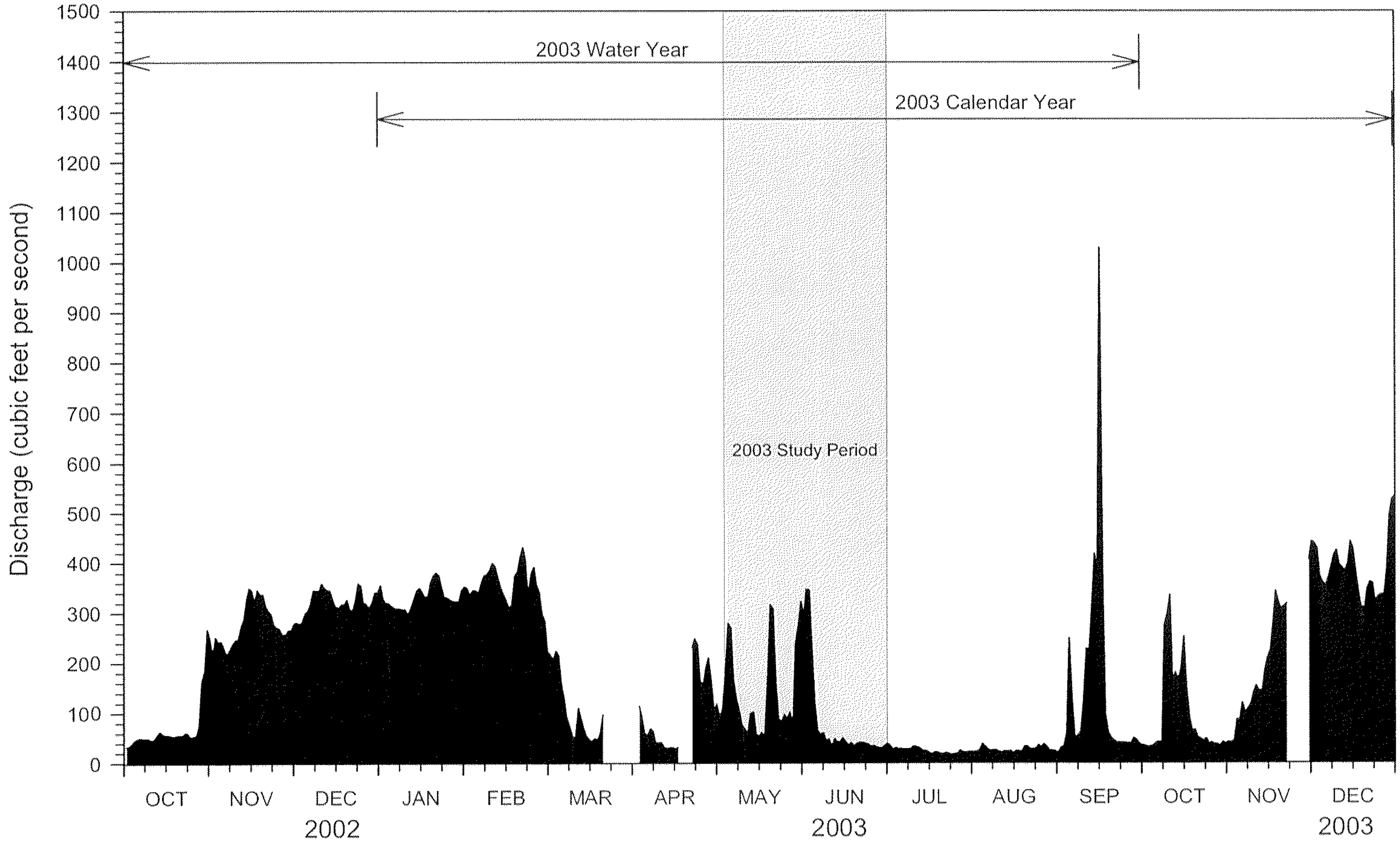


Figure 2. Hydrograph of the Rio Grande, New Mexico, at the San Marcial Railroad Bridge before, during, and after the 2003 study period. Gaps in the hydrograph illustration lack mean daily discharge data due to equipment malfunction.

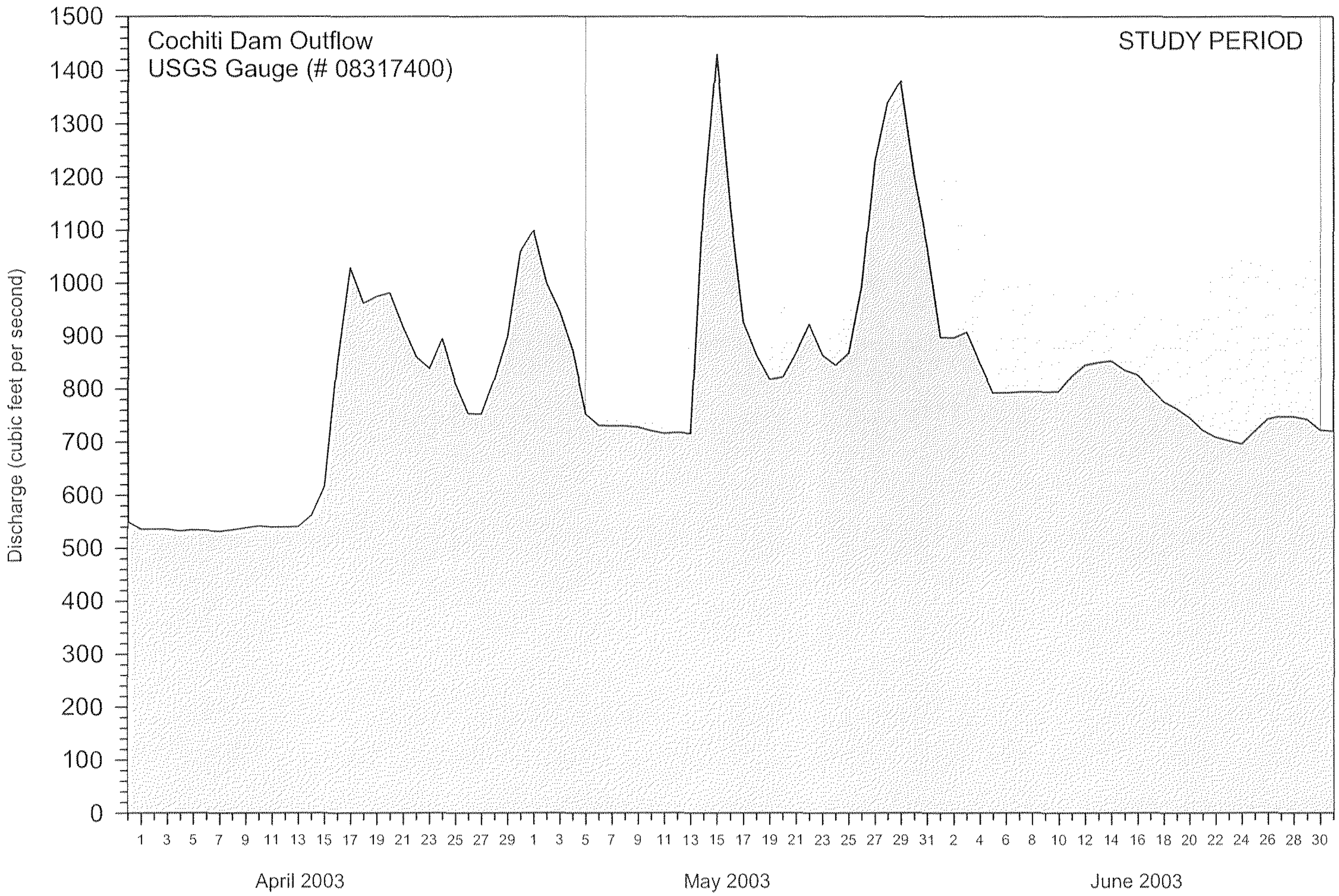


Figure 3. Hydrograph of the Rio Grande, New Mexico, at Cochiti Dam (foreground) during the 2003 study period (dark gray background).

