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NM WRRI Technical Completion Report No. 401

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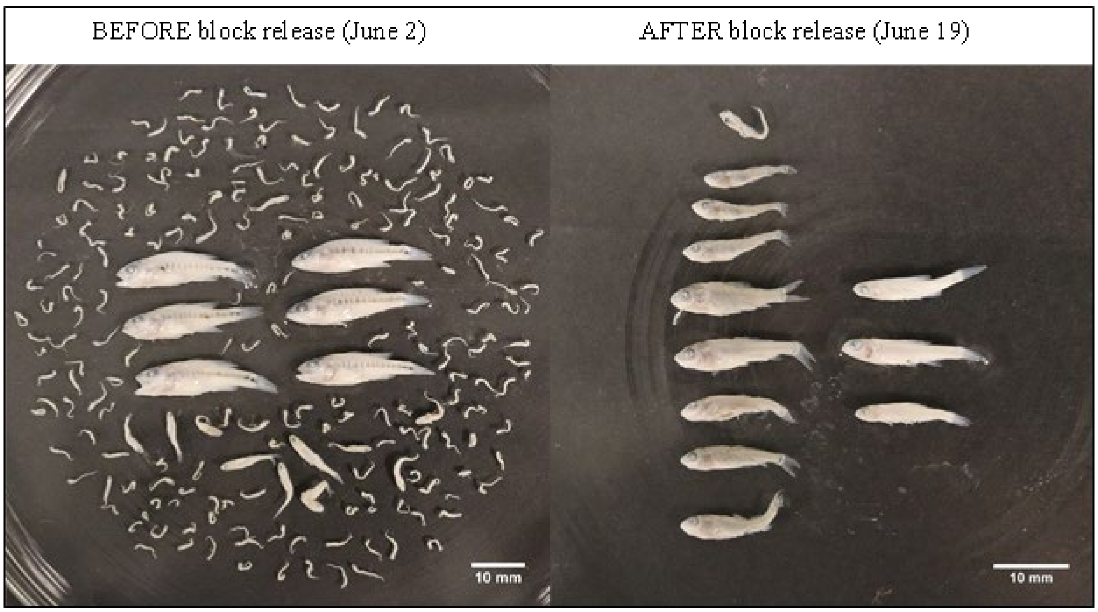

A visual comparison of the abundances, diversities, and size distributions of fish larvae and juveniles collected in a single drift net immediately before and after the June 2020 block release at the Bosque Redondo site.

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ABSTRACT

Extreme drying and water management practices threaten the persistence of native fishes across the American Southwest. We designed this study to monitor the effects of reservoir block releases on the reproductive success of fishes in the middle Pecos River near Fort Sumner, New Mexico. We intensively surveyed fish adults, drifting eggs, and drifting larvae from April through August 2020. We found species responded differently to the single reservoir block release during June 2020. The block release interrupted the production of eggs and larvae by native River Carpsucker and Sand Shiner. However, nonnative Common Carp juveniles were present in the river immediately after the release. Nonnative Plains Minnow, which were the most abundant pelagic-spawning minnows at our site, decreased in abundance and body condition after the block release. Surprisingly, we collected only 34 native adult pelagic-spawning minnows, 19 eggs, and no larvae. These patterns confirm that the broader regional observation of ecological reshuffling in favor of nonnative species is also well underway in fish communities of the middle Pecos River. To mitigate further collapse of native species, we recommend water managers consider releasing pulsed blocks of water downstream that more closely mimic the historical hydrology of the river in which native species evolved.

Keywords: reservoir releases, streamflow, fish eggs, fish larvae, drift survey, spawning condition, pelagic-spawning minnows

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INTRODUCTION

Human activities increasingly imperil native fishes of the American Southwest (Dudley and Platania 2007; Worthington et al. 2014; Ruhí et al. 2016). Dam construction has decreased mean annual stream flow, muted the intensity of high and low flow events, and changed the seasonal timing and frequency of high stream flows (Costigan and Daniels 2012). Likewise, global CO_2 emissions are increasing regional aridification, decreasing snowmelt contributions to headwaters, and increasing uncertainty in streamflow predictions (Chavarria 2017; Jones and Gutzler 2016). These ongoing disturbances are changing the physical habitat of New Mexico streams, replacing native fish communities with nonnative assemblages (Ruhí et al. 2016). Pelagic-spawning minnows are particularly threatened by current environmental conditions, because they are adapted to the historically volatile hydrological regimes of shallow, braided rivers across the Great Plains (Worthington et al. 2014). These minnows are increasingly replaced by problematic carp, catfishes, and sunfishes that thrive in the slower, warmer, and less oxygenated pools of regulated streams (Ruhí et al. 2016).

The long-term goal of our research program in the Pecos River was to quantify the effects of ongoing physical habitat alterations on its fish community dynamics. We were especially interested in monitoring the reproductive success of pelagic-spawning minnows relative to current hydrological regimens. In August 2018, we established a long-term survey at two sites in the Pecos River to quantify seasonal fish community dynamics by collecting drifting eggs and larvae. In 2019, we sampled from April through August and expanded our survey methods to include use of light traps to capture larvae in deep, slow-moving pools and side channels.

Discharge patterns in the Pecos River are highly regulated by a series of dams. Low-order, unregulated streams are typically flashy, having brief events of extremely high flow followed by quick returns to baseflow. The Pecos River, by contrast, is characterized by stable minimum flows between prolonged high discharge events from its reservoirs, each lasting days to weeks. In eight of the past ten years, at least one prolonged reservoir water release occurred during peak fish spawning months of April through August. Over the past six years, two releases typically occurred: one during early to mid-May, and a second during late June to early July. During 2019, we sampled fish eggs and larvae using drift nets one day before and one day after a two-week reservoir water release that lasted from May 13 through May 27. Using equal effort, we collected 489 fish eggs and 288 larvae before the event, and only 23 eggs and 11 larvae after the event.

Reservoir block releases dramatically alter the physical habitat of the Pecos River, which may impact reproductive timing and effort by native and nonnative fishes. The onset of high flow events may mimic natural storm events that serve as spawning cues for pelagic-spawning minnows. Alternately, the decrease in temperature and water transparency may delay reproductive development for some species. Moreover, the survival and growth of eggs and larvae produced during extended reservoir releases is unknown. In 2020, we sought to fill these knowledge gaps by quantifying the effects of reservoir block releases on adult spawning movements, drifting egg and larval densities, and survival of larvae relative to block releases.

METHODS

Study Sites

The Pecos River flows south through eastern New Mexico and west Texas, where it ultimately meets the Rio Grande. Endemic fauna evolved in this shallow, braided river system under selection pressures associated with prolonged drought punctuated by intense flooding during spring snowmelt and summer monsoons (Costigan and Daniels 2012). These conditions no longer exist in the river, and thus endemic fauna are ironically maladapted to its current hydrology (Dudley and Platania 2007). Three major dams were constructed along the river in New Mexico (i.e., Sumner in 1937, Santa Rosa in 1981, Brantley in 1989), from which managers annually release week-long blocks of water downstream during midsummer to meet the needs of downstream users. Steady release from upstream dams maintains base flows at 20–100 cfs, which increase to 1,000–1,500 cfs during block releases.

We surveyed two sites in the middle Pecos River during 2020. The downstream site was below Sumner Dam in Bosque Redondo Park (BR) near the city of Fort Sumner (WGS84 34.4248, -104.2201). The upstream site was midway between Santa Rosa and Sumner dams in the village of Puerto de Luna (PDL; WGS84 34.8267, -104.6256; Figure 1). We sampled from April through August at least twice monthly at BR. Unfortunately, we sampled PDL only once during May 2020 because of travel restrictions caused by the COVID-19 pandemic.

