INVESTIGATING THE USE OF PASSIVE IMPLANTABLE TRANSMITTER TAGS ON THE RIO GRANDE SILVERY MINNOW (*HYBOGNATHUS AMARUS*)

Phase II Annual Report

Movement of PIT-tagged Rio Grande silvery minnow and use of Alameda fish passage structure

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EXECUTIVE SUMMARY

Fragmentation of fluvial habitats is a cause of decline of many species of fishes, particularly pelagic-spawning minnows. The premise of the bypass as a recovery measure is that construction of fish passageways to allow upstream and downstream dispersal may help alleviate some effects of fragmentation caused by barriers on streams. Rio Grande silvery minnow (*Hybognathus amarus*), a federally endangered species, have the physiological capability of long-distance upstream and downstream dispersal and in laboratory trials will use model fish passageways; however, in-stream use of fish passageways has not been documented. To determine if Rio Grande silvery minnow would use in-stream fish passageways, we implanted minnows with passive integrated transponders and a used passive scanning station to document upstream movements >10 km and use of an in-stream rock channel fish passageway on the Rio Grande, Albuquerque, New Mexico. We conclude Rio Grande silvery minnow disperses both upstream and downstream and used appropriately constructed fish passageways. Construction of passageways might help reduce some impacts of habitat fragmentation in the Middle Rio Grande on Rio Grande silvery minnow.

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TIMELINE

We completed Phase I, experimental tagging of Rio Grande silvery minnow with passive integrated transponder (PIT) tags in 2008. Phase II, testing of the scanning station (October 2008) and large-scale tagging of Rio Grande silvery minnow (March 2009) continued. All fish were obtained from Dexter National Fish Hatchery. Fish were held at New Mexico Fish and Wildlife Conservation Office wet lab facility for the surgical implantation of PIT tags. A total of 4,275 PIT-tagged Rio Grande silvery minnow was released at one of six locations in or near Albuquerque, New Mexico, on 14 June 2009. We collected data from a passive scanning station located on the fish passage structure at the Albuquerque Drinking Water Project diversion dam from June 2009 to September 2010. In 2011, we will tag another 5,000 fish and continue to monitor the fish passage as well as collect data from other researchers for PIT-tagged fish and environmental data as it becomes available.

INTRODUCTION

Fragmentation of fluvial habitats has been implicated as the cause of decline in many species of fishes, particularly in fishes belonging to the pelagic broadcast-spawning guild (Cross et al., 1985; Winston et al., 1991; Platania and Altenbach, 1998; Penczak and Kruk, 2000; Gehrke et al., 2002; Alò and Turner, 2005; Dudley and Platania, 2007). 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 and are then fertilized by males, and eggs and larvae that drift 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) because 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). Stream fragment lengths have been shown to be a strong predictor of conservation status among pelagic-spawning cyprinid populations, explaining 71% of cumulative extirpations (Perkin et al. 2010). Other researchers have suggested that given the appropriate habitat complexity, reproduction of pelagic spawning fishes is possible in stream fragments <100 km (Widmer et al. 2010; Medley et al. 2007). However, these results were contradicted by Perkin, et al. (2010) who indicated the above studies did not consider the many factors that long stream fragments can play in the success of these species.

Damming of the Rio Grande for water storage and irrigation diversions creates barriers to fish movements, as well as changing the natural flow and temperature regime of the river, which might affect spawning and larval development (Dudley and Platania, 2007). Fragmentation of habitats in the Middle Rio Grande has led to a 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 fish passageways to allow upstream dispersal may help alleviate some effects of fragmentation by allowing upstream movement; however, it is not known whether Rio Grande silvery minnow will use in-stream fish passage structures. In a laboratory setting, Rio Grande silvery minnow have shown the physiological capability of sustained swimming at 0.6 m/s, covering equivalent distances of over 50 km in 72 h, and will ascend prototype rock channel fish passages (Bestgen et al., 2010). Rio Grande silvery minnow have also used scaled down prototypes of an attraction and lift system (Terina Perez, City of Albuquerque, pers. comm.), but data does not exist on in-stream use of fish passage structures by Rio Grande silvery minnow.

Long distance movements and use of fish passage structures by non-salmonid, small-bodied fishes is poorly documented in the literature. Passive scanning stations and 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 in-stream passive scanning device to document upstream and downstream movement of fish, and use of a fish passage structure in the Albuquerque reach of the Middle Rio Grande.

Project objectives-- The ultimate goal of this study and all funded projects through the MRGESACP is to recover self-sustaining populations of RGSM and/or Southwestern Willow Flycatcher in the Middle Rio Grande New Mexico (MRGNM). The long-term benefits of this study are to not only provide information on new tagging techniques for Rio Grande silvery minnow (Phase 1), but to provide information on movement and use of a constructed fish passage in the Middle Rio Grande. The specific objectives of this phase (Phase 2) were to:

1) Document temporal and spatial movement of PIT-tagged hatchery reared adult RGSM.
2) Correlate environmental variables (flow, temperature, turbidity) with temporal and spatial movement of PIT-tagged hatchery reared adult RGSM.
3) Evaluate the use of the Albuquerque Drinking Water Project Fish Passage by PIT-tagged, hatchery reared adult RGSM.
4) Document depth and velocity profiles within the Fish Passage.

MATERIALS AND METHODS

Study area-- The Middle Rio Grande was historically 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, three for irrigation, and one (Alameda Dam) for drinking water (Figure 1). The Middle Rio Grande extends 280 km from Cochiti Dam, New Mexico to Elephant Butte Reservoir, New Mexico (Figure 1). 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 rivers, downstream to the Gulf of Mexico, but now occur only between Cochiti Dam and Elephant Butte Dam (Figure 1), a 90% reduction in historical range (Treviño-Robinson, 1959; Bestgen and Platania, 1991; Propst, 1999). In the Middle Rio Grande, silvery minnow have decreased in abundance since 1984 (Hoagstrom et al., 2010), and was listed as federally endangered in 1994 (USFWS, 1994-59 FR 36988 36995).