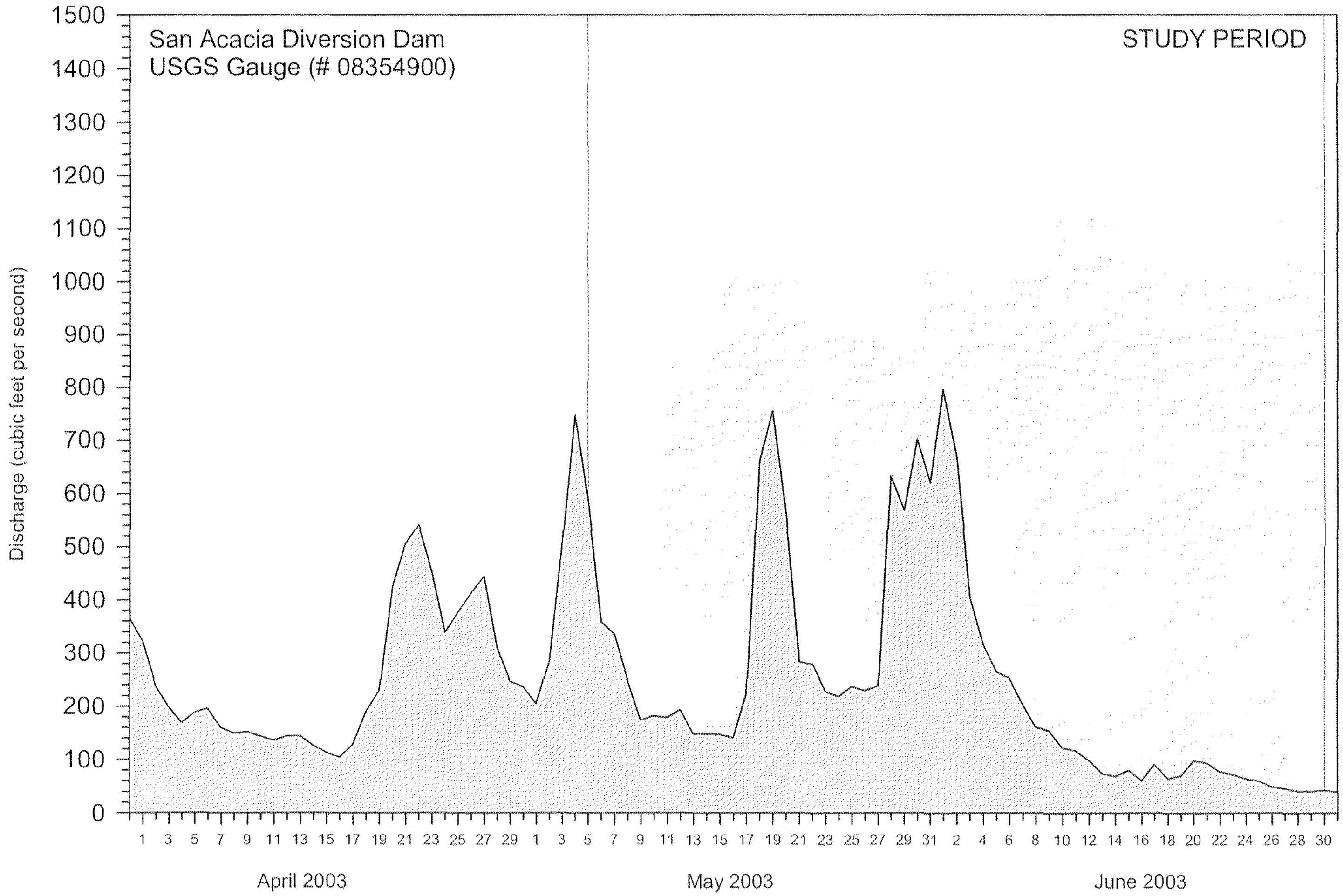


Figure 4. Hydrograph of the Rio Grande, New Mexico, at San Acacia Diversion Dam (foreground) during the 2003 study period (dark gray background).