Measuring Physicochemical River Conditions

During each site visit, we recorded environmental conditions as possible correlates of fish egg and larval drift densities. We measured turbidity with a HACH 2100Q Portable Turbidimeter (HACH, Loveland, CO). We used a HACH Pocket Pro+ Multi 2 Tester to measure salinity, conductivity, and pH. We permanently deployed Onset HOBO dataloggers (Model MX2202, Onset, Bourne, MA) in the stream channel at BR to record temperature once each minute. Stream discharge measurements were downloaded from the nearest USGS gauging stations (USGS 2021).

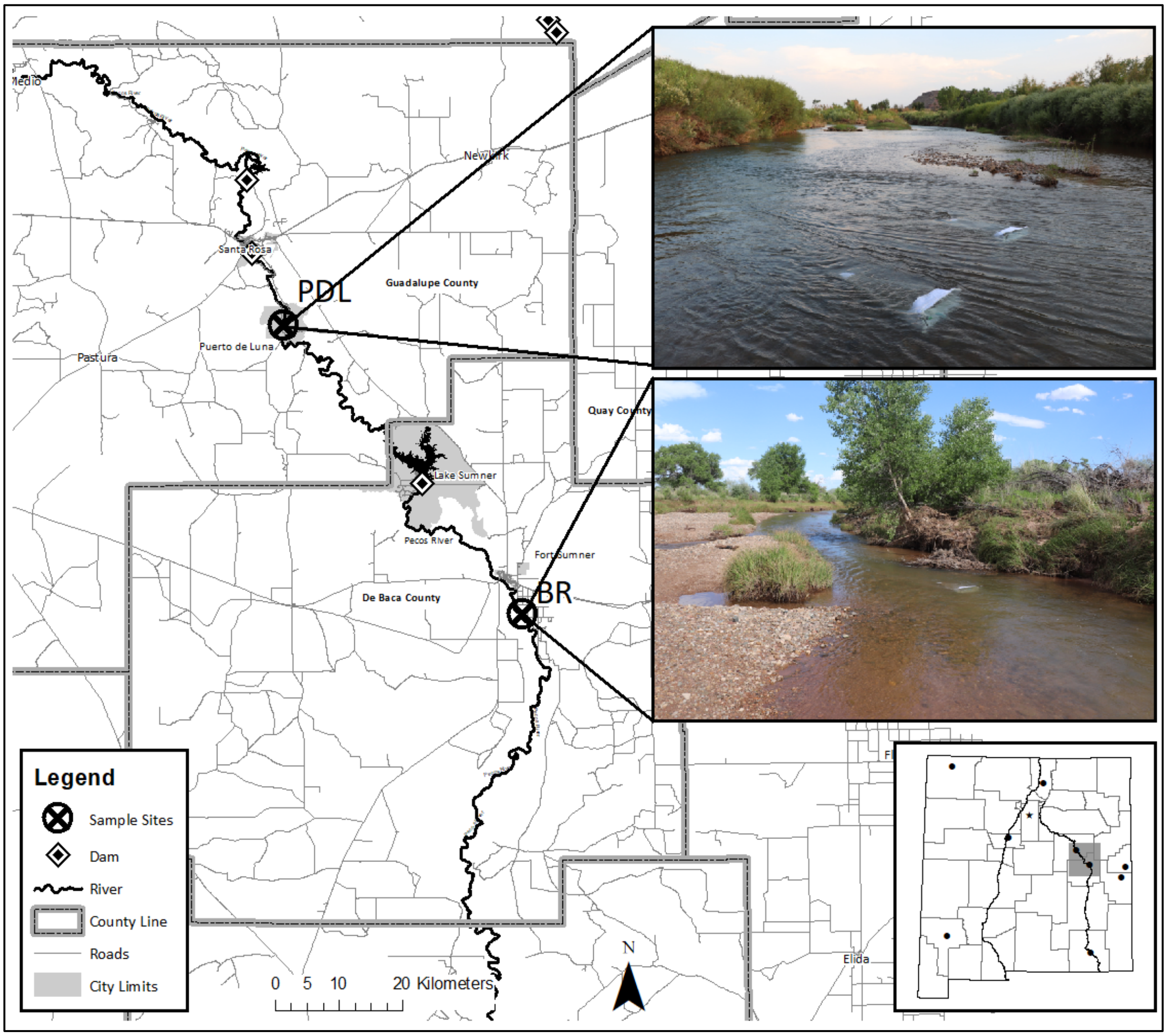

Figure 1. Locations of our collection sites along the middle reach of the Pecos River in New Mexico. The upstream location was at Puerto De Luna (PDL) and the downstream location was at Bosque Redondo (BR). The inset photographs demonstrate how the drift nets were deployed at each site.

Surveying Abundances and Body Conditions of Adult Fishes

Adult and juvenile fishes were collected using two backpack electrofishers (Model LR-20B, Smith-Root, Vancouver, WA). Backpack electrofishing was performed in the morning or late afternoon using 15 cm aluminum anode rings and coarse settings of 60Hz frequency, 50% duty cycle, 120V voltage. Settings were finely adjusted throughout the field season to account for changes in conductivity and fish responses to the electric fields. All shallow (< 0.8 m deep), accessible habitats were surveyed within the 800 m study reach (Figure 2).

Figure 2. Aerial photograph of the Bosque Redondo (BR) sampling site below Sumner Dam on the Pecos River. The upper and lower limits of the study reach, where adult fish sampling occurred, have been marked with rectangles. Stream drift net surveys were performed at the downstream limit with approximate net locations indicated with circles. The image is from the National Agriculture Imagery Program and was captured on May 21, 2020.

Adult fish collections were performed using a two-person crew equipped with backpack electrofishing units that surveyed independently. All collected specimens were held in buckets equipped with battery-powered aerators, identified to species level, and counted. Specimens of select species of interest (Sand Shiner *Notropis stramineus*, Red Shiner *Cyprinella lutrensis*, Plains Minnow *Hybognathus placitus*, and Speckled Chub *Macrhybopsis aestivalis*) were measured to the nearest 0.1 mm total length and wet weight to the nearest 0.1 g. Specimens were identified as female if they expressed ova and/or had exceptionally distended abdomens characteristic of gravid females (Figure 3). Males were identified if they expressed milt and/or displayed spawning characters unique to males (e.g., breeding tubercles and colors of male Red Shiner). Gravid females and mature males of the target species were transported to and stored in aquaria at Eastern New Mexico University. These fishes were measured and weighed in the field or in the laboratory within days.

Figure 3. Examples of sexually mature fishes collected during the summer 2020 field season at the Bosque Redondo (BR) site in the Pecos River using backpack electrofishers. The Plains Minnow (PM) and Sand Shiner (SS) are both gravid females (note the distended abdomens). The Red Shiner (RS) is a large mature male in spawning condition with breeding tubercles and brightly colored fins.

Total length (TL) and wet weight (WW) measurements of target species were used to determine the relative body conditions of individuals. TL and WW were $\log_e$-transformed to fit the linear form (Equation 2) of the general power model (Equation 1) for each species:

$$WW = a\ TL^b \quad \text{......... Equation 1}$$

$$\ln WW = \ln a + b \ln TL \quad \text{......... Equation 2}$$

wherein ln WW is the natural log of WW, ln a and b are constants estimated by linear regression, and ln TL is the natural log of TL (Wootton 1998). The predicted wet weight (WW_{pred}) for each individual was calculated from its observed TL using Eq. 1 with species specific constants. Relative body condition factor (K_n) was then calculated as the ratio between the observed and predicted weight:

$$K_n = WW_{obs} / WW_{pred} \quad \text{......... Equation 3}$$

wherein WW_{obs} is the observed wet weight, and WW_{pred} is the predicted weight for that individual based on its TL (LeCren 1951). K_n values can be compared through time within a population to interpret shifts in body weight associated with spawning activities (LeCren 1951; Thomas 1969). K_n values > 1 were interpreted as individuals in excellent body condition for spawning, whereas individuals with values < 1 having relatively poor condition. K_n values for each species were plotted through time to interpret seasonal patterns in spawning activities. Mann-Whitney U tests were used to statistically compare K_n values of each species before and after reservoir releases, and to compare K_n values between sexes. All individuals collected before and after the release were pooled for all tests. We did not compare K_n values immediately before and after the release due to small sample sizes.