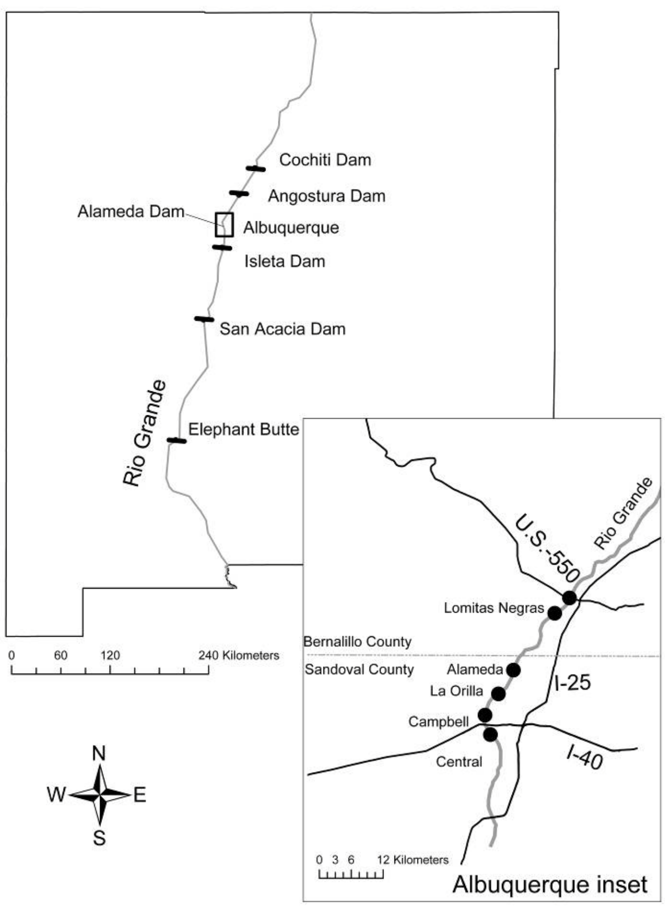

Figure 1-Middle Rio Grande, New Mexico, and upstream barriers to fish movement. Inset map shows locations in the Rio Grande, Albuquerque, New Mexico, where PIT-tagged Rio Grande silvery minnow were released.

A rock channel fish passageway was constructed in 2006 in Albuquerque, New Mexico, to provide passage around the Alameda diversion dam. Both were constructed by the Albuquerque Bernalillo County Water Utility Authority on the Rio Grande (Figure 2). The dam height is adjustable, operated by Obermeyer gates, which are steel panels ranging in length from 3-12m. The panels are raised or lowered pneumatically to control the amount of water being diverted (for a description of dam operations, see http://www.abcwua.org/content/view/34/27/). The channel was equipped with a PIT tag transceiver (Destron-Fearing FS1001M, South St. Paul, MN) with upstream and downstream crump weir antenna pairs in 2007(4 total), which span the width of the fish passage channel so that directional data could be collected as fish passed over the weirs (Figure 2). The crump weir antennas are a fiberglass shell which is anchored to the streambed. On the underside of each shell, an antenna is attached to the crump weir. These antennas are then energized and connected to the transceiver. The channel is approximately 220m in length, 8m wide, and less than 0.6m deep, and functional at all operational levels of the diversion dam. Typical detection range for this type of antenna is 0.7m, which is within the range of depths observed in the channel. 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 bypass is intended to offer upstream passage, and this study is intended to document whether the bypass does function this way.

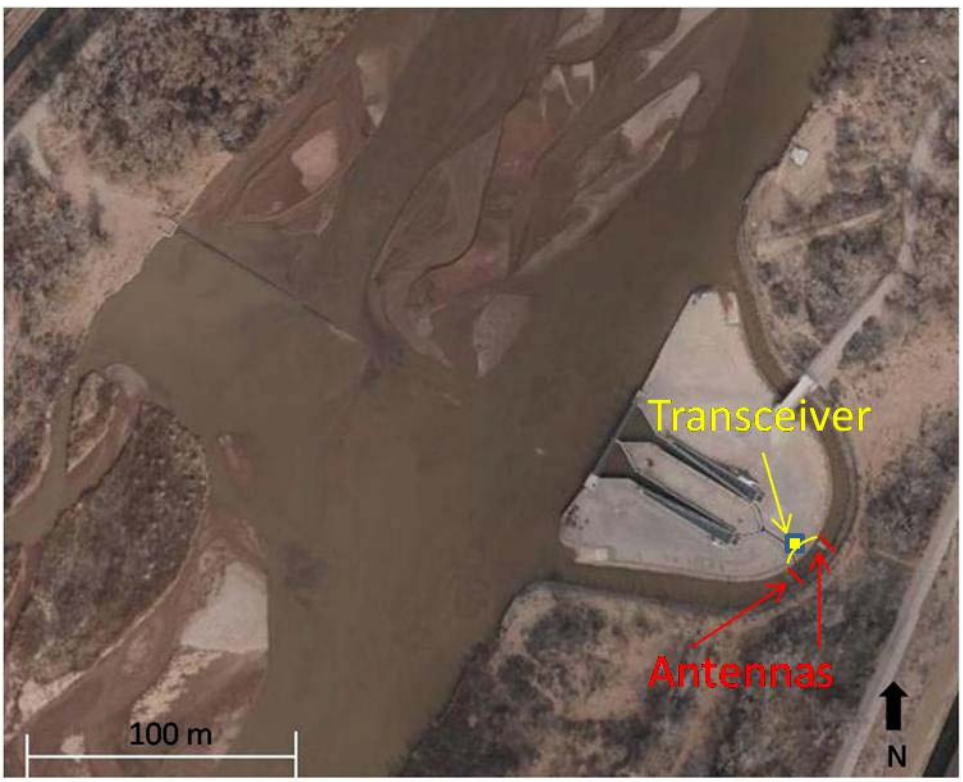

Figure 2-Aerial view of the Rio Grande drinking water diversion and fish bypass channel in Albuquerque, New Mexico.

Field methods--In October, 2008 we tested the effectiveness of the fish passage antennas by releasing 80 PIT-tagged Rio Grande silvery minnow between the two antennas. These were individuals from Phase I of the study where we developed the tagging protocols (Remshardt, et al. 2008).

Following this initial test of the antennas, we inserted PIT tags (Biomark TX1411SST, Boise, ID) in 12 month old hatchery reared Rio Grande silvery minnow >50 mm standard length, obtained from Dexter National Fish Hatchery and Technology Center and the City of Albuquerque's Biopark, in April, 2009. Fish were anesthetized with Finquel™ MS-222 (0.1 g/L), and we made incisions approximately 2mm in the abdomen, and PIT tags inserted into the abdominal cavity (Archdeacon et al., 2009). All fish were measured to nearest SL and sex was visually determined if evident. Rio Grande silvery minnow were treated with antibiotics for 8-12 h, and held in fiberglass tanks for four-six weeks, to maximize survival and tag retention of released fish. Efforts were made to split tagged fish into 6 equal lots to represent the 6 release sites chosen.

