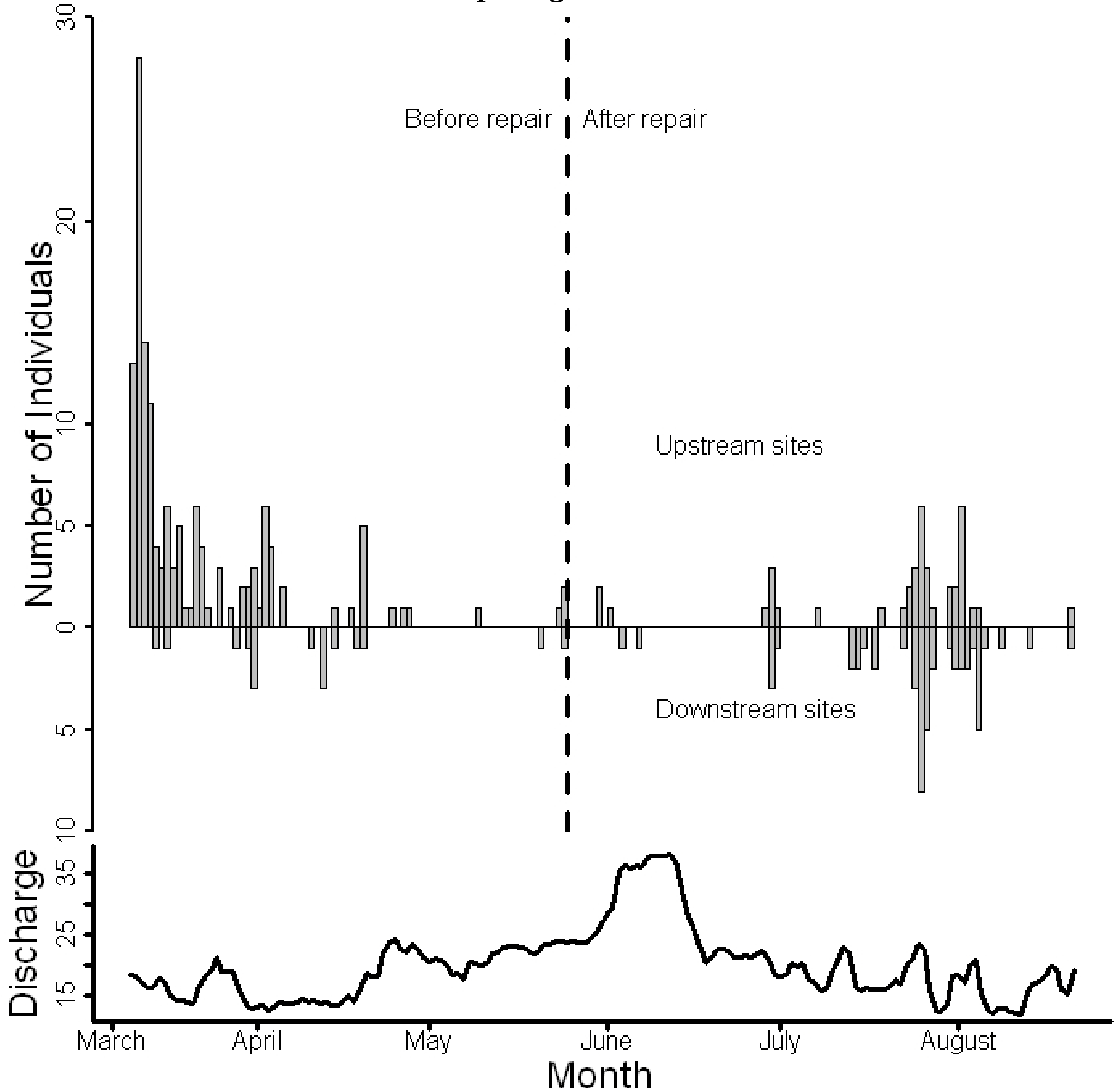
Continuing observations of Rio Grande silvery minnow *Hybognathus amarus* using a fish passage structure



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Executive Summary

Recent research suggests fragmentation of fluvial habitats is a cause of decline of many species of fishes, particularly pelagic-spawning minnows, a reproductive guild characterized by semi-buoyant eggs released directly in the water column. Construction of fish passageways ("fishways") might help alleviate some effects of barriers on stream-dwelling fishes including Rio Grande silvery minnow. Rio Grande silvery minnow *Hybognathus amarus*, a federally endangered species, have the physiological capability of long-distance upstream dispersals, and have been documented using model fishways in laboratory trials. However, in-stream use of fishways has not been documented. To determine if Rio Grande silvery minnow would use in-stream fishways, we implanted 6,657 Rio Grande silvery minnows with passive integrated transponders and a used passive scanning station to document movements from seven release locations, up to 19.7 km upstream and 13.5 km downstream of a bypass structure, and to document successful ascension of an in-stream rock channel fishway on the Rio Grande, Albuquerque, New Mexico. Between 18 March, one week after release, and 21 August 2011, 157 individuals were detected (2.4% of total); with 61.1% fish detected upstream release sites and 39.9% from downstream release sites. More than half (60.2%) of detections occurred between 0700 and 1900 hours, suggesting Rio Grande silvery minnow are more active during daylight hours. The number of daily detections was inversely related to discharge ($P < 0.0001$), while distance of each release location to the passageway was not related to the proportion of fish detected from each release location. We conclude Rio Grande silvery minnow can use appropriately constructed fishways which may reduce associated negative impacts of habitat fragmentation in the Middle Rio Grande on Rio Grande silvery minnow.