Collecting Drifting Fish Eggs and Larvae

At each sampling site and date, we deployed sets of three standard drift nets (500 µm mesh; 46 x 30 x 100 cm), each equipped with a mechanical flow meter (General Oceanics Model 2030, General Oceans, Inc., Miami, FL). Each net was positioned vertically using metal stakes so that the bottom of the mouth frame touched the gravel substrate and the top of the frame was at the water surface. Nets were deployed immediately after sunset at around 2100 hours, which we previously determined was the peak timing of drifting fish eggs and larvae in the river. We visually checked all nets for clogging at 10 min intervals and ended the deployments after 20–30 min. For each set, we usually placed the drift nets in the middle of the main reach in a longitudinal series (one upstream, mid-stream, and downstream), because the stream was often too shallow to set the nets across the stream in one transect.

Figure 4. Example of a drift net deployed at the Bosque Redondo (BR) field site. Each net was fitted with a mechanical flow meter to quantify filtered volumes.

We calculated filtered volume by multiplying the net mouth area by the filtered distance from flow meter readings. In cases wherein the flow meter failed or became wrapped by debris, we reported densities based on the area of the net mouth and sampling time (i.e., areal densities). When we retrieved each net, we rinsed and transferred the contents into a sampling cup, and rapidly chilled the contents by immersion in an ice bath to euthanize fish eggs and larvae. We then passed the contents through a 64 µm mesh sieve to remove all water and preserved the samples in 90% denatured ethanol (changed once after 24 hours). In the laboratory, we used an LED light pad to visually sort all fish eggs and fish larvae from each sample. Eggs and larvae were photographed with a high-resolution digital camera (Canon Rebel T7i, Canon, Oita, Japan) under a stereomicroscope (Wild M5A, Wild Heerbrugg, Heerbrugg, Switzerland) and to measure sizes from photographs in ImageJ (NIH, Bethesda, MD). All sorted specimens were stored in glass vials using 90% denatured ethanol at -20 °C.

We subsampled morphologically distinct eggs and larvae collected throughout the 2020 season to confirm their species-level identities using the barcoding region of the cytochrome *c* oxidase subunit I mitochondrial gene (i.e., the COI DNA barcode; Ivanova et al. 2007; Hubert et al. 2008). Genomic DNA was extracted from whole specimens using Qiagen DNeasy spin-column kits (Qiagen, Germantown, MD). The COI DNA barcode was amplified using the methods and universal primer sets outlined by Ivanova et al. (2007). Raw PCR products were sent to GeneWiz (South Plainfield, NJ) for enzymatic cleanup and Sanger sequencing using forward and reverse primers. Sequencing results were visually inspected, trimmed, and aligned to generate a consensus sequence for each specimen using BioEdit (Hall 1999). The finest taxonomic resolution possible was assigned by comparison to reference sequences of vouchers in BOLD (Ratnasingham and Hebert 2007).

Survival of Eggs and Larvae Relative to the Reservoir Block Release

We sampled the BR site within 24 hr before a reservoir release and within 24 hr after the river returned to base flow. To infer the effects of the reservoir release event on fish eggs and larvae, we compared the numbers and diversity of fish eggs and larvae before and after the event. We also quantified the hatch dates of any larvae collected immediately after the event to determine if they were hatchedbefore or during the event. Otoliths were removed, mounted to glass slides using thermoplastic adhesive, and imaged under a compound light microscope at 400–1000x magnification. Daily otolith growth increments were counted from images using ImageJ (Schneider et al. 2012).

DISCUSSION OF RESULTS AND THEIR SIGNIFICANCE

Due to travel restrictions imposed by Eastern New Mexico University in response to the COVID-19 pandemic, we visited the PDL site once on May 26, 2020. We collected no fish eggs or larvae in the drift nets we deployed on that date. We also did not electrofish at the PDL site. Thus, all subsequent results reflect our focused sampling efforts at the BR site only.

Physicochemical River Conditions

Aside from the June block release, the physicochemical variables in the river were largely invariant from April through August 2020 (Figure 5). Seasonal water temperatures generally followed daylength. Discharge of about 40–100 cfs near our BR study site (below Taiban Creek; USGS 08385522) was maintained by steady release from Sumner Dam upstream (USGS 08384500; USGS 2021). During baseflows, water temperatures oscillated about 5 °C during a diel cycle and turbidities were 4–42 NTU. Discharge from Sumner Dam increased from 100 to 1320 cfs in 30 min on June 3. The water block reached the BR site about 12 hr later, when discharge increased near our site from 48 to 1,160 cfs over the next 10.5 hr and remained at about 1,175 cfs for 16 d (USGS 08385522). On June 18, dam discharge was dropped back to baseflow in 30 min (USGS 08384500) and discharge near our site dropped from 1,120 to 110 cfs over 15 h (USGS 08385522). During the release, water temperature was cooler, diel temperature fluctuations were smaller, and sediment turbidity increased to 155 NTU. The block release also lowered both the conductivity and pH of the river (Figure 5).

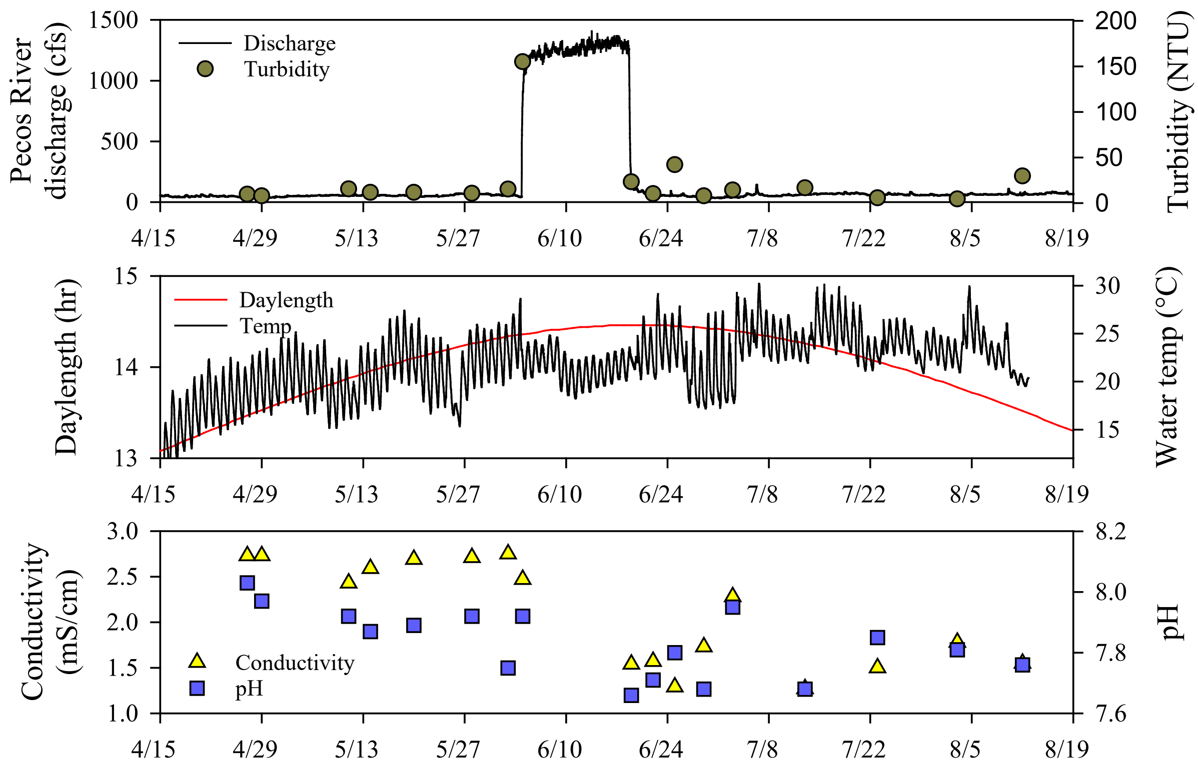

Figure 5. Summary of physicochemical conditions in the Pecos River at the Bosque Redondo (BR) site during 2020. Discharge measurements are reported from USGS 08385522 near Taiban Creek.