We counted the number of unique fish detected by the PIT tag transceiver, along with the number of unique upstream and downstream movements, the number of detections per week, and detections by time of day to determine patterns such as diel (diurnal) movements. Several 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 the passageway, or through the dam. We assumed a fish moved in the direction of the last scanner detection, e.g. a fish that was detected only on the lower scanner was assumed to not have moved upstream out of the passageway. If the same fish was detected more than once at any scanner, we considered movements to be unique if >24 h. We did not consider fish detected on only the upstream or only the downstream scanner in a 24-h period to have crossed both weirs, and thus they were not counted as incidences upstream or downstream movement through the passageway, but were indicative of movements from the original release location. We chose a conservative approach to quantifying movement to ensure we did not over represent the numbers of fish moving upstream through the fish passageway. We used a χ^2 test to determine movement and detection for PIT-tagged Rio Grande silvery minnow. The null hypothesis was that equal proportions of PIT-tagged Rio Grande silvery minnow would be detected at the fish passage.

In addition to collecting data at the fish passage antenna, efforts were made to scan all Rio Grande silvery minnow captured during monitoring efforts for other projects during the same time period. No PIT-tagged Rio Grande silvery minnow were detected by this method, therefore all other methods and results listed are strictly from the fish passage itself.

We plotted the number of detections by discharge at the nearest gage (Rio Grande at Alameda Bridge at Alameda, USGS 08329918) and by date within the range of detections. At this point, we do not have sufficient data sources for temperature and turbidity to compare and correlate with detections. Future work will attempt to address these issues. To document the water depths and velocities that Rio Grande silvery minnow might encounter in the fish passageway, we collected water depth (m) and velocity (m/s) data at 11 transects across the channel. One transect was conducted directly over the lower crump-weir antenna, where water velocity was swiftest, and one transect at the downstream confluence of the passage channel with the main channel. The remaining nine transects were chosen randomly in the channel, with three upstream of the crump weirs, three downstream, and three between the two weirs. Water depth and velocities were collected when the diversion dam was in use and fish could not move upstream in the main channel. We used a flow meter (Marsh-McBirney Flowmate 2000, Loveland, CO) to determine water velocities at 0.02m above the substrate and 60% of the water depth at each of 10 evenly spaced points for each transect.

RESULTS

Of the 80 Rio Grande silvery minnow released between the antennas, 78 were detected by at least one antenna (97.5%). Detection ranges for this antenna are typically less than 0.7m, and average depths of the channel are 0.6m. This, along with the fact that fish moving through the channel are likely near the bottom to take advantage of velocity breaks, means that our scanning effectiveness was high. We deemed the fish passage antennas functional and proceeded with the project. This initial success of detection indicated that if PIT-tagged fish were to pass through the fish passage, they would most likely be detected.

On 15 June 2009, 4,275 PIT-tagged Rio Grande silvery minnow were released at six locations in the Rio Grande, Albuquerque, New Mexico (Figure 1). Average SL of fish released was 62.9 mm (Range 52-89 mm), and for those that could be determined (1577, 37%), 60% were females and 40% were males. Distances from each release location to the fish passageway, and number of fish released at each location are presented below (Table 1). A total of six sites, with three release sites upstream and three release sites downstream of the fish passage were chosen. The release sites were chosen based on access and favorable release habitat conditions where we could install holding cages. Fish were placed in these holding cages for 4 hours to reduce the stress of handling and hauling and improve survival prior to release. Although the numbers of fish originally PIT-tagged were equal, the eventual numbers of fish released at each location were not equal due to the fact that the PIT-tagged fish exhibited differential survival and PIT tag retention prior to release. It would not have been feasible to handle and re-assign fish to different stocking groups prior to release.

From 30 June 2009 to 14 June 2010, we collected 169 records of Rio Grande silvery minnow on all scanners combined, representing 84 unique fish, or 2.0% of all PIT-tagged fish. These detections were entirely from the second, larger release of 4,275 fish. Although the transceiver was operational, no fish were detected from 15 June to 27 September 2010. There were not significant numbers to evaluate differences in movement patterns by either SL or sex. It is anticipated that further data collection will allow us to evaluate this at a later date.

Table 1-Number of PIT-tagged Rio Grande silvery minnow (*Hybognathus amarus*) released at six sites in the Rio Grande near Albuquerque, New Mexico, and subsequently detected in a fish passage channel equipped with a passive scanning station (percent). Distances of each release location are noted as upstream (u) or downstream (d) of the fish passageway.

	550 Bridge	Lomitas Negras	Alameda Bridge	La Orilla	Campbell Road	Central Bridge	Total
No. Released	734	1,142	715	542	850	292	4,275
No. Detected	16(2.2)	25(2.2)	32(4.5)	7(1.3)	2(0.2)	2(0.7)	84(2.0)
Distance (km)	19.7u	15.4u	0.5u	4.5d	9.2d	13.5d	-

Chi-square (χ^2) test indicate significant differences (χ^2 40.03, 5df, $P < 0.05$) from expected (Table 2). Of the 6 sites, 2 contributed the majority of the differences. Alameda Bridge was the closest upstream site (0.5 RM) and detections from this release site were relatively higher than other locations. Campbell Road was 9.2 RM downstream and had relatively fewer detections than the other locations.

Table 2- χ^2 table for number of PIT-tagged Rio Grande silvery minnow (*Hybognathus amarus*) released at six sites in the Rio Grande near Albuquerque, New Mexico, and subsequently detected in a fish passage channel equipped with a passive scanning station.

Release Site (RM)	Number Released	Observed % (N)	Expected % (N)	χ^2
550 Bridge (203.5)	734	19.0 (16)	17.2 (14.4)	0.17
Lomitas Negras (199.2)	1142	30.8 (25)	27.7 (22.4)	0.29
Alameda Bridge (189.3)	715	38.1 (32)	17.7 (14.1)	22.94
La Orilla (185.3)	542	8.3 (7)	13.7 (10.7)	1.25
Campbell Road (180.6)	850	2.4 (2)	20.9 (16.7)	12.94
Central Bridge (176.3)	292	2.4 (2)	7.8 (5.7)	2.43
Total	**4275**	**100 (84)**	**1.00 (84)**	**40.03, 5df, P<0.05**

First, we evaluated movement from release sites to the fish passage. Seventy-three fish moved downstream from their release locations, while 11 moved upstream. Most fish detections (53.8%) occurred in the morning (27.8% between 0600 and 1000 h) or early afternoon (26.0% between 1500 and 1900 h), suggesting a diel pattern to movement. Fifty-seven percent (56.8%) occurred during the first four weeks, though detections occurred up to one year after release (Figures 3,4,5). There was little information available to detect any relationship between discharge and detections (Figures 4,5) as the number of detections decreased over time.