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Introduction

Fragmentation of fluvial habitats has been implicated as the cause of decline in many species of fishes, particularly in Great Plains fishes belonging to the pelagic broadcast-spawning guild (Winston et al. 1991; Platania and Altenbach 1998; Alò and Turner 2005; Dudley and Platania 2007; Perkins and Gido 2011). Rio Grande silvery minnow *Hybognathus amarus*, and other fishes in the pelagic broadcast-spawning guild, are characterized by females that release eggs directly into the water column, with eggs and larvae drifting downstream for several days until larvae are able to move to slower areas at the stream margins (Fausch and Bestgen 1997; Platania and Altenbach 1998; Wootton 1998). Unobstructed reaches of river exceeding 100 km are an important habitat component for riverine fishes with semi-buoyant eggs (Platania and Altenbach 1998; Dudley and Platania 2007; Hoagstrom et al. 2008; Perkins and Gido 2011) because net downstream displacement of eggs and larvae are presumably offset by subsequent upstream dispersal of juveniles and adults (Fausch and Bestgen 1997). Dams prevent upstream movements and can cause a decrease in abundance or extirpation of native fishes (Winston et al. 1991; Penczak and Kruk 2000; Gehrke et al. 2002), and even small obstructions, such as diversion dams, prevent small-bodied fishes from moving upstream (Ficke and Myrick 2009).

Historically, Rio Grande silvery minnow was one of the most abundant species of fishes in the Rio Grande, ranging from northern New Mexico in the Rio Grande and Pecos River, downstream to the Gulf of Mexico (Treviño-Robinson 1959). It now occurs only between Cochiti Dam and Elephant Butte Dam (Figure 1), a greater than 90% reduction in historical range (Bestgen and Platania 1991; Propst 1999). In the Middle Rio Grande, Rio Grande silvery minnow have decreased in abundance (Hoagstrom et al. 2010), and are listed as endangered by the U. S. Fish and Wildlife Service (Federal Register 59:36988). Recovery efforts within the current range of Rio Grande silvery minnow include habitat restoration, augmentation with hatchery-reared fish, and transplantation of fish stranded in isolated pools following channel drying, and includes frequent monitoring of catch rates at 20 sites (U.S. Fish and Wildlife Service 2010).

The Middle Rio Grande in New Mexico is dammed for water storage and diversion in four locations within the current range of the Rio Grande silvery minnow (Figure 1). Reduction in discharge in the Middle Rio Grande has led to habitat loss, simplification, and fragmentation which has subsequently been attributed to low effective population size of Rio Grande silvery minnow (Alò and Turner 2005), and is a primary cause of its decline in distribution and abundance (Propst 1999; Dudley and Platania 2007). Construction of fishways to allow upstream (and unimpeded downstream) dispersal may help alleviate the effects of fragmentation and is currently a requirement of the Rio Grande silvery minnow recovery plan (U.S. Fish and Wildlife Service 2010); however, it is not known whether Rio Grande silvery minnow will use in-stream fish passage structures. Laboratory research suggests Rio Grande silvery minnow are capable of long-distance dispersal, covering distances of over 50 km in 72 h, and will ascend rock channel fish passages (Bestgen et al. 2010). Longer movements have been observed in the wild with Visible Implant Elastomer

(VIE) tagged Rio Grande silvery minnow (Platania et al. 2003), but data are limited with no specific information on in-stream use of fish passage structures. In general, movement and dispersal data, as well as use of fish passage structures by non-salmonid, small-bodied fishes is poorly documented in the literature (Clough and Beaumont 1998). Passive scanning stations and passive integrated transponder (PIT) tags offer the ability to document fish movements in certain situations, and provide insight into seasonal and diel movement patterns.

We used PIT tags inserted in Rio Grande silvery minnow and an in-stream passive scanning device to monitor movements through a fish passage structure in the Rio Grande near Albuquerque, New Mexico. Our primary objective was to determine if Rio Grande silvery minnow were capable of using an in-stream rock-channel type fishway, and whether environmental variables influenced fishway use. Secondarily, we wanted to verify dispersal of Rio Grande silvery minnow from stocking locations located both upstream and downstream of the fishway.