Abundances and Body Conditions of Adult Fishes

In total, 2,928 fishes representing 19 species and 8 families were collected from March through August 2020 during backpack electrofishing surveys at the BR site. (We did not electrofish at PDL). Among adults of target species, 38.9% were Sand Shiner (N = 1,137), 25.5% were Red Shiner (N = 746), 12.8% were Plains Minnow (N = 374), and 1.0 % were Speckled Chub (N = 29). Sand Shiner and Red Shiner were common across all dates (Figure 6). Sand Shiner, Red Shiner, and Plains Minnow were the three most common species collected before the June reservoir release. Plains Minnow abundance decreased dramatically after the June release and remained at low levels for the rest of the collection season. Speckled Chub were always rare, but peaked in late June.

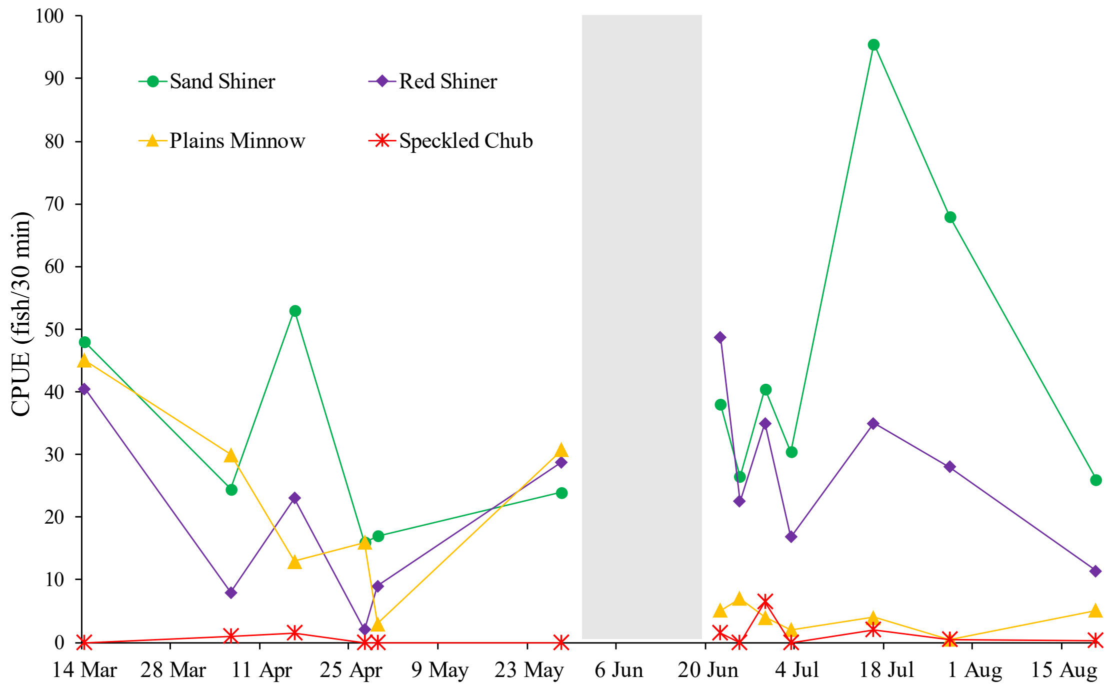

Figure 6. Comparisons of the relative abundances of target species collected by electrofishing at the Bosque Redondo (BR) site in the Pecos River during 2020. The gray box represents the timing of the June Sumner Dam block release.

Relative body conditions (K_n values) of both Plains Minnow (Mann-Whitney U, $U_{(179)}$ = 3192, $P < 0.01$) and Sand Shiner (Mann-Whitney U, $U_{(180)}$ = 3663.50, $P < 0.01$) declined after the June reservoir release (Figure 7). By contrast, Speckled Chub K_n values were marginally higher after the reservoir release ($U_{(27)}$ = 24, P = 0.06) and Red Shiner K_n values were not different before and after the release ($U_{(163)}$ = 3160.50, P = 0.15). The highest observed K_n values for Plains Minnow, Red Shiner, Sand Shiner, and Speckled Chub occurred on May 28, April 29, April 29, and July 16, respectively.

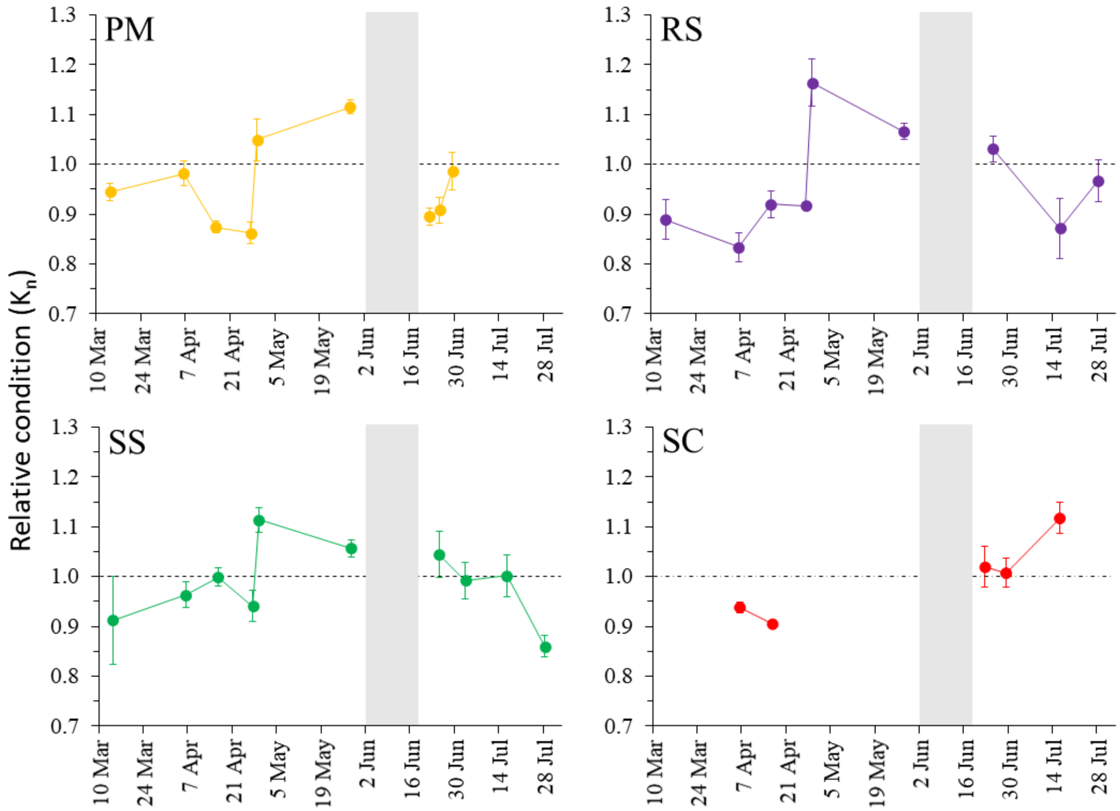

Figure 7. Comparisons of the relative body conditions (K_n values) of target species (PM = Plains Minnow, RS = Red Shiner, SS = Sand Shiner, SC = Speckled Chub) collected by electrofishing at the Bosque Redondo (BR) site in the Pecos River, 2020. The gray box represents the timing of the June Sumner Dam reservoir release. Symbols represent mean ± standard error of the mean (SEM). The horizontal reference lines at "1" represent fish with average weight at length and hence in average condition for that population.