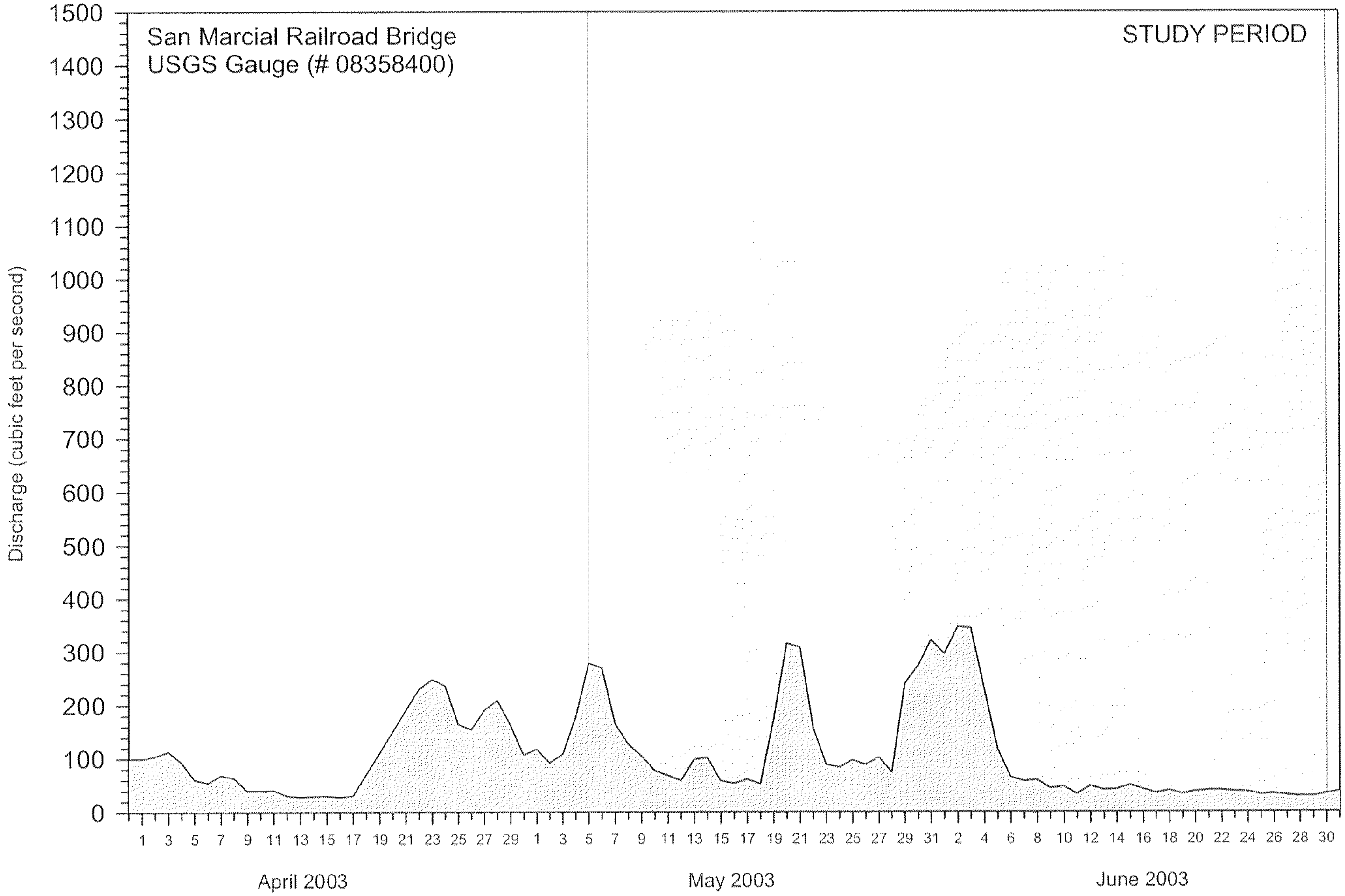


Figure 5. Hydrograph of the Rio Grande, New Mexico, at San Marcial Railroad Bridge (foreground) during the 2003 study period (dark gray background).

The 19-21 May 2003 spawn produced 91% (n=12,033) of the total 2003 catch and yielded a cumulative catch rate of 284.3 eggs/100 m^3 of water sampled. Daily catch rate rose markedly from 1.4 eggs/100 m^3 on 19 May to 475.6 eggs/100 m^3 on 20 May 2003 and declined to 51.9 eggs/100 m^3 on 21 May 2003 (Figure 6; upper graph). The 20 May catch rate was the highest recorded during 2003 and the cumulative catch during that day (n=11,121) was 84% of the 2003 total. The number of eggs collected declined by one-order of magnitude each day from 20-23 May 2003 while the magnitude of the decline in catch rates during this same period, although not as dramatic as number of eggs, was also almost 10-fold between 20-21 May.

Hourly sampling during the period of peak reproductive activity (20 May 2003) documented a pattern of relatively marked increase in catch rates with post-peak catch rates being more gradual and extending over a greater time-period (Figure 6; lower graph). Hourly catch rate on 20 May 2003 went from ca. 50 eggs/100 m^3 to 600 eggs/100 m^3 in two hours (0400-0600) and from 600 eggs/100 m^3 to ca. 1,000 eggs/100 m^3 in one hour (0900-1000). Maximum hourly catch rate during this study (1,027 eggs/100 m^3) was recorded between 1000-1100 h on 20 May with the three highest hourly catch rates occurring between 0900-1200 on 20 May. Hourly catch rate on 20 May remained relatively constant (ca. 550-650 eggs/100 m^3) between 1200 and 1600 h but declined to 300-400 eggs/100 m^3 from 1600-1800 h. Catch rate during the remainder of the 20 May 2003 hourly collections was about 220 eggs/100 m^3. The pattern of gradual decline in hourly egg catch rates continued throughout 21 and 22 May with catch rates at 1700 h being 14.7 and 9.3 eggs/100 m^3, respectively, during those two days. The last eggs associated with the 19 May 2003 flow spike were taken in two samples on 25 May; six eggs were present in the morning sample and one in the evening collection. Almost 1,900 m^3 of water was sampled between 0700 h on 26 May and 1700 h on 29 May but no eggs were collected.

The final flow spike during the study period arrived 29 May 2003 and persisted until 5-6 June 2003. That flow spike appeared to have initiated two separate and small magnitude spawning events whose peaks were about 48 h apart. Silvery minnow eggs associated with the aforementioned flow spike were first collected at 2200 h 29 May 2003 with the peak catch rate during the first event (94.2 eggs/100 m^3 of water sampled) recorded at 0200 h on 30 May 2003. The main portion of the spawn was of short duration (ca. 12 h) as very few eggs (n=4) were taken after 1100 h on 30 May 2003. Two of the five samples made after 1100 h on 30 May yielded single eggs and one sample produced two eggs. The cumulative catch rate of the approximately 24-h period that produced eggs was 31.4 eggs/100 m^3 of water sampled with the total catch (n=106) comprising <1% of the 2003 catch.

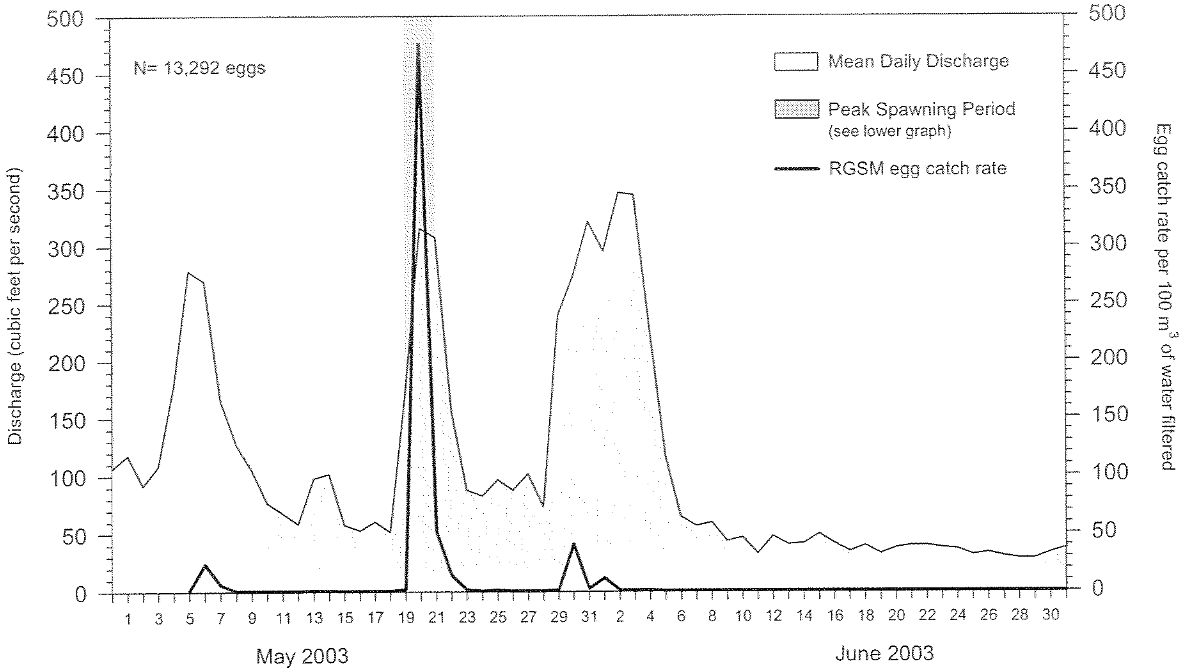
The second spawning event associate with the final flow spike produced 107 Rio Grande silvery minnow eggs and lasted for about 48 h. Eggs were taken in each of the seven samples obtained from 0700 on 31 May through 0700 on 2 June 2003. The egg catch rate during this period ranged from <1 to 15.4 eggs/100 m^3 of water sampled with the cumulative rate being 6.5 eggs/100 m^3 of water sampled. The final 2003 collection of eggs occurred on 3 June (n=3; 0.4 eggs/100 m^3) and 4 June (n=1; 0.2 eggs/100 m^3).