Next, we attempted to evaluated movement direction within the fish passage. Thirty fish were first detected at the downstream antenna, likely indicating entrance into the channel from the river, and 8 of those fish crossed both weirs in an upstream direction, a passage rate of 26.7% for all tagged fish moving in from downstream. Twelve fish crossed both weirs in a downstream direction, and 42 were detected only on the upstream antenna, but directional conclusions for movement within the fish passage for all fish should be made cautiously (see discussion).

Water velocities in the channel were variable, but swiftest velocities occurred in the water column between the weirs and at the lower weir (Figure 6). Median water velocities 0.02m above the substrate were below 0.40 m/s, while median velocities in the water column were >0.50 m/s (Figure 6). We recorded several negative velocities in both the water column and above the substrate, indicating eddies caused by large boulders in the passage channel.

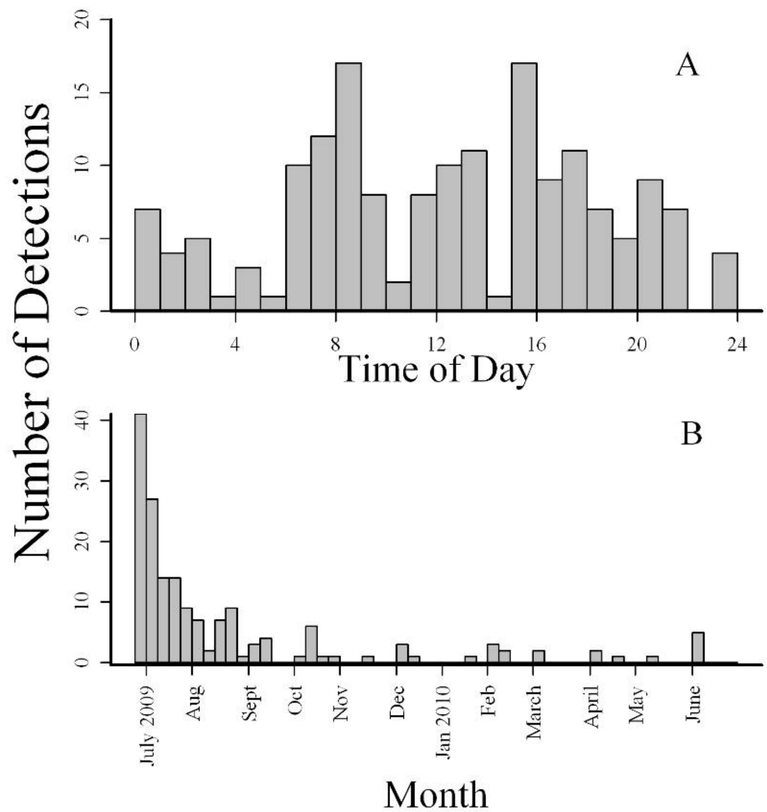

Figure 3-Number of PIT-tagged Rio Grande silvery minnow detections, by time of day, and B) number of detections by week. Fish were detected by a passive scanning station located on a fish passageway on the Rio Grande, Albuquerque, New Mexico. Data are from 30 June 2009 to 14 June 2010 and represent 169 detections of 84 unique fish.

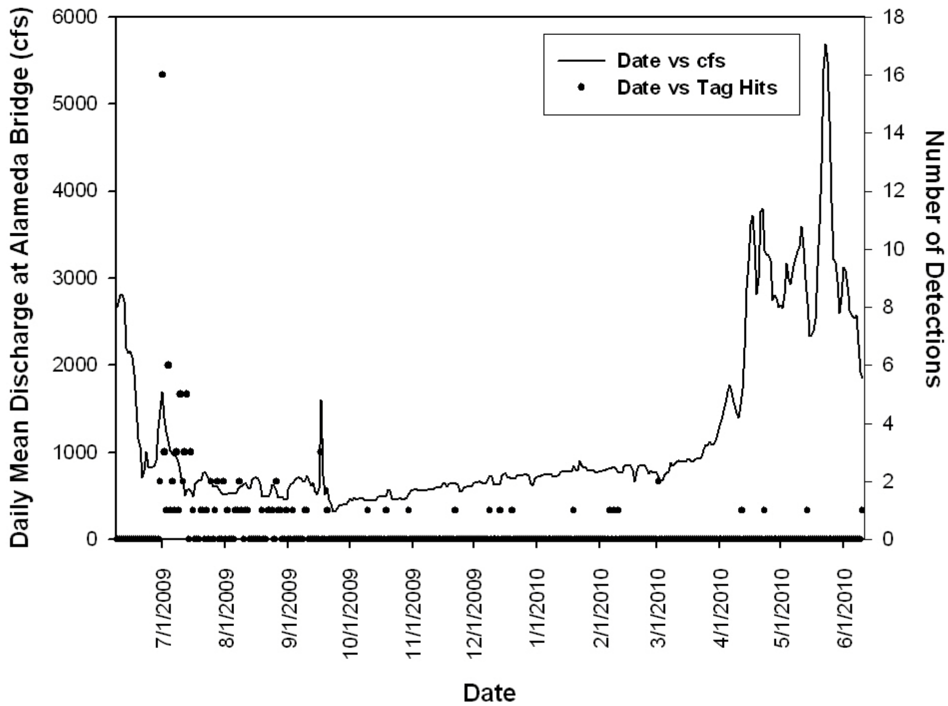

Figure 4-Daily mean discharge and Number of PIT-tagged Rio Grande silvery minnow detections by date. Data are from 30 June 2009 to 14 June 2010 and represents unique daily detections.