Densities of Drifting Fish Eggs and Larvae

We collected 4,389 fish eggs over 15 dates at BR. The distribution of egg diameters was unimodal with an extended right tail consisting of rarer, relatively large eggs (Figure 8). The median egg diameter was 1.10 mm. The largest and smallest diameters of eggs collected were 0.62 mm and 3.13 mm, respectively. About 85% of all eggs collected (N = 3,753) had diameters between 0.80 and 1.40 mm. Pelagic-spawning minnow eggs (N = 19) were visually distinguished from all other eggs by having a distinct perivitelline space, and in several cases a developing embryo was visible. All remaining eggs were generally opaque.

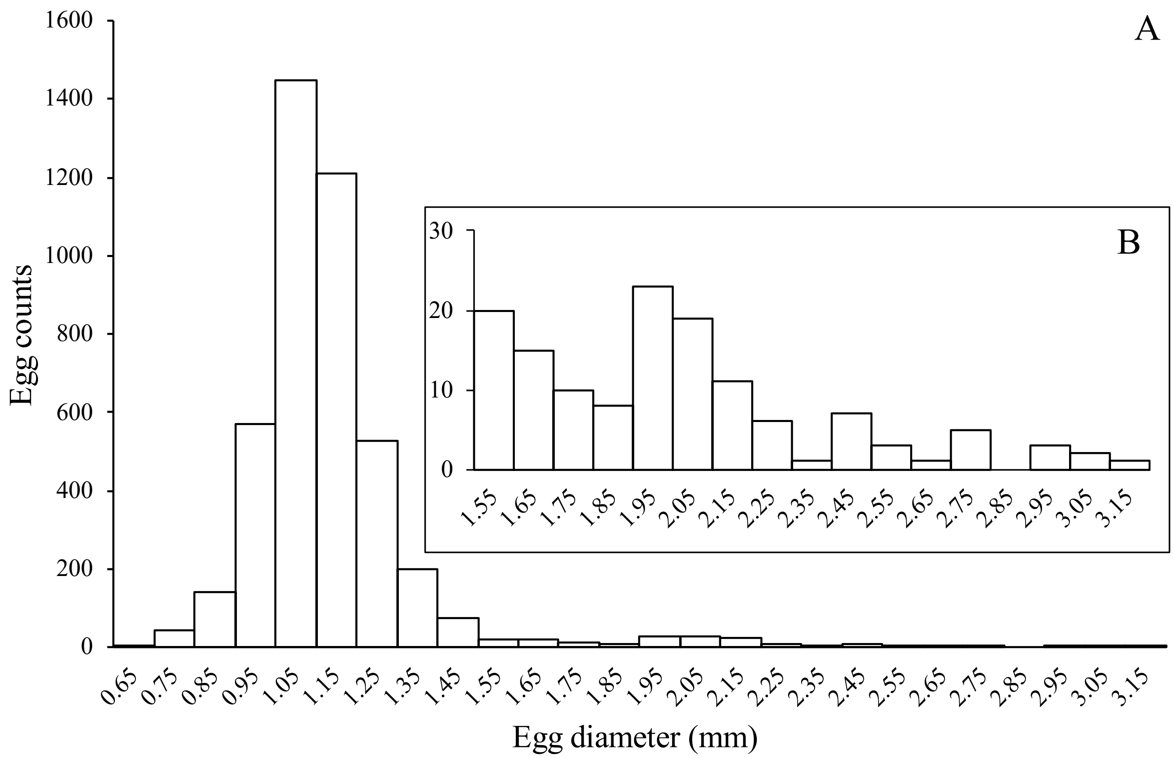

Figure 8. Size distribution of all drifting eggs (N = 4,389) collected from the Pecos River at the Bosque Redondo (BR) site during the 2020 sampling season (A) with an insert (B) showing the right tail of the size distribution, rescaled to improve resolution.

Using DNA barcoding, we identified 84 Sand Shiner eggs, 40 River Carpsucker (*Carpiodes carpio*) eggs, 12 Speckled Chub eggs, and 1 Suckermouth Minnow (*Phenacobius mirabilis*) egg. The largest uniformly opaque eggs were River Carpsucker, and the large eggs with a distinct perivitelline space were all Speckled Chub. Sand Shiner eggs were dominant across all sampling dates, but decreased after the reservoir release (Figure 9; Mann-Whitney U test, $U_{(15)} = 48$, $P = 0.02$). River Carpsucker eggs also dropped after the release (Mann-Whitney U test, $U_{(15)} = 38$, $P = 0.03$). Speckled Chub egg densities again were rare, but increased one week after the reservoir release ended and on the last day of sampling in August.

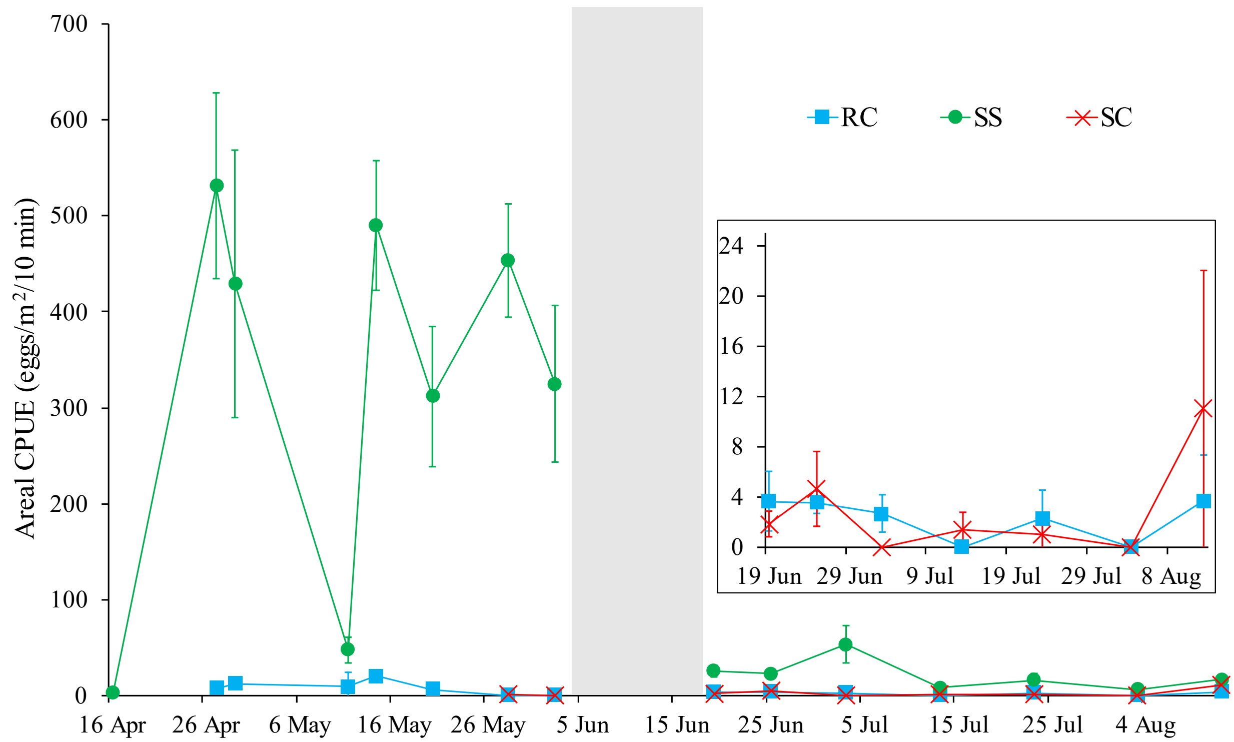

Figure 9. Comparisons of areal catch per unit effort (CPUE) (eggs/m^2/10 min) of eggs of Sand Shiner (SS; green), River Carpsucker (RC; blue) and Speckled Chub (SC; red) relative to the June Sumner Dam reservoir release (gray box) (A) on the Pecos River. The inset panel (B) shows only the period after the June release with Sand Shiner removed to clarify patterns in Sand Shiner and River Carpsucker egg densities. Symbols represent mean ± SE. All eggs were collected at the Bosque Redondo (BR) site during the 2020 sampling season.