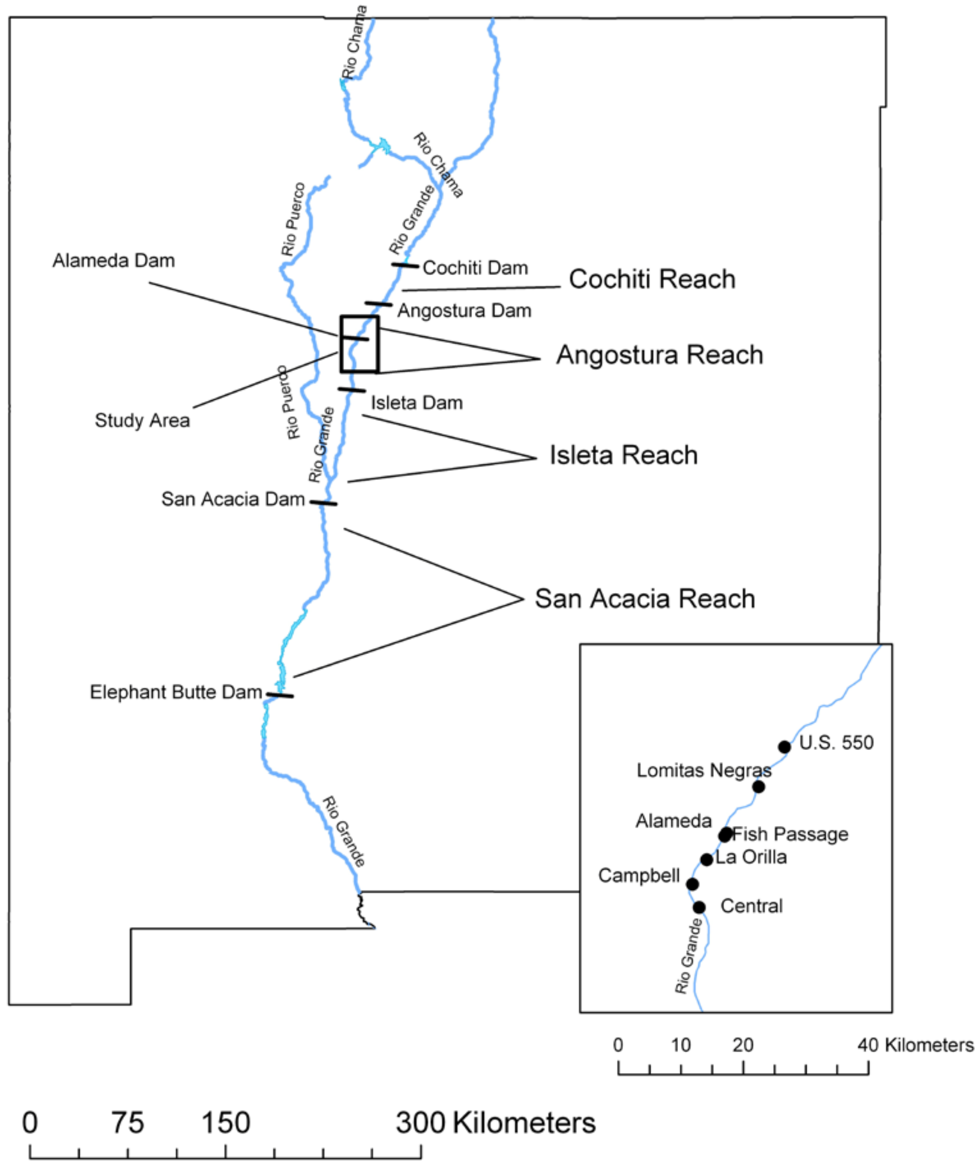

Figure 1-Location of barriers on the middle Rio Grande, New Mexico, and release locations for PIT-tagged Rio Grande silvery minnow and locator map.

Figure 2-Fish passage structure on the Rio Grande, Albuquerque, New Mexico. A) Shows the scour pool that formed below the passage, which was filled with concrete rip-rap on 26 May 2011. B) shows the passage after completion.

Methods

Study area–The Middle Rio Grande is characterized by a wide, shallow, primarily sand-bottomed channel. The Middle Rio Grande is divided by four water diversion structures between Cochiti Dam and Elephant Butte Dam, of which three are for irrigation diversion, and one (Alameda Dam) is for drinking water (Figure 1). The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) drinking water diversion on the Rio Grande (Figure 2) was completed in early 2006 with limited trial diversions through 2008, becoming fully operational in late 2009 (personal communication, R. Billings, ABCWUA). This dam is the only diversion structure in the Middle Rio Grande with any type of fish passage. The dam height is adjustable, operated by Obermeyer gates, which are steel panels ranging in length from 3-12m in length. The panels are raised or lowered pneumatically to control the amount of water being diverted.

A rock-lined bypass channel was constructed to allow fish passage when the dam is operational. In 2007, the channel was equipped with a PIT tag transceiver (Destron-Fearing FS1001M, South St. Paul, MN), and upstream and downstream crump-weir antennas, so that directional data could be collected as fish passed over the weirs. The channel is approximately 220m in length, 8m wide, and less than 0.6m deep. Discharge patterns prior to and during the current study period indicated that conditions were moderate to below average at the site during the study period (Figure 3).