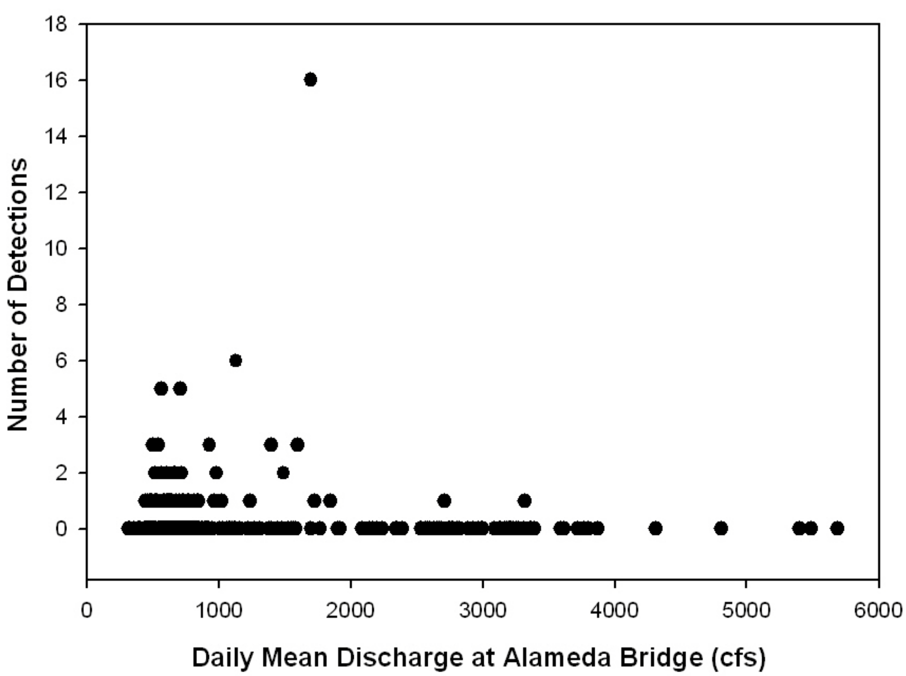

Figure 5-Plot of Number of hits by discharge. Data are from 30 June 2009 to 14 June 2010 and represent unique daily detections.

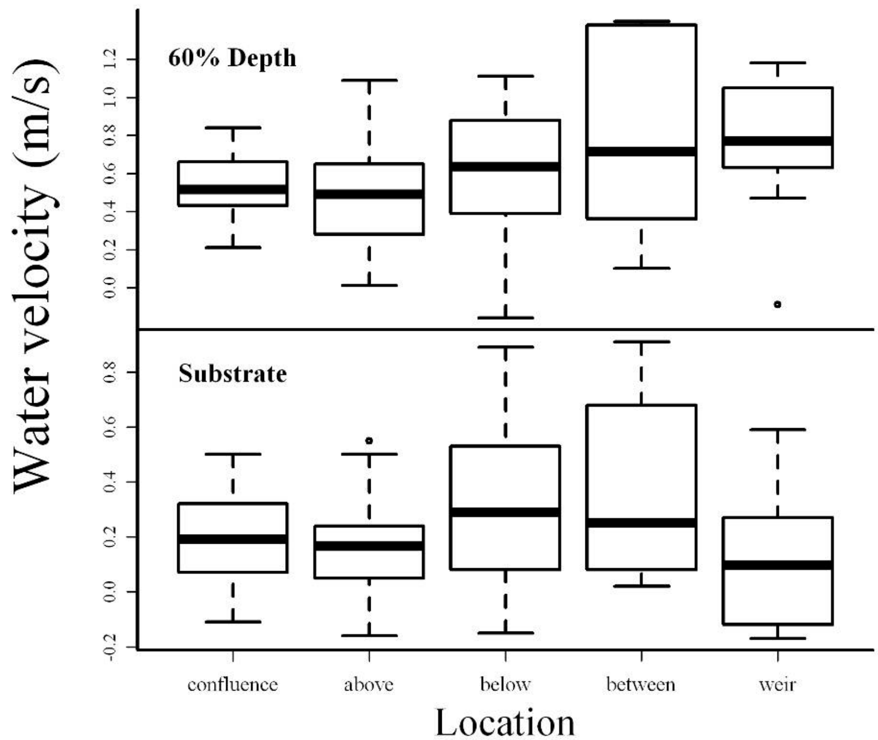

Figure 6-Box and whisker plots of water velocities in a fish passage channel in the Rio Grande, Albuquerque, New Mexico with median (dark bar), 25-75% confidence interval (box) and 5-95% confidence interval (whiskers). The top graph is water velocities at 60% of the water depth, the bottom graph is water velocities 0.02m above the substrate. The locations in the passage channel are the downstream confluence with the Rio Grande (confluence), above two crump-weirs (above), below the crump-weirs (below), between the crump-weirs (between), and at the downstream crump-weir (weir), where water velocity was greatest.

DISCUSSION

We were able to successfully document temporal and spatial movement of PIT-tagged hatchery reared adult RGSM both from release sites and to a lesser extent within the fish passage for a small percentage of released fish. We were not able to correlate environmental variables (flow) with temporal and spatial movement of PIT- tagged hatchery reared adult RGSM due to decreased detections within a few weeks of release. We were not able to obtain temperature and turbidity data to correlate with detections. We anticipate obtaining this data for later reports. We were able to document the use of the Albuquerque Drinking Water Project Fish Passage by PIT-tagged hatchery reared adult RGSM and document depth and velocity profiles within the fish passage.

Although the number of detections was relatively low (2.0% of all fish released), we were able to document Rio Grande silvery minnow moving both downstream and upstream >10 km from release location through a rock channel fish passageway. Higher proportions of PIT-tagged Rio Grande silvery minnow were detected from upstream sites, especially the ones nearest the fish passage at Alameda Bridge. This is similar to what has been reported for VIE-tagged Rio Grande silvery minnow as hatchery-released fish tend to distribute downstream immediately after release (Remshardt 2007).

The majority of minnow detections occurred soon after initial release into the river, likely due to mortality and the probability of fish remaining in the area of the passageway decreasing with time. Due to the timing of this project, some portion of the fish tagged and released were in varying stages of reproductive status. Many of the females appeared gravid during tagging, but by time of the release (June 15), many of these same fish had apparently resorbed their eggs. Regardless, the reproductive status of these fish may have affected their subsequent survival and movement patterns. Future work will focus on tagging and releasing fish well prior to estimated spawning in the river (May).