There were 82 collections made during the 27 days following the last collection that contained a Rio Grande silvery minnow egg. During that 27-day period, over 8,000 m^3 of water was filtered at the study site. That amount (8,000 m^3) was approximately 20% of the total volume sampled during the study despite that the 27-day sampling period comprised about 50% of the total study period. Low discharge in the Rio Grande from 6 June through the remainder of the study limited the volume of water that could be sampled. The reduced volume of water sampled after 6 June 2003 does not alter the results of the data which documented an absence of Rio Grande silvery minnow reproductive activity in the vicinity of the San Acacia Reach study site during that period.

Water temperature

Mean daily water temperature at the study site rose steadily from 16.2°C on 9 May to 22.4°C on 19 May 2003 (Figure 7). The gradual rise in water temperature during this period occurred concurrent with the low flow conditions (<100 cfs) present in the lower portion of the San Acacia Reach of the river. The arrival of the 20 May 2003 flow spike temporarily depressed mean daily water temperature (by almost 3°C; to 19.6°C) before it again began to gradually increase. By 22 May 2003, mean daily water temperature had surpassed that of the pre-flow spike period and continued to increase as daily discharge declined. Peak mean daily water temperature during May 2003 occurred on 28 May (25.7°C) as did maximum hourly water temperature (30.4°C at 1700 h).

The late May flow spike that arrived at San Marcial Railroad Bridge on 29 May 2003 did not have as marked an effect on water temperature as that of the mid-May flow increase. Mean daily water temperature at the study site declined 2.2°C (from 25.7 to 23.5°C) concurrent with the 28-30



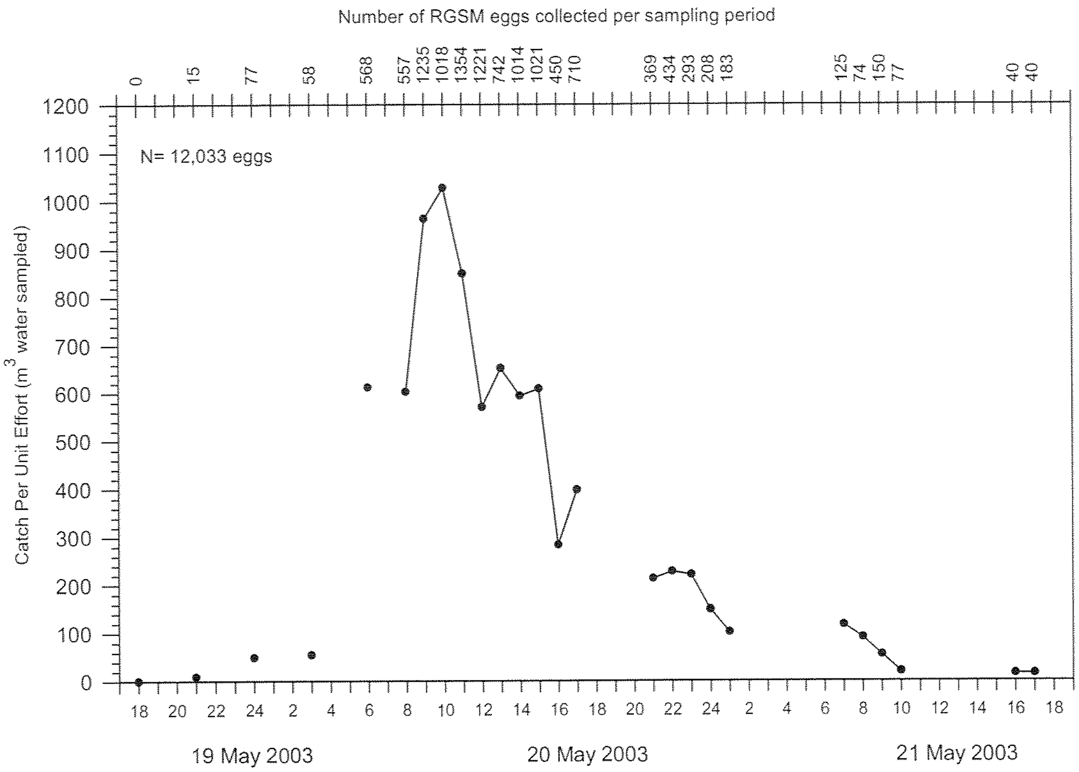


Figure 6. Upper graph: Mean daily catch rate of Rio Grande silvery minnow eggs during 2003. Lower graph: Hourly catch rate of Rio Grande silvery minnow eggs during peak 2003 spawning period.

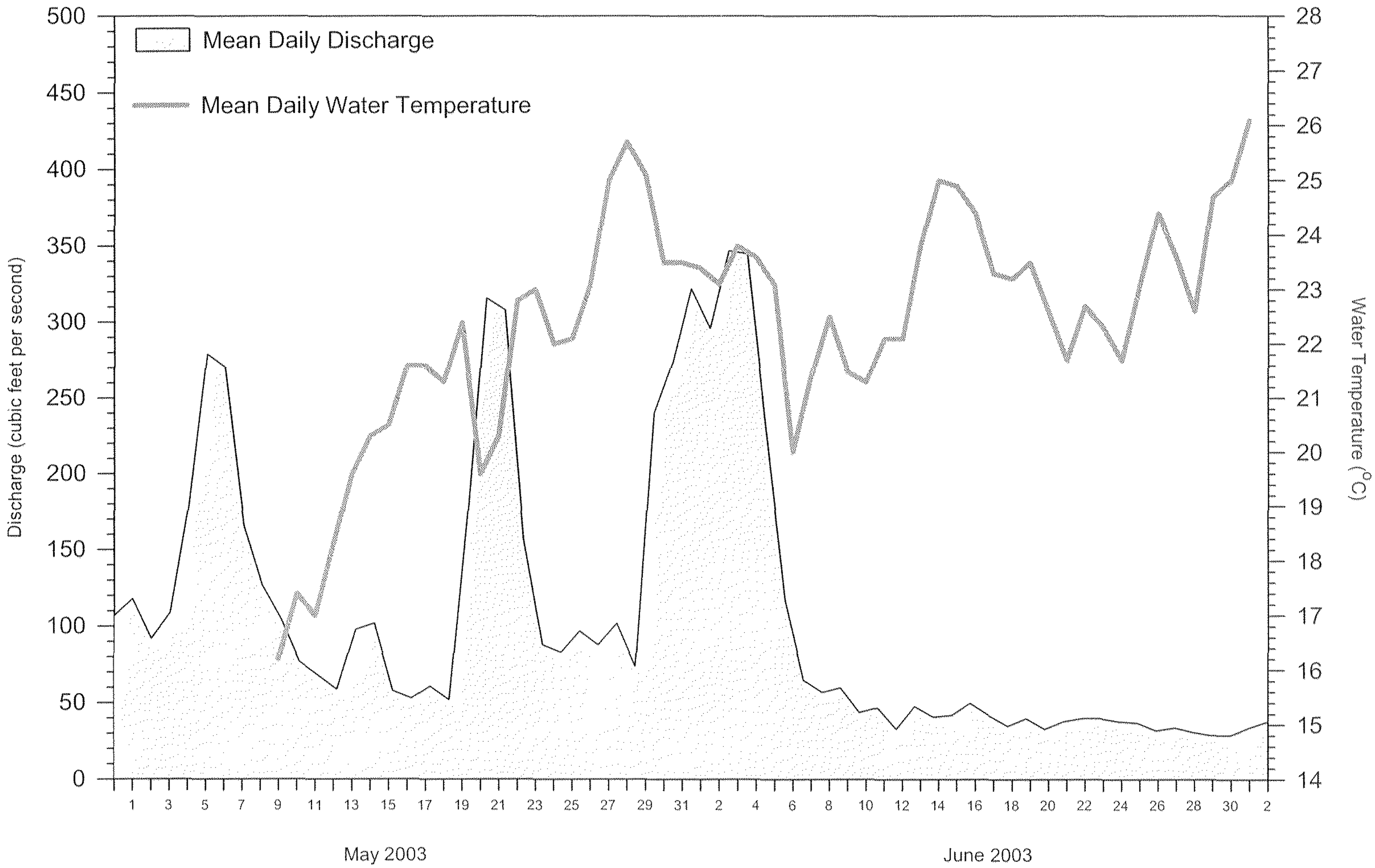


Figure 7. Mean daily discharge at San Marcial Railroad Bridge compared with mean daily water temperature at the study site during the 2003 study period.