Under normal operations, the Alameda dam is an upstream barrier to fish movements, forcing fish to use the passageway, but fish may still pass downstream through the dam. The dam is likely no longer a barrier when the diversion is not operational, but the fishway might be impassable because of low water. Although it is assumed the dam is operational the majority of the study period, no record of daily dam operations is available. In 2011, a scour pool formed below the downstream confluence of the passage and the river (visible in Figure 2), resulting in approximately a 30cm difference in water levels. The pool was filled in with rocks to raise the water level on 26 May 2011 and a more permanent repair is scheduled for 2012.

Fish tagging–We inserted PIT tags (Biomark TX1411SST, Boise, ID) in Rio Grande silvery minnow >50 mm standard length (mean ± standard deviation = 65.4 ± 5.1), obtained from Dexter National Fish Hatchery and Technology Center, in February, 2011. The majority of fish were age I, with <1% age II fish. Fish were anesthetized with MS-222, and we made incisions approximately 2 mm long in the abdomen, and inserted PIT tags into the abdominal cavity (Archdeacon et al. 2009). Rio Grande silvery minnow were treated with antibiotics for 8-12 h in a static bath, and held in fiberglass tanks for 10 d to maximize survival and tag retention of released fish. Approximately 1,000 fish were tagged for each of seven release locations (Figure 1, inset). Tagging activities were performed at Dexter National Fish Hatchery and Technology Center in Dexter, New Mexico. We chose to tag hatchery fish because the effort to capture 7,000 wild fish >50 mm standard length would have prevented successful completion, as well as the unknown, but likely greatly increased, mortality and tag loss associated with tagging and releasing fish directly in the river.

Fish release–Tagged Rio Grande silvery minnow were transported from Dexter National Fish Hatchery & Technology Center and released at seven locations on 11 March 2011. The “fish passage” stocking location was immediately below the downstream end of the passage (Figure 2). Tagged fish were held in mesh cages (1-2m x 1m x 1m) anchored in low velocity habitat 0.4–0.7m deep. Fish were held in cages for a minimum of 2 h to allow acclimatization, and then released into the river.

Fish movements–We counted the number of individual fish detected by the PIT tag transceiver, the number of upstream and downstream movements, and total detections by time of day. Several conservative assumptions were required to track the movement of Rio Grande silvery minnows in the fish passage structure. We assumed that fish must use the passageway for upstream movements, but downstream movements were possible through either the passageway or dam. To be certain fish moved upstream through the passageway, we considered only cases that included detection on a downstream and an upstream scanner. Fish detected only on a downstream scanner, but not upstream, were considered failures to ascend. We calculated the upstream passage rate by dividing the total number of fish known to cross by the total number of fish first detected by the lower scanner. We chose a conservative approach to quantifying movement to ensure we did not over-represent the numbers of fish moving upstream through the fishway. Detection of tagged fish began on 11 March 2011, and concluded on 21 August 2011, when dam operations ceased and was no longer a barrier to upstream movement.

In addition to scanner downloads, monthly monitoring efforts from other projects (i.e., augmentation monitoring and population monitoring) included the manual scanning of each captured Rio Grande silvery minnow. All Rio Grande silvery minnow over 50 mm SL (minimum SL of PIT tagged) were scanned. If PIT tag was present, the number, location of sample and time of day were recorded.

Data analyses–We used generalized linear regression with a negative binomial distribution (White and Bennetts 1996; O’Hara and Kotze 2010) to relate the raw count of individual fish detected per day and total number of detections per day to discharge (USGS gauge 08329928). We also used a time-lag model (1-d lag) to account for autocorrelation among discharge measurements.

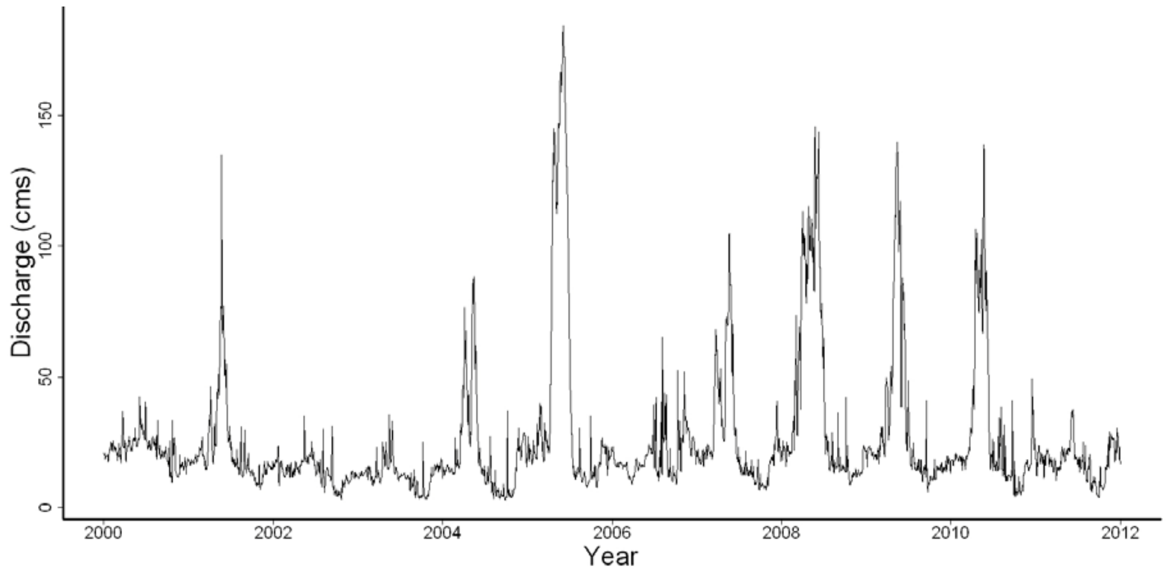

Figure 3-Daily discharge in the Rio Grande, measured at the Albuquerque gage.