Detections and movement patterns, both to the fish passage from release sites and within the fish passage were not always clear. For instance, while 11 fish from downstream stocking locations were detected at the fish passage, 30 individuals were first detected at the downstream antenna. Further examination of detailed encounter history shows that there were some fish from upstream stocking locations that apparently dispersed downstream through the dam itself, before moving back upstream through the fish passage. Caution should be used when evaluating direction of movement within the passage. While overall detection probability for any one fish being in the passage was estimated at 97.5%, the probability that we could determine direction of movement was probably quite lower. For example, fish ID “3D9.1C2D3AE167” (see Appendix A), which was originally released downstream of the fish passage, was detected a total of 8 times over the course of 2 hours with the following sequence of antenna detections: D,U,D,D,U,D,U,D, (D=downstream antenna and U=upstream antenna), making it unclear whether the fish successfully passed through the channel. Another example was fish ID “3D9.1C2C6122F1”, which was also originally released downstream of the passage and had the following sequence of 5 antennal detections over the course of 24 hours:

U,U,D,D,U. This individual, while being released downstream, first encountered an antenna upstream. The likelihood of any fish passing through the dam itself is highly unlikely, more likely is the chance that it passed over the downstream antenna without being detected, making it difficult to determine directional movement within the fish passage for this and other individuals.

The diel pattern of detections suggests Rio Grande silvery minnow are diurnal, though detections occurred at nearly every hour. The fact that detections decreased over time inhibited our ability to compare with time of year or discharge. Future work could add to this dataset and provide additional comparisons. Since they were not encountered after release, the fate of the 4,191 fish not detected at the fish passage is unknown. Most likely scenarios are that they moved but did not pass through the fish passage, did not move from their stocking locations, and/or died prior to being detected. Less likely scenarios are that the fish moved upstream past the dam and did not use the fish passage or moved through the channel but were not detected. It seems highly unlikely that fish movement could occur during normal operation of the dam. Typically, only 1 or 2 gates are open at any one time creating extreme velocities and vertical drop that cannot even safely be measured. The effectiveness of the antennas to document PIT-tagged Rio Grande silvery minnow (97.5%) makes is highly improbable that if individual fish passed over one of the antennas that they were not detected. Many of the individuals detected by only one antenna might have crossed both weirs. At all dam operational levels, the passageway is passing water, but the water depth might be greater than the effective detection distance of the antenna (~70 cm), and minnows may be able to cross the weir undetected by the antenna.

We were able to PIT tag and monitor movements of larger (>50 mm standard length), older (e.g., >1 year), hatchery raised Rio Grande silvery minnow. Although not observed in Rio Grande silvery minnow (Remshardt 2007), some hatchery raised fish are typically known to have higher rates of mortality than wild fishes (Brown and Day, 2002). While hatchery reared Rio Grande silvery minnow have been shown to have similar if not higher survival rates (Remshardt 2007), utilize the same microhabitats (Remshardt 2007), and contribute to future generations (Osborne et al. 2005), it is unknown how the swimming abilities (and therefore movement) of hatchery fish might be affected by PIT-tagging. Future work should focus on determining potential effects of PIT-tagging on swimming ability. Future research should also include monitoring of smaller, younger fish, which can make up a significant proportion of the population (Dudley and Platania, in litt.). This is problematic for PIT tags, because their use in smaller fish will dramatically decrease post-surgery survival (Archdeacon et al., 2009), so other methods might need to be implemented. Originally, we had planned on tagging only fish that were > 60 mm SL, but found that with care we were able to successfully tag fish as small as 50 mm SL for this project, but it is unlikely that smaller fish than that could be tagged in the future.

This is the first direct evidence of Rio Grande silvery minnow using an in-stream fish passageway, and a rare example of long-distance upstream movement of small-bodied, non-salmonid fishes. Our results agree with Bestgen et al. (2010), Rio Grande silvery minnow are physiologically capable of upstream movement more than a few kilometers, and are capable and will use rock channel type fish passageways. Hatchery-raised Rio Grande silvery minnow have been documented to move up and downstream distances of 25 km (Platania et al., in litt.). Upstream movements of several hundred meters by small-bodied fishes have been documented (Fausch and Bestgen, 1997; Skalski and Gilliam, 2000; Ficke and Myrick, 2009), but because of the difficulty in relocating marked individuals, few examples of long-distance movements exist in the literature. Water velocities in the passageway were below velocities Rio Grande silvery minnow can easily sustain for long periods, even when the dam is operational (Bestgen et al., 2010). It was difficult to determine daily operations schedules for the dam and how that affected daily changes in the fish passage and over the dam itself. Future observations should include this data if possible.

Evaluation of fish passageways, though rare, suggest that a wide variety of species will utilize fish passageways, including small-bodied species (Schwalme et al., 1984; Nicola et al., 1996; Laine et al. 1998; Bunt et al., 1999; Lucas et al., 1999; Moser et al., 2002), but might not have the intended effects because of a poor design or lack of understanding of species ecology and habitat requirements (Agostinho et al., 2002). Current efforts to reconnect fragmented habitats by removing barriers to fish passage should focus on the entire fish community, fish passageways should be designed to allow all ages and sizes of fish to pass (Mallen-Cooper and Brand, 2007).

Habitat fragmentation currently divides the extant population of Rio Grande silvery minnow into three distinct reaches, and diversion dams limit exchange between the reaches. Even small obstacles can bias normal patterns of fish movement, and prevent upstream movements of small-bodied fishes (Ficke and Myrick, 2009). It is likely that this structure, even with fish passage, will affect the movement and dispersal of Rio Grande silvery minnow, but we determined that Rio Grande silvery minnow will move upstream and use appropriately constructed fish passageways. In 2011, we are PIT-tagging another 5,000 or more Rio Grande silvery minnow and continue to collect information on fish passage use and environmental variables during pre-spawn conditions.

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Appendix A.

Tag Detection Histories (30 June 2009 to 14 June 2010)

Tag encounter histories for the 169 detections. For antenna; 1 and 2=upstream, 3 and 4=downstream. For release codes; 1=550 Bridge, 2=Lomitas Negras, 3=Alameda Bridge, 4=La Orilla, 5=Campbell Road, 6=Central Bridge.