May 2003 increase in discharge. During the remainder of the final flow spike (31 May-5 June), mean daily water temperature remained between 23.1-23.8°C. The large single day decline (3.3°C) in daily water temperature that occurred between 5-6 June 2003 was the result of reduced air temperature and extensive cloud cover. The magnitude of the ambient air temperature decline was somewhat masked as this event coincided with markedly diminished flow (ca. 65 cfs).

More important and informative than the mean daily water temperatures were maximum daily water temperatures. Water temperatures between 12.4 and 33.1°C were recorded during the tenure of the study (Figure 8). Both the minimum and maximum 2003 water temperatures were recorded during low flow (i.e., <100 cfs). During these periods, maximum daily water temperatures were between 24.4-33.1°C while minimum daily water temperatures remained between 12.6-21.5°C.

Water temperatures in excess of 30°C were recorded at the study site on 10 dates in May-June 2003 compared with 29 days during that same period in 2002. After the final flow spike, maximum daily water temperature was <25°C on only one date, and ≤27°C on three days. For the remainder of the study period, maximum daily water temperature was generally between 28-32°C. The mean daily difference between minimum and maximum daily water temperatures after the final flow spike (7 June-1 July 2003) was 10.7°C. Conversely, mean daily difference between minimum and maximum daily water temperatures during the spawning (20-22 May) and final (30 May-5 June) flow spikes were only 6.7°C and 5.3°C, respectively.

COMPARISON OF 2001-2003 RESULTS

While flow in the river during the three-year study period (2001-2003) was relatively low, the drought conditions during the latter two years 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 (Figure 9). 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. Albeit relatively small and of short duration, the last spring snowmelt runoff 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 three 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 2001-2003 (Figure 10). Spawning occurred during early May in each of the three sampling years. 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.

The apparent length of the spawning season is likely misleading as the annual level of reproduction by Rio Grande silvery minnow is 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.

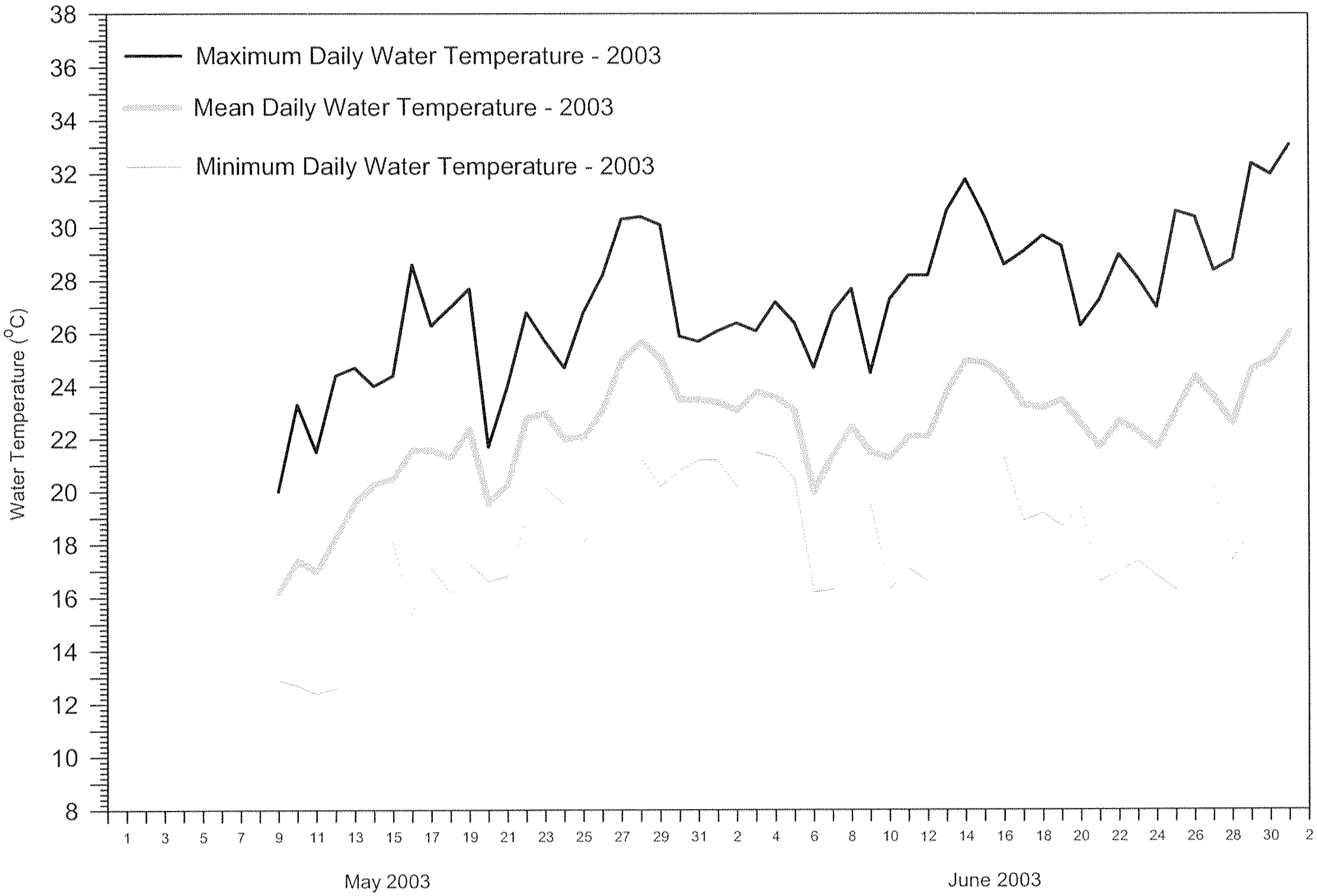


Figure 8. Maximum, mean, and minimum daily water temperatures at the study site during the 2003 study period.