We collected 8,822 larvae at BR during 2020. Species-level sorting and identification of larvae is ongoing (using morphology and DNA barcoding). To date, we have barcoded 65 larval fishes and 32 vouchers (6 juveniles and 26 adults) representing most of the common fishes we sampled by electrofishing. Overall, larval densities increased up to the June reservoir release, dropped dramatically immediately following the release, and then peaked again within two weeks after the release (Figure 10). Larval densities continued to decline through July into August. Our early results reveal the April peak of larvae was Common Carp (*Cyprinus carpio*), following by a peak of River Carpsucker and several true minnows (i.e., lueciscids) in May. River Carpsucker larvae dropped to zero immediately following the June block release, but thereafter rebounded and peaked 1–2 weeks later. Drifting juvenile catfishes (Flathead Catfish *Pylodictis olivaris* and Channel Catfish *Ictalurus punctatus*) peaked in late July and into August.

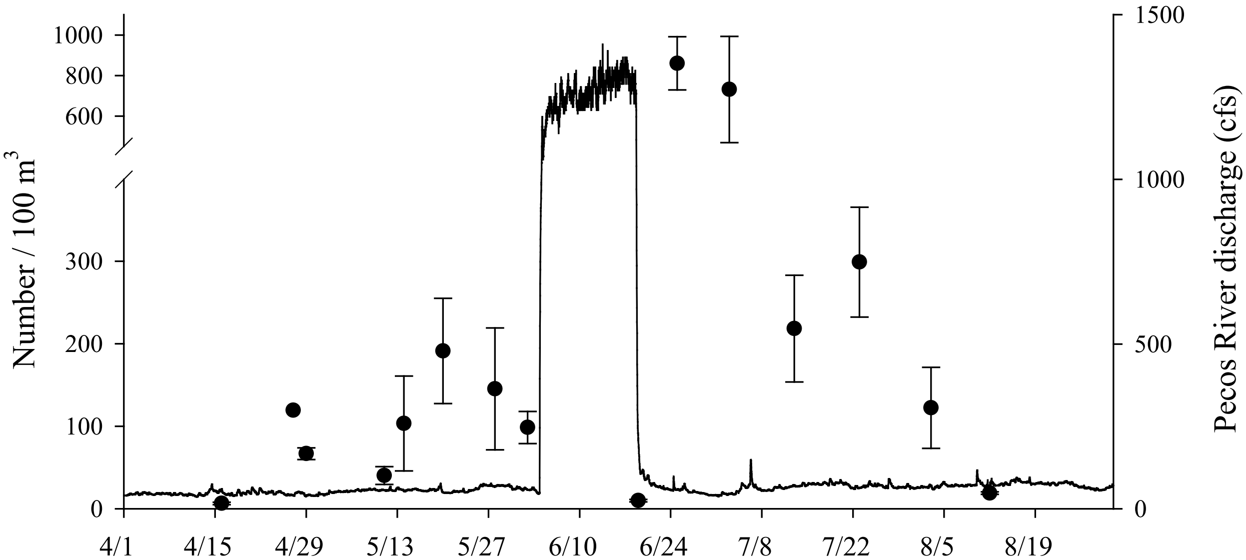

Figure 10. Seasonal pattern of larval fish drift densities at the Bosque Redondo (BR) site during 2020 relative to river discharge. Drift densities symbols represent mean ± SE. Discharge measurements are reported from USGS 08385522 near Taiban Creek.

Survival of Eggs and Larvae Relative to the Reservoir Release

We quantified the effects of the block release on reproductive effort by fishes in two ways. First, we directly compared the densities of eggs and larvae immediately before and after the release on June 2 and 19, respectively. Second, we used otolith growth increments to determine the birthdates of larvae collected on June 19. We collected 355 and 55 eggs before and after the release, respectively. Drifting egg densities dropped from 85 ± 19 (mean ± SE) to 16 ± 19 eggs/100 m^3. Based on measured sizes, most eggs were likely Sand Shiner, followed by River Carpsucker. Likewise, the density, composition, and size distributions of larvae differed before and after the release (Figure 11). We collected 417 and 33 larvae/juveniles before and after the block release. Drifting larval/juvenile densities dropped from 99 ± 19 to 10 ± 1 fish/100 m^3. Before the release, most larvae were River Carpsucker, followed by a mix of larval and juvenile true minnows (leuciscids), plus several juvenile Spotted Bass (*Micropterus punctulatus*). After the release, there were only juvenile Common Carp and Sand Shiner (Figure 11).

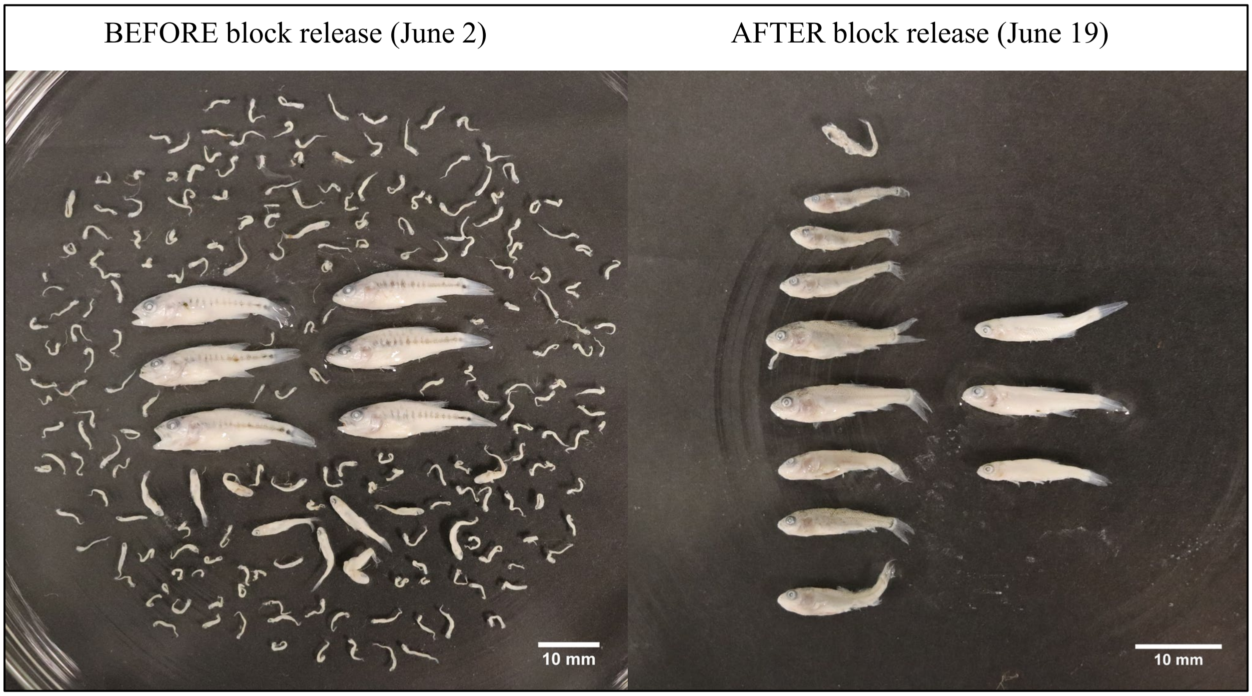

Figure 11. A visual comparison of the abundances, diversities, and size distributions of fish larvae and juveniles collected in a single drift net immediately before and after the June 2020 block release at the Bosque Redondo (BR) site. Before the release, there was a mix of larval River Carpsucker, true minnows, and juvenile Spotted Bass. After the release, there were only juvenile Common Carp and Shiner.