Count	Antenna	tagID	Scan Date	Scan Time	Release
1	3	3D9.1C2D423A92	30-Jun-09	11:56:42	3
2	3	3D9.1C2D423A92	30-Jun-09	11:56:42	3
3	1	3D9.1C2D3C605E	30-Jun-09	16:38:57	4
4	2	3D9.1C2D3C605E	30-Jun-09	16:42:55	4
5	3	3D9.1C2D3AE167	1-Jul-09	7:21:40	4
6	1	3D9.1C2D3AE167	1-Jul-09	7:25:34	4
7	3	3D9.1C2D3AC986	1-Jul-09	7:49:08	3
8	3	3D9.1C2D3F6DF9	1-Jul-09	8:14:50	3
9	3	3D9.1C2D3AC986	1-Jul-09	8:14:51	3
10	3	3D9.1C2D3AE167	1-Jul-09	8:16:18	4
11	3	3D9.1C2D3AC986	1-Jul-09	8:16:46	3
12	3	3D9.1C2D3AC986	1-Jul-09	8:16:47	3
13	3	3D9.1C2D3F6DF9	1-Jul-09	8:16:47	3
14	1	3D9.1C2D3F6DF9	1-Jul-09	8:34:12	3
15	3	3D9.1C2D3AE167	1-Jul-09	8:44:49	4
16	1	3D9.1C2D3AE167	1-Jul-09	8:46:46	4
17	3	3D9.1C2D3F6DF9	1-Jul-09	8:50:48	3
18	3	3D9.1C2D3AE167	1-Jul-09	9:07:17	4
19	1	3D9.1C2D3F6DF9	1-Jul-09	9:23:18	3
20	1	3D9.1C2D3AE167	1-Jul-09	9:23:46	4
21	3	3D9.1C2D3AE167	1-Jul-09	9:29:09	4
22	1	3D9.1C2D3AC986	1-Jul-09	11:19:25	3
23	3	3D9.1C2D3AC986	1-Jul-09	11:20:01	3
24	1	3D9.1C2D3AC986	1-Jul-09	11:27:06	3
25	2	3D9.1C2D3AC986	1-Jul-09	12:00:38	3
26	2	3D9.1C2D3AC977	1-Jul-09	16:33:09	3
27	3	3D9.1C2D3B9D9C	1-Jul-09	17:21:21	3
28	1	3D9.1C2D3AC986	1-Jul-09	19:22:09	3
29	3	3D9.1C2D3F9785	2-Jul-09	6:59:56	2
30	2	3D9.1C2D3F855B	2-Jul-09	8:14:36	2
31	1	3D9.1C2D41D181	2-Jul-09	15:10:27	3
32	2	3D9.1C2D418E3B	3-Jul-09	7:57:50	2
33	2	3D9.1C2D3C7761	4-Jul-09	6:51:28	1
34	2	3D9.1C2D3D81B4	4-Jul-09	7:07:19	2
35	3	3D9.1C2D3BBBB8	4-Jul-09	8:17:02	1
36	2	3D9.1C2D3F8D87	4-Jul-09	8:30:22	6
37	3	3D9.1C2D3F6A9E	4-Jul-09	13:21:43	4
38	1	3D9.1C2D3AC7EC	4-Jul-09	16:37:48	3
39	2	3D9.1C2D3F731F	5-Jul-09	11:12:10	2
40	2	3D9.1C2D3F64C3	6-Jul-09	8:24:14	2
41	1	3D9.1C2D41C715	6-Jul-09	12:51:47	2
42	2	3D9.1C2D41985A	7-Jul-09	0:51:53	2
43	2	3D9.1C2D41A201	8-Jul-09	15:26:54	2
44	3	3D9.1C2D3AC5E9	8-Jul-09	15:47:58	4
45	3	3D9.1C2D3BA8AB	8-Jul-09	16:57:22	3

46	3	3D9.1C2D3AC5E9	9-Jul-09	15:48:59	4
47	3	3D9.1C2D3F7D70	10-Jul-09	7:53:32	1
48	1	3D9.1C2D3A6329	10-Jul-09	9:17:59	3
49	2	3D9.1C2D3A6329	10-Jul-09	9:18:03	3
50	3	3D9.1C2D3AEE5D	10-Jul-09	17:44:59	3
51	1	3D9.1C2D3BB49E	10-Jul-09	19:53:39	3
52	1	3D9.1C2D3DAB14	10-Jul-09	20:41:49	6
53	3	3D9.1C2D3AEE5D	11-Jul-09	16:51:20	3
54	1	3D9.1C2D3DAB14	11-Jul-09	20:22:54	6
55	2	3D9.1C2D3AEE5D	12-Jul-09	6:38:28	3
56	3	3D9.1C2D3AEE5D	12-Jul-09	7:37:59	3
57	2	3D9.1C2D3AEE5D	12-Jul-09	7:40:41	3
58	1	3D9.1C2C613D74	12-Jul-09	15:20:58	3
59	2	3D9.1C2D3A86D6	12-Jul-09	18:48:04	3
60	2	3D9.1C2D3AEE5D	13-Jul-09	10:36:42	3
61	3	3D9.1C2D3BDF72	13-Jul-09	13:23:50	4
62	2	3D9.1C2D3BDF72	13-Jul-09	13:33:46	4
63	3	3D9.1C2D3AEE5D	13-Jul-09	15:00:42	3
64	1	3D9.1C2D3AEE5D	13-Jul-09	15:07:20	3
65	2	3D9.1C2D3AEE5D	13-Jul-09	15:07:36	3
66	3	3D9.1C2D41A799	13-Jul-09	17:33:17	3
67	1	3D9.1C2D41A799	13-Jul-09	17:39:46	3
68	1	3D9.1C2C6122F1	13-Jul-09	19:56:07	4
69	2	3D9.1C2C6122F1	14-Jul-09	5:10:39	4
70	3	3D9.1C2C6122F1	14-Jul-09	11:09:57	4
71	3	3D9.1C2C6122F1	14-Jul-09	17:03:12	4
72	2	3D9.1C2C6122F1	14-Jul-09	17:06:59	4
73	2	3D9.1C2D3BA6F9	15-Jul-09	6:18:30	3
74	1	3D9.1C2D3BA6F9	15-Jul-09	6:59:40	3
75	2	3D9.1C2D3BA6F9	15-Jul-09	7:05:46	3
76	2	3D9.1C2D3BA6F9	15-Jul-09	9:47:22	3
77	2	3D9.1C2D3BA6F9	15-Jul-09	11:20:51	3
78	2	3D9.1C2D3A6329	15-Jul-09	19:23:31	3
79	1	3D9.1C2D3BA6F9	15-Jul-09	20:05:23	3
80	2	3D9.1C2D3BA6F9	15-Jul-09	20:11:30	3
81	3	3D9.1C2D3A6329	16-Jul-09	19:37:54	3
82	2	3D9.1C2D41C47B	20-Jul-09	0:59:01	2
83	4	3D9.1C2D3F913C	21-Jul-09	20:43:13	3
84	3	3D9.1C2D3A9BB4	23-Jul-09	17:31:52	3
85	2	3D9.1C2D3AA148	25-Jul-09	12:57:26	3
86	4	3D9.1C2D3AA148	25-Jul-09	12:59:45	3
87	4	3D9.1C2D3AA148	25-Jul-09	12:59:51	3
88	4	3D9.1C2D3AF053	25-Jul-09	12:59:51	3
89	4	3D9.1C2D3AF053	26-Jul-09	13:26:02	3
90	3	3D9.1C2D3AF053	26-Jul-09	13:26:34	3
91	2	3D9.1C2D3AF053	26-Jul-09	13:47:49	3
92	2	3D9.1C2D3F6DF9	27-Jul-09	0:02:40	3
93	4	3D9.1C2D3F6DF9	27-Jul-09	18:18:28	3
94	3	3D9.1C2D3F6DF9	27-Jul-09	18:22:54	3
95	3	3D9.1C2D3F6DF9	27-Jul-09	18:23:59	3