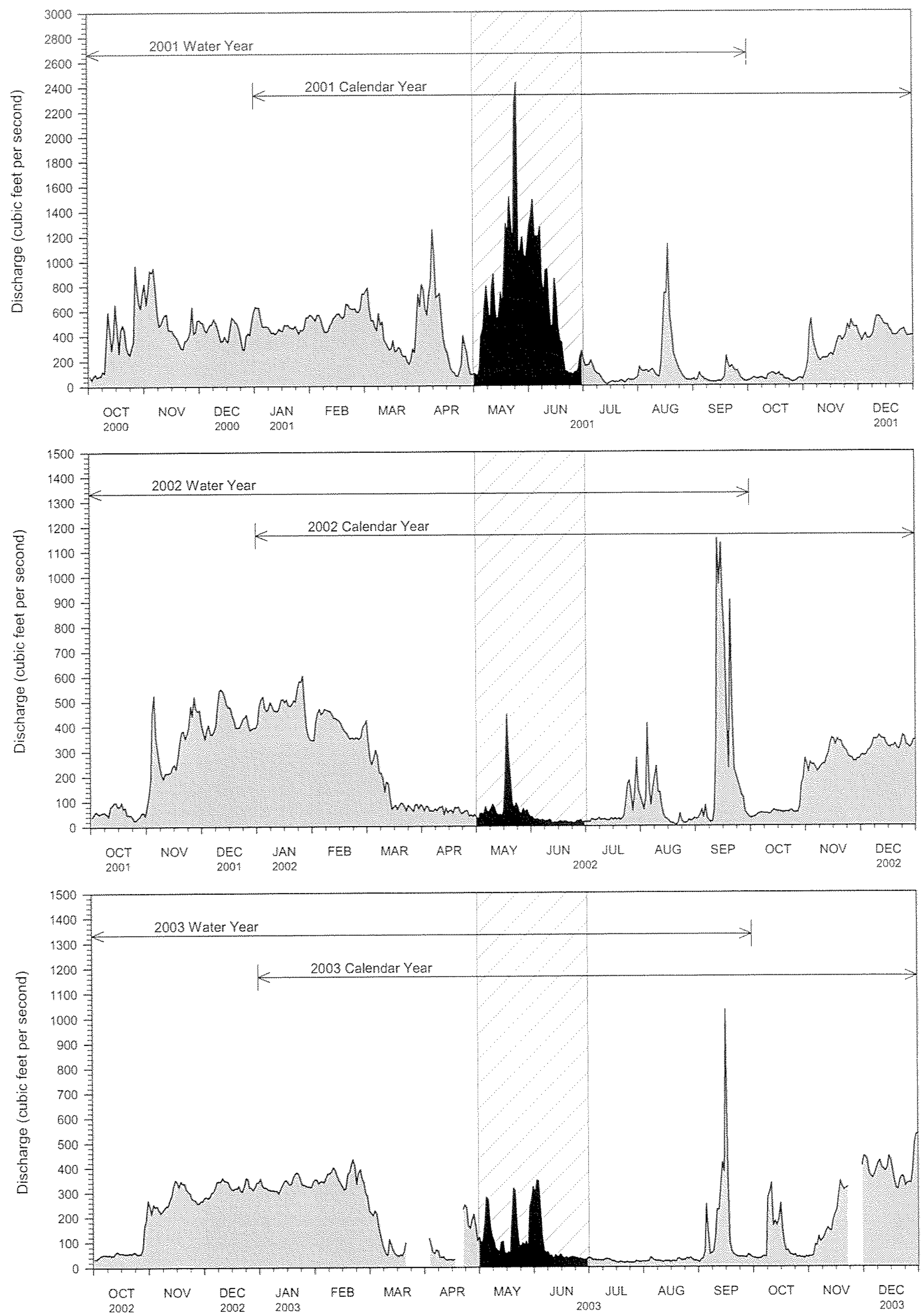


Figure 9. Annual hydrographs of the Rio Grande, New Mexico, at the San Marcial Railroad Bridge before, during, and after the 2001-03 Rio Grande silvery minnow reproductive monitoring study periods. Cross-hatching indicates annual study periods. Note 2001 Y-axis scale.

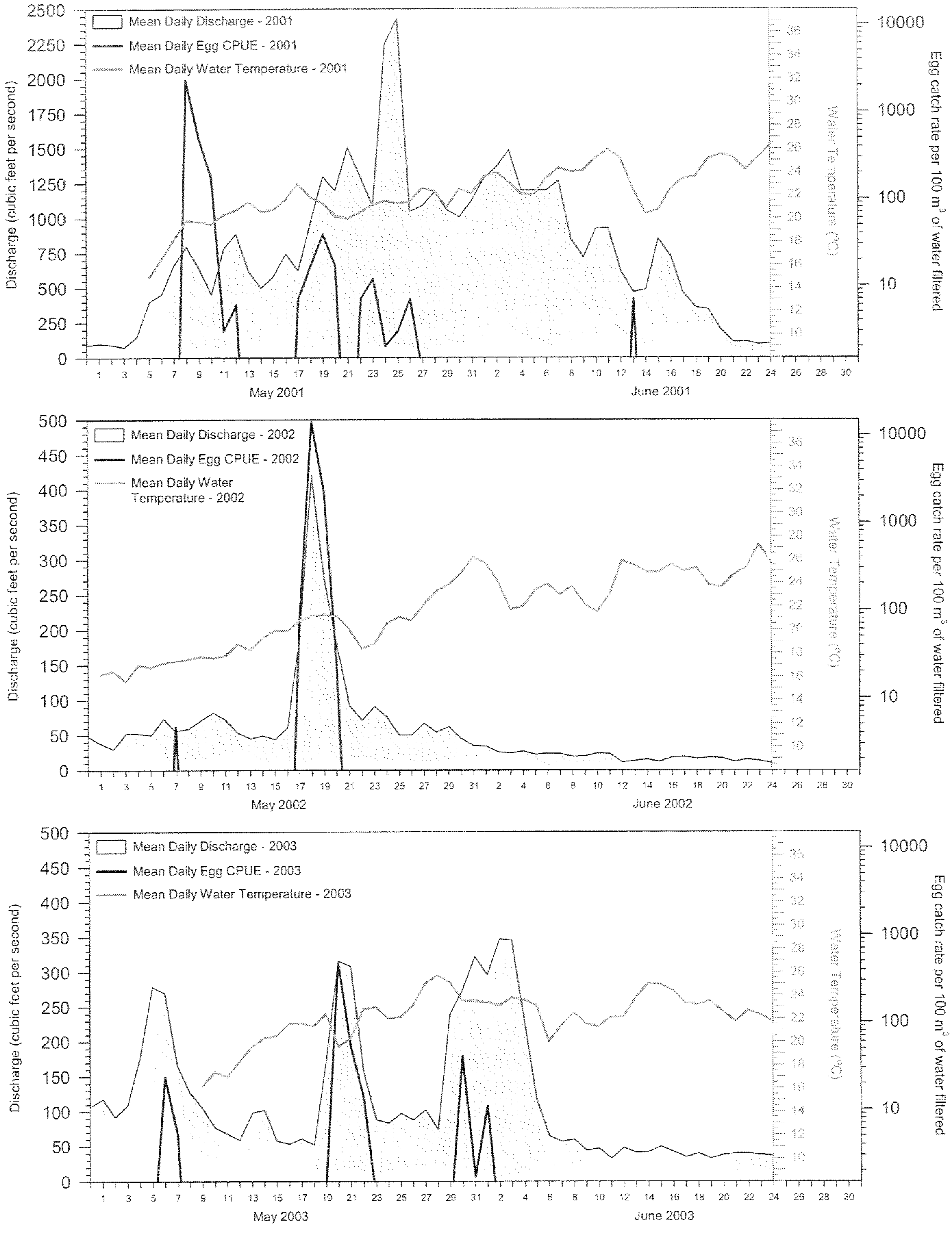


Figure 10. Mean daily discharge (San Marcial Railroad Bridge), mean daily egg catch rate, and mean daily water temperature during the 2001-03 Rio Grande silvery minnow reproductive monitoring study periods. Note 2001 Y-axis discharge scale and catch rate log-scale.

The 2003 effort yielded the lowest catch and cumulative catch rate recorded to date. In addition, catch rates during the principal 2003 spawning spike were also markedly lower than either of the two previous years of this investigation (Table 1). 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 is 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. The 2003 sampling effort consistently yielded the lowest catch rates during this study no matter the temporal variable incorporated in the analysis.