Results

Through 21 August 2011, there were 323 PIT tag detections, representing 247 individuals of the 6,657 tagged fish released at the seven locations (Table 1). The maximum time between first and last detection was over 4 months. Of the 247 individuals, there were 2 that were manually scanned by crews conducting monitoring efforts related to other projects and 3 that could not be assigned to a release site, resulting in 242 used in further analysis. Of the 2 manually scanned, one was recaptured near Central Bridge by the ASIR (American Southwest Ichthyological Researchers, LLC) population monitoring crew near midday on 6 April 2011and 1 was recaptured at the downstream side of the Alameda dam on 18 April 2011. This monitoring was conducted by our office in conjunction with emergency repairs being conducted at the dam. The Central Bridge recapture was from the Bernalillo Bridge release site 33.2 km upstream and the Alameda dam recapture was from the release at the Alameda Bridge 0.5 km upstream.

Of the 242 individuals, 74.0% were from detected from upstream release sites. However, the majority of detections occurred during the first week (Figure 4), and removing these from the sample decreases the percentage of upstream fish detections to 61.4% of all detections (Table 2). The number of detections of fish from downstream release sites increased from 14 to 47 after the scour pool was temporarily repaired by filling with rip-rap by ABCWUA (Table 3), though the time period was only 36% longer. During the same time period, the number of fish detected from upstream sites decreased from 54 to 43. More than half (60.2%) of detections occurred between 0700 and 1900 hours, suggesting Rio Grande silvery minnow are more active during daylight hours (Figure 5).

Table 1-Number of PIT-tagged Rio Grande silvery minnow released in the Rio Grande, Albuquerque, New Mexico, on 11 March 2011. Positive distances are upstream of fish passage, negative distances downstream of the fish passage.

Location	Distance from fish passage (km)	Number released	Number detected (% of released)	Number detected after first week (% of detected)
Bernalillo	+19.7	956	43 (4.5%)	22 (51.2%)
Lomitas Negras	+15.4	962	61 (6.3%)	30 (49.2%)
Alameda Bridge	+0.5	957	75 (7.8%)	45 (60.0%)
Alameda Fishway	-0.01	891	17 (1.9%)	15 (1.7%)
La Orilla	-4.5	941	20 (2.1%)	20 (100.0%)
Campbell Road	-9.2	922	7 (0.8%)	7 (100.0%)
Central Bridge	-13.5	928	19 (2.0%)	19 (100.0%)
Total Upstream	–	2,875	179 (6.2%)	97(54.2%)
Total Downstream	–	3,682	63(1.7%)	61(96.8%)
Grand Total	–	6,557	242 (3.7%)	158 (65.3%)

We determined 94 fish first entered the passageway from the downstream end; of which, 14 successfully ascended the channel (15%). Nine of the 14 fish that successfully ascended the channel were from downstream release locations, demonstrating some fish released upstream moved downstream at least as far as the diversion, and then moved back upstream.

Table 2-Number of individual PIT-tagged Rio Grande silvery minnow detected at a fish passage in Albuquerque, New Mexico, during the first week after release, before repair of passage, and after repair of passage. Fish were released 11 March 2011, repair of the fish passage was 26 May 2011, and end of study period was 22 August 2011.

Location	First week (3/11-3/18)	Before repair (3/19-5/26)	After repair (5/27-8/22)
Bernalillo	21	15	7
Lomitas Negras	31	16	14
Alameda Bridge	30	23	22
Fishway	2	8	7
La Orilla	0	1	19
Campbell Road	0	2	5
Central Bridge	0	3	16
Total	**84**	**68**	**90**

Daily discharge (Figure 3) was negatively related to the number of individuals detected per day in all cases (Table 3), discharge was autocorrelated, but time-lag models were not significant (results not shown).