The size distributions and ages of the drifting fishes were strikingly different before and after the block release. Before the release, most drifters were larval River Carpsucker and true minnows < 8.25 mm (N = 387), with fewer larger larvae and juveniles (N = 30). After the release, there were zero drifters < 8.25 mm (Figure 12). The 33 larger drifters were all Common Carp and Sand Shiner. Early aging results of a representative subsample of 8 post-release fishes revealed these individuals were 9–41 days old and were born either before or during the first week of the block release (Figure 13). Their natal origin is unknown.

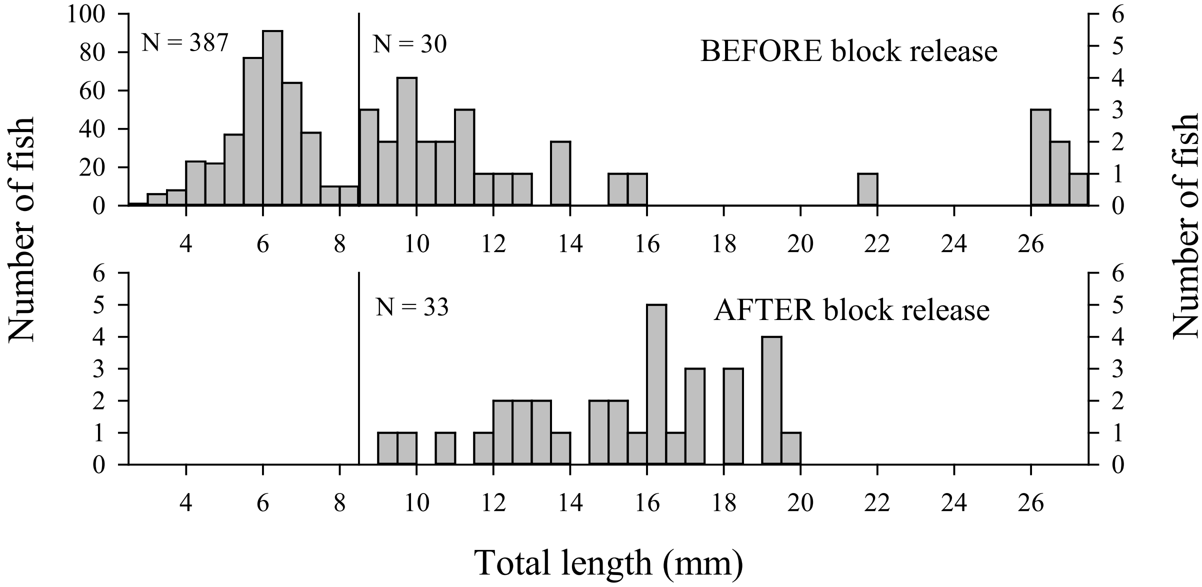

Figure 12. Comparison of the size distribution of larval and juvenile fishes captured in drift nets before and after the June 2020 block release at the Bosque Redondo (BR) site. The larval fishes < 9 mm before the release were almost entirely River Carpsucker.

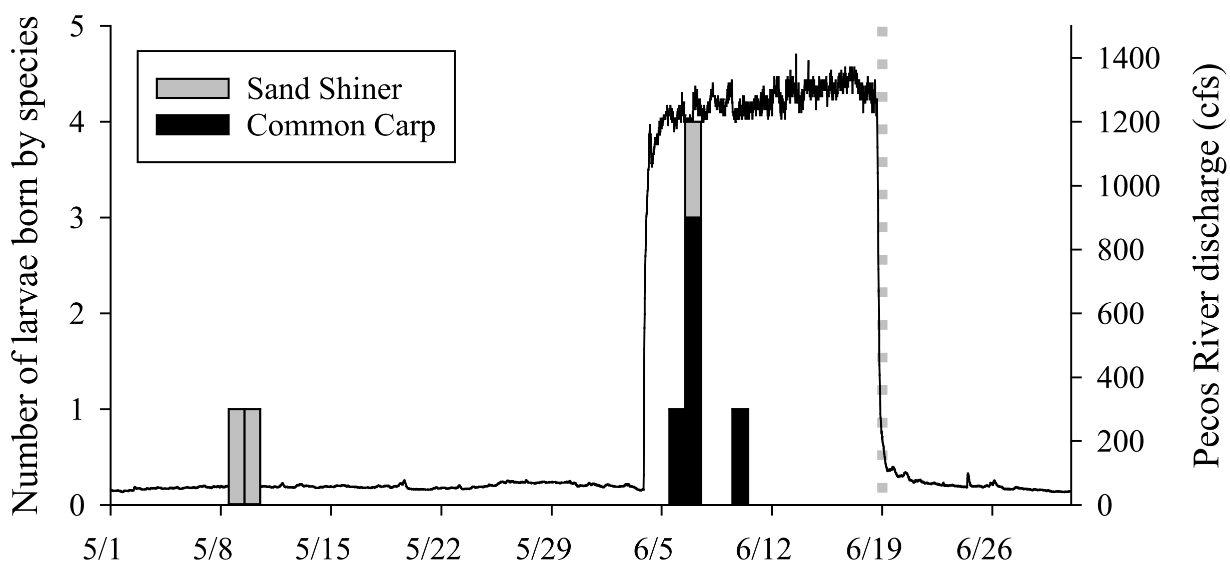

Figure 13. Birth dates of an early subsample of juvenile Sand Shiner and Common Carp collected in drift nets on June 19, 2020, immediately after the block release. Note that none of the fish were less than a week old, and some Sand Shiner were much older, advanced juveniles.

PRINCIPAL FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Many studies have documented ecological collapse of native fishes across the American Southwest in response to habitat fragmentation and climate change (Perkin et al. 2014; Worthington et al. 2014; Hoagstrom and Turner 2015; Ruhí et al. 2016; Haworth and Bestgen 2017; Pennock et al. 2017). During 2020, we completed the most comprehensive and finely resolved survey (both temporally and taxonomically) of all life stages of fishes in the middle reach of the Pecos River in New Mexico. Our results illuminate the short-term effects of reservoir block releases on reproductive effort by fishes and provide a baseline for future surveys to investigate the long-term impacts of climate change at this site. Overall, the middle Pecos River is a highly regulated, artificial system with ecological "winners" and "losers" in the context of current water management practices. The most alarming result is the overall scarcity of native pelagic-spawning minnows across all life stages at our site (i.e., ecological "losers") relative to the abundance of resilient exotic and translocated (nonnative) fishes (e.g., Common Carp and Plains Minnow; ecological "winners").

We designed our survey to capture drifting eggs and larvae of pelagic-spawning minnows to assess their reproductive responses to environmental disturbances. Surprisingly, 90% of collected eggs were Sand Shiner (N = 3,943), which have not been described as semi-buoyant or drifting in flowing systems. In laboratory spawning trials, Platania and Altenbach (1998) described Sand Shiner eggs as demersal adhesive, because they attached to gravel in tanks. The next most common eggs were River Carpsucker (N = 117; 3% of total), followed by Speckled Chub (N = 19; < 1% of total). The dramatic drop in drifting egg densities, which were almost entirely Sand Shiner, provides strong evidence that the block release interrupted spawning activities of this native minnow. River Carpsucker eggs are also reported as demersal adhesive

(Sublette et al. 1990), which explains their low catch rates in nets as compared to their dominance in larval assemblages. Indeed, we observed that River Carpsucker eggs were usually attached to clumps of filamentous algae that became dislodged upstream before drifting into nets. It is alarming that we collected only 19 Speckled Chub eggs (and no other pelagic-spawning minnow eggs), because our drift nets are biased towards collecting these egg types.