Table 1. Rio Grande silvery minnow reproductive monitoring program summary information on annual egg catch rates during 2001-2003.

	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

[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. Egg catch rates (CPUE) were calculated at three-hour intervals during the maximum spawning period (ca. three days). The 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-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). These data provide additional statistical validation to the marked decline in the reproductive output of Rio Grande silvery minnow as noted in the reproductive monitoring program for this species.

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 spawning period of Rio Grande silvery minnow observed in 2003 were higher (20-24°C) than recorded during previous years was likely the result of low flows and higher ambient temperatures.

Comparison of 2001-2003 water temperatures at the study site during May and June demonstrate relatively few differences in mean daily water temperatures across this period (Figure 11). The highest minimum daily water temperatures generally occurred 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 in 2001. 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 served to ameliorate water temperatures and minimize diel variation (Figure 12). 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.

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.

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 the eggs of these two 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

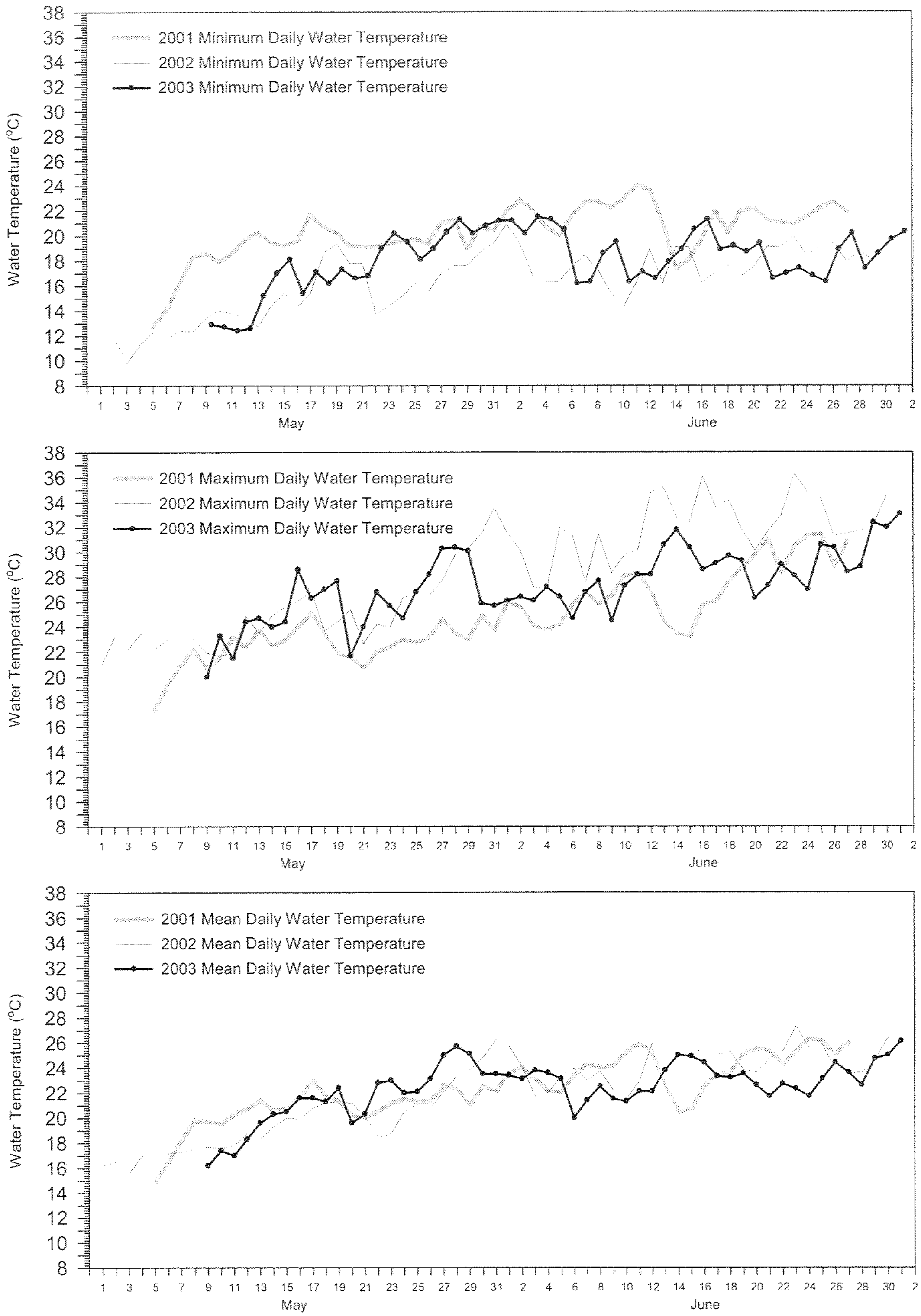


Figure 11. Comparisons of annual minimum, maximum, and mean daily water temperatures during the 2001-03 Rio Grande silvery minnow reproductive monitoring study periods.