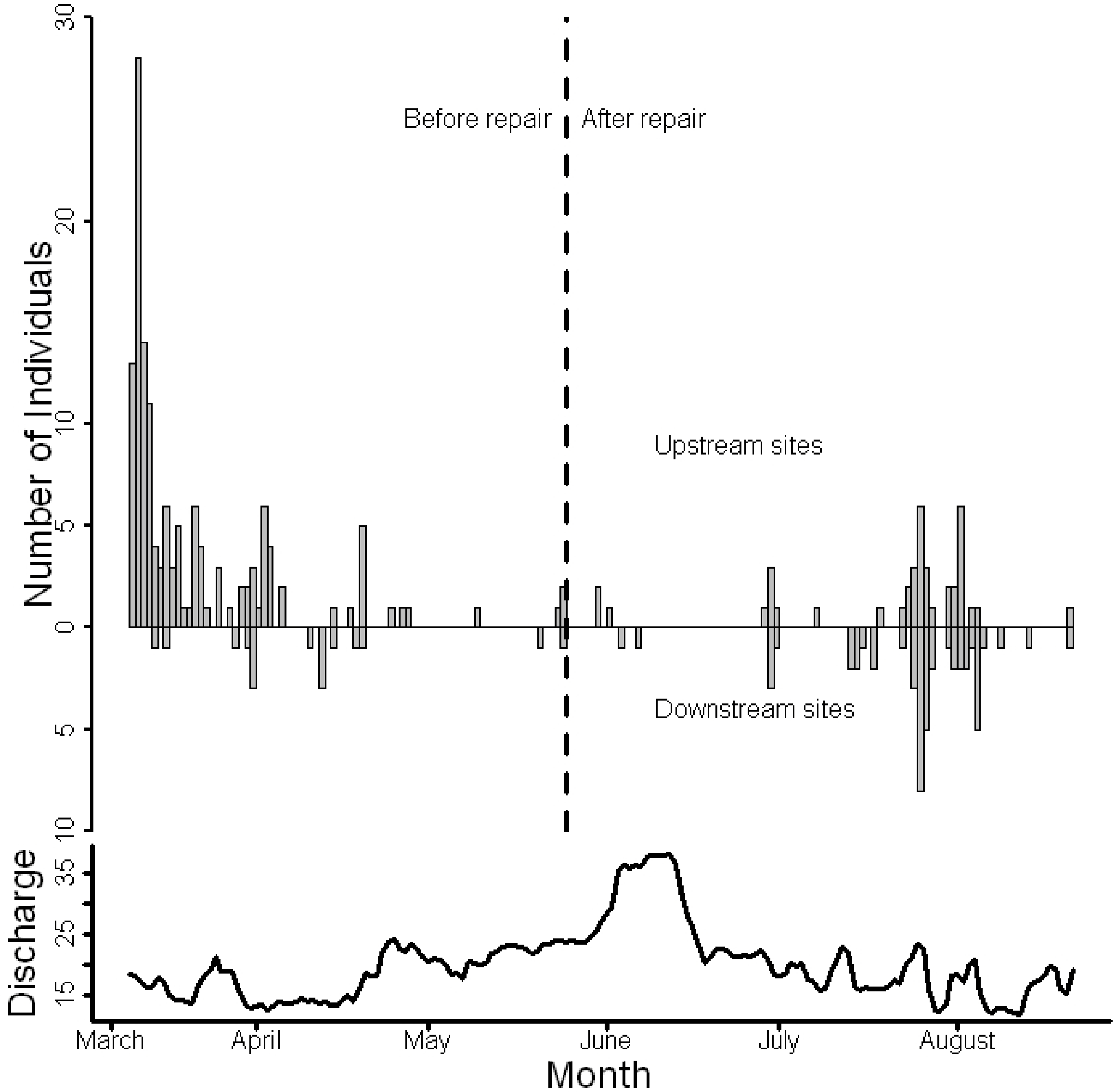

Figure 4-Daily number of PIT-tagged Rio Grande silvery minnow detected at a fish passage facility in Albuquerque, New Mexico. Detections are divided by upstream and downstream locations, with discharge from Albuquerque gage. Before and after indicates before a repair was made below dam.