Larval assemblages shifted in response to spawning activities by adults. Although our efforts to completely sort and identify all larvae are in progress, we identified a dense April pulse of nonnative Common Carp larvae at our site, followed by a ramping up of larvae of native River Carpsucker and Sand Shiner in May. The absence of River Carpsucker and Sand Shiner immediately after the block release provides further evidence that this event interrupted spawning activities of these fishes. Thereafter, densities of River Carpsucker larvae increased rapidly, and peaked during late June into early July. Finally, densities of drifting juvenile Flathead Catfish (native) and Channel Catfish (nonnative) peaked in late July into August.

Sand Shiner were the most common adults in our study reach, as they constituted 39% of adults collected by electrofishing. Although Sand Shiner adult body conditions (K_n values) and egg areal CPUEs declined significantly after the June reservoir release, there was no statistical correlation between these values averaged over two-week periods. Sand Shiner egg drift densities should peak during or after adult K_n values peak, but our adult data lacks the resolution to investigate potential correlation and lag times between these two variables.

Many Great Plains pelagic-spawning minnows are reproductive bet hedgers, releasing many small batches of eggs over a prolonged spawning season to increase overall fitness (Durham and Wilde 2005; Dudley and Platania 2007; Worthington et al. 2014). Furthermore, downstream drift is critical for the early life stages of pelagic-spawning minnows, and juvenile recruitment occurs downstream of where spawning occurred. Thus, juveniles and adults likely disperse upstream to occupy spawning grounds. Indeed, Archdeacon et al. (2018) observed mass upstream movement of young-of-year pelagic-spawning minnows (> 1000 fish/min), including Speckled Chub, in the Pecos River near Lake Arthur, New Mexico. At our study site, Speckled Chub adults and eggs were rare and increased in density after the reservoir release. Only five adults and one egg were captured before the release, compared to 24 adults and 18 eggs after. Because our study site is in close proximity to Sumner Dam, we interpret the increased densities of adults and eggs as evidence of upstream migration to occupy preferred spawning grounds.

Spawning events of Speckled Chub are known to occur after high flow events and during periods of sustained high flow (Dudley and Platania 1999), but there is a lack of information for spawning during periods of intermittent flow. Insights into Speckled Chub spawning behaviors can be made by comparison to a closely related species in the Canadian River, Peppered Chub. Much like Speckled Chub, populations of Peppered Chub have decreased as a result of river fragmentation through reservoir construction, drought-influenced low flows, and desiccation (Wilde and Durham 2008; Pennock et al. 2017). Peppered Chub are known to spawn during periods of low flow but reproductive and recruitment success was found to rely on higher flows that prevent eggs and larvae from falling out of suspension during the drifting phase. As documented by Bonner (2000) and Pennock et al. (2017), populations of Peppered Chub persist in areas that experience low flows but have unmodified tributaries providing high flow events, likely initiating spawning behavior (Pennock et al. 2017). We observed similar seasonal patterns at the BR site in 2020. Though eggs of Speckled Chub were collected before the reservoir release when there was little fluctuation in river discharge, possibly due to asynchronous spawning, adult and egg densities increased significantly after the June reservoir release, indicative of synchronous spawning in response to the block release. These results may be indicative of a deviation from the bet hedging strategy and a reliance on strong environmental cues for synchronous spawning behavior, though more research is necessary to investigate potential correlations with environmental cues. Surprisingly, we did not collect eggs belonging to any other species of pelagic-spawning minnows after the reservoir release.

Plains Minnow is a nonnative pelagic-spawning minnow in the Pecos River that was translocated from the Arkansas River drainage. Of the thousands of eggs collected at our site in 2020, including dozens of pelagic-spawning minnow eggs, we identified zero Plains Minnow eggs. This result was surprising because Plains Minnow adults were prolific at the sampling site before the reservoir release with densities rivaling those of Sand Shiner. Additionally, not only did adult density drop significantly after the reservoir release, but relative body conditions (K_n values) of the adults declined more so than any of the target species. The physiological effects of the reservoir release and the disappearance of adults from the study reach is unknown. It is possible that the drift nets were deployed upstream of their preferred spawning grounds, in which case we would not expect any egg collections. However, gravid females and ripe males were collected after the reservoir release throughout the entire study site. Another possibility is that spawning is occurring during the reservoir release when we could not safely or practically deploy drift nets or electrofish. Even though this behavior has been observed before, Plains Minnow are also known to spawn throughout the season with or without discharge spikes (Taylor and Miller 1990). The decrease in adult condition after the reservoir release suggests that spawning occurred, but the total absence of their eggs in our drift collections remains puzzling. The only other pelagic-spawning minnow we collected at our site was Rio Grande Shiner (*Notropis* *jemezanus*). On March 10, 2020, we collected four adults by seining, and one more adult was collected by electrofishing on April 16. No eggs or larvae of this species were identified.

After Sand Shiner, Red Shiner was the most abundant minnow collected during electrofishing surveys. No eggs of this minnow were collected during 2020 in drift nets, which is to be expected as they deposit demersal adhesive eggs in crevices (Cross 1967). We confirmed this reproductive mode in our own laboratory spawning trials in the Behavioral Ecology Laboratory at Eastern New Mexico University. Body condition (K_n values) of Red Shiner males were higher than those of females, which is opposite to the pattern found for the other three target species in this study (i.e., Plains Minnow, Sand Shiner, Speckled Chub). Male Red Shiner are known for guarding territories and will try to move females into their territory while chasing males away (Gale 1986). We also observed this behavior in the laboratory. Thus, larger males may be the result of sexual selection in this species.

The reproductive success and continued downstream dispersal of nonnative species in this section of the river is alarming. We monitored synchronous spawning by Common Carp in the river, as monitored by a dense April pulse of larvae. Larval and juvenile Common Carp were also the most abundant fishes collected in drift nets immediately after the block release. As the youngest individuals were 9 days old and water traveled from Lake Sumner reservoir to our site in about 12 hours, these fishes may have originated from distant upstream reaches. Other nonnative fishes we observed at our site included abundant adult Plains Minnow, juvenile Channel Catfish, and one juvenile Walleye (*Sander vitreus*).

SUMMARY

We designed our study to monitor reproductive success of fishes in the middle Pecos River near Fort Sumner, New Mexico, with special interest in the reproductive guild of pelagic-spawning minnows. By sampling adults/juveniles, drifting larvae, and drifting eggs, we found species responded differentially to the short-term reservoir block release from Sumner Dam during June 2020. The block release interrupted spawning activities of native River Carpsucker and Sand Shiner. Nonnative Common Carp juveniles, however, were present in the river immediately after the release. Nonnative Channel Catfish were also commonly collected in our survey. In contrast, native pelagic-spawning minnows were rare at our site. Of the thousands of total fish adults, eggs, and larvae collected at our site, we collected only 34 native adult pelagic-spawning minnows (29 Speckled Chub, 5 Rio Grande Shiner), 19 eggs (all Speckled Chub), and zero larvae. These patterns confirm that the broader regional observation of ecological reshuffling in favor of nonnative species is also well underway in fish communities of the middle Pecos River. To mitigate further collapse of native species, we recommend water managers consider releasing pulsed blocks of water downstream that more closely mimic the historical hydrology of the river in which native species evolved. Clearly, reproductive events of native fishes are finely tuned to the frequency, intensity, and duration of high discharge events.

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