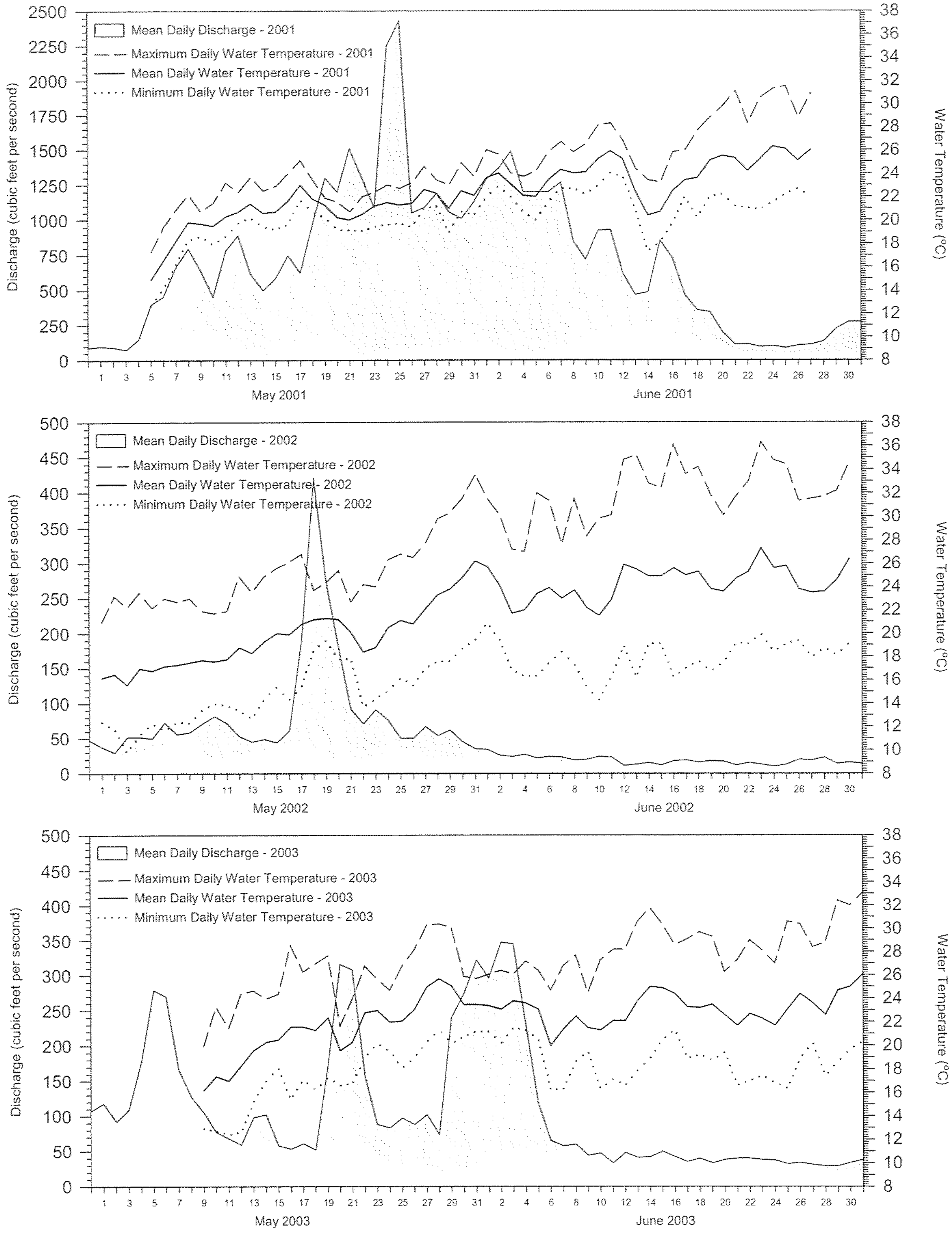


Figure 12. Mean daily discharge (San Marcial Railroad Bridge) and minimum, maximum, and mean daily water temperatures during the 2001-03 Rio Grande silvery minnow reproductive monitoring study periods. Note 2001 Y-axis discharge scale.

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.

Population monitoring efforts continue to document the dramatic decline of this species in the Middle Rio Grande. The 2003 monthly sampling efforts had produced only 167 individuals by May. These individual would have been members of the cohort that would have been capable of spawning in 2003. This was the lowest cumulative catch of Rio Grande silvery minnow recorded to date.

Given the extremely low numbers of adult silvery minnow present in pre-spawning 2003 samples, it is not surprising that the catch rate of Rio Grande silvery minnow was markedly lower in 2003 than during any of the previous egg collection activities. The relatively meager catch of eggs during 2003 further highlights the dismal status of this fish and brings into question its likelihood of survival in the wild. The declining trend of Rio Grande silvery minnow documented by both population and reproductive monitoring suggest that the 2004 catch of eggs will be even less than that of 2003. If 2004 spring flow conditions in the Middle Rio Grande return to a more normal level, the increased volume of water will likely translate to reduced catch rate due to dilution of the concentration of eggs. Under the aforementioned scenario, the catch rate of eggs during peak spawning would likely be one-two levels of magnitude lower than recorded in 2003.

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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Finally, we thank Lee E. Renfro (MSB) and Connor C. McBride who were stationed and worked at the collecting locality throughout most of the duration of this study. 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. Dr. M. D. Porter (USBR) and Hector Garcia (USBR) assisted with this project on several levels including assuming contract administration for the USBR.

LITERATURE CITED

Altenbach, C. S., Dudley, R. K., and S. P. Platania. 2000. A new device for collection drifting semibuoyant fish eggs. Transactions of the American Fisheries Society 129:296-300.

Bestgen, K. R., and S. P. Platania. 1990. Extirpation and notes on the life history of Notropis simus simus and Notropis orca (Cypriniformes: Cyprinidae) from the Rio Grande, New Mexico. Occasional Papers of the Museum of Southwestern Biology 6:1-8.

Bestgen, K. R., and S. P. Platania. 1991. Status and conservation of the Rio Grande silvery minnow, Hybognathus amarus. Southwestern Naturalist 36:225-232.

Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas, p. 155-165. In: Community and evolutionary ecology of North American stream fishes. W. J. Matthews and D. C. Heins (eds.). University of Oklahoma Press, Norman, Oklahoma.

Cross, F. B., O. T. Gorman, and S. G. Haslouer. 1983. The Red River shiner, Notropis bairdi, in Kansas with notes on depletion of its Arkansas River cognate, Notropis girardi. Transactions of the Kansas Academy of Science 86:93-98.

Cross, F. B., R. E. Moss, and J. T. Collins. 1985. Assessment of dewatering impacts on stream fisheries in the Arkansas and Cimarron rivers. University of Kansas Natural History Museum, Lawrence, Kansas.

Dudley, R. K., and S. P. Platania. 1999. 1997 population monitoring of Rio Grande silvery minnow. Submitted to the U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Dudley, R. K., and S. P. Platania. 2000. 1999 population monitoring of Rio Grande silvery minnow. Submitted to the U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Dudley, R. K., and S. P. Platania. 2001. 2000 population monitoring of Rio Grande silvery minnow. Submitted to the U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Dudley, R. K., and S. P. Platania. 2002. 2001 population monitoring of Rio Grande silvery minnow. Submitted to the U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Dudley, R. K., S. J. Gottlieb, and S. P. Platania. 2003. 2002 population monitoring of Rio Grande silvery minnow. Submitted to the U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Gold, R. L., and L. P. Denis. 1985. National water summary: New Mexico surface-water resources. U.S. Geological Survey Water-Supply Paper 2300:341-346.

Lagasse, P. F. 1985. An assessment of the response of the Rio Grande to dam construction--Cochiti to Isleta reach. A technical report for the U.S. Army Engineer District, Albuquerque, Corps of Engineers, Albuquerque, New Mexico.

Luttrell, G. A., A. A. Echelle, W. L. Fisher, and D. J. Eisenhour. 1999. Declining status of two species of the Macrhybopsis aestivalis complex (Teleostei: Cyprinidae) in the Arkansas River Basin and related effects of reservoirs as barriers to dispersal. Copeia 1999:981-989.

Platania, S. P. 1991. Fishes of the Rio Chama and Upper Rio Grande, New Mexico, with preliminary comments on their longitudinal distribution. Southwestern Naturalist 36:186-193.

Platania, S. P., and C. S. Altenbach. 1998. Reproductive strategies and egg types of seven Rio Grande Basin cyprinids. Copeia 1998:559-569.

Platania, S. P., and R. K. Dudley. 2002. Spawning periodicity of Rio Grande silvery minnow, *Hybognathus amarus*, during 2001. Submitted to the U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Platania, S. P., and R. K. Dudley. 2003. Spawning periodicity of Rio Grande silvery minnow, *Hybognathus amarus*, during 2002. Submitted to the U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Scurlock, D. 1998. From the rio to the sierra: An environmental history of the Middle Rio Grande Basin. General Technical Report RMRS-GTR-5. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Speirs, D. C., and W. S. C. Gurney. 2001. Population persistence in rivers and estuaries. Ecology 82:1219-1237.

Stanford, J. A., and J. V. Ward. 1979. Stream regulation in North America, p. 215-236. In: The ecology of regulated streams. J. V. Ward and J. A. Stanford (eds.). Plenum Press, New York, New York.

U.S. Department of the Interior. 1994. Endangered and threatened wildlife and plants: final rule to list the Rio Grande silvery minnow as an endangered species. Federal Register 59: 36988-36995.

U. S. Fish and Wildlife Service. 1999. Rio Grande silvery minnow Recovery Plan. Albuquerque, New Mexico.

Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120:98-105.

APPENDIX I:

Rio Grande silvery minnow spawning periodicity study 2003

World-Wide-Web pages

URL: http://msb-fish.unm.edu/rgsm2003/Egg_Salvage/index.html