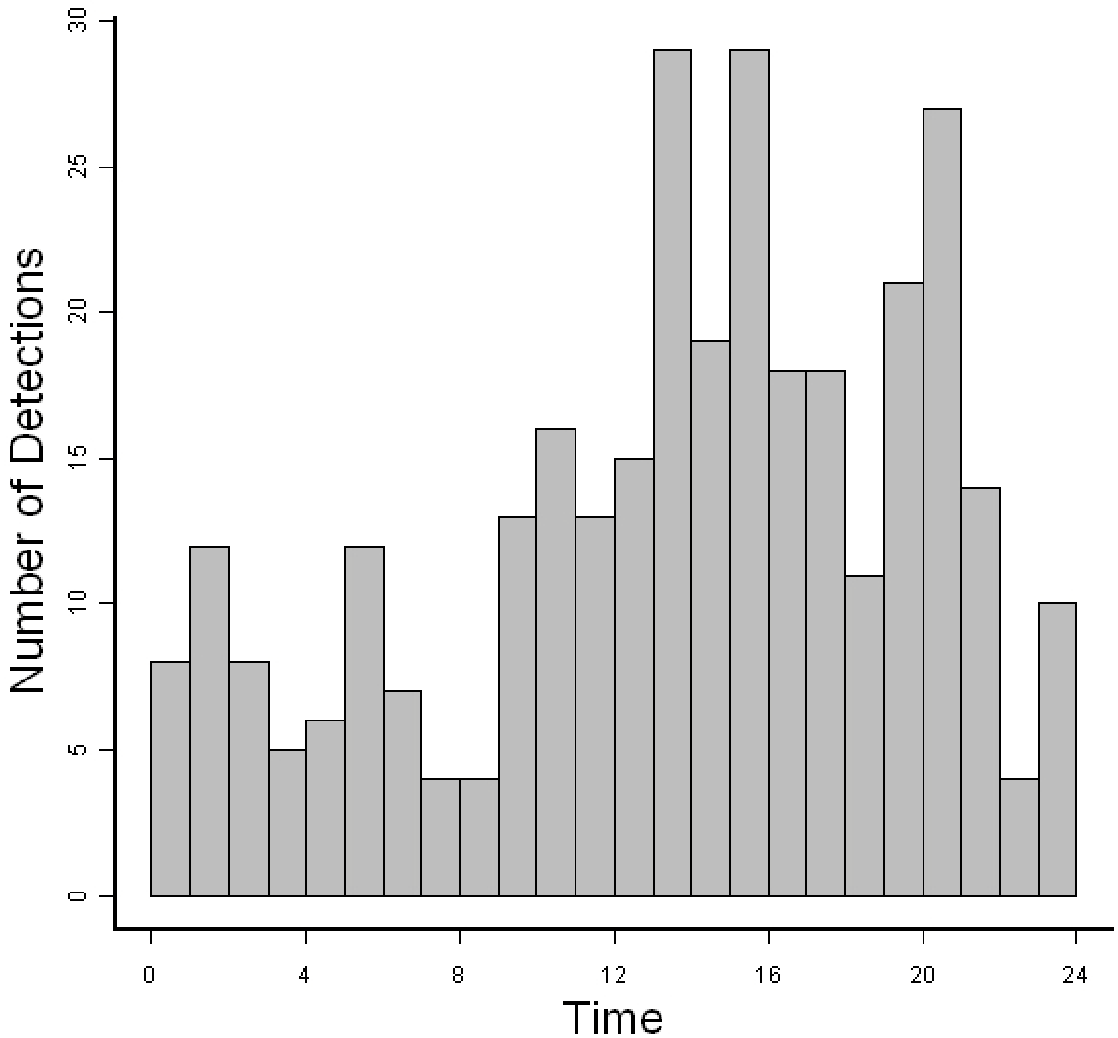

Figure 5-Number of detections by hour of PIT-tagged Rio Grande silvery minnow from 11 March to 22 August 2011 at a fish passage facility in Albuquerque, New Mexico.

Table 3-Model parameters relating Rio Grande discharge at the Albuquerque gage to number of PIT-tagged Rio Grande silvery minnows detected at a fish passage facility.

Dataset	Model	Deviance	*df*	*P*
Full-total	-0.003*Q+2.62	131.9	162	<0.0001
Full-upstream	-0.004*Q+2.70	108.9	162	0.0001
Full-downstream	-0.002*Q+0.36	92.2	162	0.074
Truncated-total	-0.003*Q+1.76	125.1	155	0.0021
Truncated-upstream	-0.003*Q+1.57	104.6	155	0.0028
Truncated-downstream	-0.002*Q+0.40	86.8	155	0.0747

Discussion

We documented successful ascension by Rio Grande silvery minnow of a rock-lined channel fishway. Conservatively, about 15% of fish that entered the passageway from the downstream end successfully moved completely through the channel. Successful ascension of fishways by non-salmonid large-bodied fishes ranges from <1% (Mallen-Cooper and Brand 2007), to over 80% (Bunt et al. 1999), but small-bodied non-salmonids was only about 17% (Lucas et al. 1999). However, small-bodied fishes, <160mm total length, in other systems have <1% passage success (Knaepkens et al. 2006; Calles and Greenberg 2007), suggesting that Rio Grande silvery minnow are more capable of using fish passage than other similarly-sized non-salmonid fishes. While this fish passage was constructed for the benefit of the Rio Grande silvery minnow, it did not include any specific design elements that were suggested by Bestgen et al. (2010) and it is possible that specifically designed fishways could produce higher success rates. Further research is need to determine if they will use other types of fishways, though Bestgen et al. (2010) strongly suggests Rio Grande silvery minnow can ascend a variety of different fishways. Repair of the fishway scour pool strongly suggests barriers even 30 cm high hinder upstream movements of RGSM, designs of future fishways for RGSM passage should consider eliminating any vertical drops.

We also verified Rio Grande silvery minnow upstream and downstream dispersal >1 km from release location. Platania et al. (2003) collected tagged Rio Grande silvery minnow >20km upstream of release locations. Platania et al. (2003) point out that the presence of adults in upper reaches documents upstream dispersal of Rio Grande silvery minnow, as there is net downstream displacement of eggs and larvae (Platania and Altenbach 1998). The current study further verifies that some Rio Grande silvery minnow disperse upstream, and in greater numbers than reported by Platania et al. (2003), as 63 fish moved upstream. Of these, 46 moved upstream ≥ 4.5km. Also noted by Platania et al. (2003), these dispersals represent small proportions of the total population and are not migrations. Although the exact reason for upstream dispersal is unknown, and might be a consequence foraging or exploratory movements, the end result is still repatriation of upstream reaches. Critics of the requirement of fish passage in the Middle Rio Grande cite the small numbers of fish moving upstream (PBS&J 2011), based on a pilot study done in 2009 (Remshardt and Archdeacon 2010), as evidence that fish passage will not provide noticeable effects on the Rio Grande silvery minnow population. Although still a small percentage of the total released Rio Grande silvery minnow moved upstream in this study, there does not need to be 1:1 replacement of upstream dispersers to eggs and larvae displaced downstream to maintain the population in upstream reaches. Based on pilot data (Remshardt and Archdeacon 2010), an estimated 0.2% of fish (about 2,000) moved upstream (PBS&J 2011).

This analysis only examined fish known to have successfully ascended the channel, disregarding fish that were known to have moved upstream but failed to cross the scanner, to generate dispersal estimates. From the current study, the proportion of fish released downstream detected on the scanner, extrapolated to a population of 1.2 million, is 19,778 upstream disperses. Assuming a 15% passage rate, as many as 2,967 fish might be moving past the diversion structure. Females of Rio Grande silvery minnow produce on average 2,463 eggs (95% confidence interval 1,474–3,472), with some individuals producing over 3,000 eggs each (Platania 1995). Assuming a sex ratio of 1:1, movement of even 1,500 females might represent over 3.75 million eggs. We also note that for nearly 33% of the study period, the fish passage was essentially impassable to Rio Grande silvery minnow, and the total number of observed upstream dispersers is likely lower than would have been observed had the channel been accessible.

The period of greatest movements occurred for the 1 week post-release, and consisted on mostly downstream movements from release locations, especially fish released at the site directly upstream of the fishway. Downstream movement of hatchery fish after stocking has been is expected and has been observed for a variety of fishes (Brown 1961; Moring and Buchanan 1978; Marsh and Brooks 1989), justifying exclusion of the first week of data, as movements are likely related to stocking and not natural dispersal. Removal of the first week after stocking showed much more even movement rates. However, because of incomplete detection for both upstream and downstream dispersers, the actual numbers of fish moving both upstream and downstream are likely higher.

Analysis of the pilot study (Remshardt and Archdeacon 2010) suggested increasing distance was negatively related to proportion of fish detected (PBS&J 2011), though the authors failed to provide any statistical analyses. In the current study, after the first week, detections of fish from upstream and downstream release sites was nearly even, suggesting that Rio Grande silvery minnow are just as likely to move upstream as downstream. Most fish detections occurred from the release location immediately upstream within 1 week. After this period, the closer a fish was released to the fishway, the more likely it was to be detected, in conjunction with higher detection rates for upstream release sites. Net movement may be downstream or zero, Examining Figure 3, it is apparent that certain dam operations render the fish passage either impassable or unnecessary, as detections from upstream and downstream release locations almost exclusively occur jointly. On a daily basis, Rio Grande silvery minnow appear to be most active in the late morning through afternoon, but this apparent behavior might be caused by dam operations.

The 2009 pilot study (Archdeacon and Remshardt 2011) suggested that Rio Grande silvery minnows could ascend the fishway, however, stocking groups contained varying numbers of fish, and estimation of movement rates was difficult. Similarly, data from the current study should be used cautiously to estimate movement rates. These data provide insights about potential dispersal distances, and upstream and downstream dispersal rates. However, because only one scanning location exists in the river, many movements are not detected. Fish at the upstream location might have moved downstream only 1 km and moved upstream 10 km, or might have moved downstream through the dam undetected for many more kilometers. Estimation of movement rates and not just minimum dispersal distances and minimum upstream dispersal rates would require multiple scanning stations to capture smaller movements from release locations, or different types of tracking devices.

Unfortunately, we were not able to relate some site-specific water quality parameters (temperature, dissolved oxygen, turbidity) to fishway use due to equipment malfunction, and further research should concentrate on these factors. Although discharge was apparently not a biologically significant influence on movement, and other environmental factors may have similar influence, short-term flow events impact movement patterns of fish (Franssen et al. 2006).

Construction of fishways in the Middle Rio Grande, similar to the passageway constructed in Albuquerque, will help alleviate some problems associated with fragmentation of current habitat by reconnecting reaches fragmented by diversion dams and allowing upstream movements of Rio Grande silvery minnow. However, increased drift distances of egg and larvae due to changes in flow and temperature regime (Dudley and Platania 2007), and creation of new habitat will require additional management actions.

Attributing recovery to a single management action is impossible. However, due to the life-history of Rio Grande silvery minnow, unfragmented reaches of stream are important (Alò and Turner 2005; Dudley and Platania 2007) and construction of bypass structures may restore some connectivity. We verified that Rio Grande silvery minnows moving upstream are capable of ascending rock-channel type bypass channels. Although the number of fish moving upstream might be a small percentage of the population, this is not evidence they are unimportant to maintenance of the species in upstream reaches. Based on the diel movements of Rio Grande silvery minnow, results from this study could assist in plans for current and future fish passage projects when daily operational procedures are considered. Continued monitoring of Rio Grande silvery minnow populations and use of the fish passage structure will help determine the importance of passage structures for pelagic-spawning cyprinids.

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