96	3	3D9.1C2D3F6DF9	27-Jul-09	23:23:25	3
97	3	3D9.1C2D3F6DF9	28-Jul-09	0:31:12	3
98	3	3D9.1C2C6145D0	28-Jul-09	14:30:40	2
99	2	3D9.1C2D3ADCAD	28-Jul-09	15:38:05	3
100	3	3D9.1C2D3AD53E	31-Jul-09	13:11:20	3
101	1	3D9.1C2D3AD53E	31-Jul-09	13:19:18	3
102	3	3D9.1C2D3C5922	31-Jul-09	17:40:10	4
103	3	3D9.1C2D3BA36B	2-Aug-09	2:52:31	3
104	4	3D9.1C2D3BA36B	2-Aug-09	2:53:20	3
105	2	3D9.1C2D3BA36B	2-Aug-09	2:55:49	3
106	2	3D9.1C2D3AB04C	6-Aug-09	15:41:15	3
107	1	3D9.1C2D3AB04C	6-Aug-09	15:42:39	3
108	1	3D9.1C2D41C0C3	7-Aug-09	15:18:07	1
109	4	3D9.1C2D41C0C3	7-Aug-09	15:18:23	1
110	2	3D9.1C2D41C511	8-Aug-09	6:15:26	3
111	2	3D9.1C2D3F93B2	8-Aug-09	23:51:13	3
112	4	3D9.1C2D3C4061	9-Aug-09	13:24:12	3
113	1	3D9.1C2D41B360	11-Aug-09	10:16:44	3
114	2	3D9.1C2D3DAE6C	12-Aug-09	17:19:18	3
115	2	3D9.1C2D3AC4E0	19-Aug-09	7:05:21	3
116	3	3D9.1C2D3AC4E0	19-Aug-09	7:05:51	3
117	2	3D9.1C2D3F97AF	22-Aug-09	16:13:32	1
118	4	3D9.1C2D3F97AF	22-Aug-09	16:13:48	1
119	2	3D9.1C2D3D8206	23-Aug-09	15:24:07	3
120	2	3D9.1C2D3F6826	24-Aug-09	1:16:40	1
121	3	3D9.1C2D3F6826	24-Aug-09	1:16:59	1
122	2	3D9.1C2D3F77F4	26-Aug-09	8:55:34	2
123	4	3D9.1C2D3F77F4	26-Aug-09	8:55:53	2
124	4	3D9.1C2D425A43	26-Aug-09	13:15:33	2
125	4	3D9.1C2D3AC30C	27-Aug-09	15:51:57	1
126	2	3D9.1C2D41CB50	28-Aug-09	17:28:18	2
127	4	3D9.1C2D41CB50	28-Aug-09	17:28:49	2
128	2	3D9.1C2D3D9DF4	31-Aug-09	21:17:39	2
129	4	3D9.1C2D3D9DF4	31-Aug-09	21:17:55	2
130	3	3D9.1C2D3D9DF4	31-Aug-09	21:17:55	2
131	3	3D9.1C2D3AEE64	3-Sep-09	1:09:54	3
132	1	3D9.1C2D3B9F70	9-Sep-09	4:50:30	3
133	2	3D9.1C2D3F7C30	10-Sep-09	0:49:08	2
134	1	3D9.1C2D3F7C30	10-Sep-09	0:49:10	2
135	1	3D9.1C2D3F7A16	17-Sep-09	0:07:16	1
136	2	3D9.1C2D3F8CCB	17-Sep-09	12:44:33	2
137	2	3D9.1C2C67FC3C	17-Sep-09	16:40:11	2
138	1	3D9.1C2D419138	20-Sep-09	12:26:30	2
139	2	3D9.1C2D41B694	10-Oct-09	1:09:06	2
140	4	3D9.1C2D3AA148	19-Oct-09	7:59:24	3
141	4	3D9.1C2D3AA148	19-Oct-09	8:41:00	3
142	4	3D9.1C2D3AA148	19-Oct-09	9:45:51	3
143	3	3D9.1C2D3AA148	19-Oct-09	13:04:18	3
144	4	3D9.1C2D3AA148	19-Oct-09	21:23:41	3
145	4	3D9.1C2D3AA148	19-Oct-09	23:18:15	3

146	4	3D9.1C2D3AA148	20-Oct-09	6:11:13	3
147	2	3D9.1C2D3C6D3F	30-Oct-09	3:55:28	1
148	3	3D9.1C2D3AC952	22-Nov-09	15:19:17	1
149	4	3D9.1C2D3C8344	9-Dec-09	23:34:30	1
150	2	3D9.1C2D41C4BA	14-Dec-09	6:22:33	1
151	4	3D9.1C2D41C4BA	14-Dec-09	6:22:53	1
152	3	3D9.1C2D41A42D	20-Dec-09	4:39:10	1
153	1	3D9.1C2D3BBEAF	19-Jan-10	15:26:05	1
154	3	3D9.1C2D3DA24C	6-Feb-10	20:30:48	2
155	2	3D9.1C2D418E2A	8-Feb-10	2:29:36	2
156	3	3D9.1C2D418E2A	8-Feb-10	2:30:21	2
157	2	3D9.1C2D41CBE3	10-Feb-10	18:00:47	1
158	4	3D9.1C2D41CBE3	10-Feb-10	18:01:08	1
159	1	3D9.1C2D41D33A	2-Mar-10	12:29:02	2
160	4	3D9.1C2D3A7C77	2-Mar-10	21:01:12	2
161	2	3D9.1C2D3F8460	12-Apr-10	20:48:54	2
162	1	3D9.1C2D3F8460	12-Apr-10	20:48:54	2
163	1	3D9.1C2D3ACD34	23-Apr-10	18:24:08	5
164	1	3D9.1C2D3F896C	14-May-10	21:38:00	5
165	3	3D9.1C2D3C78B4	10-Jun-10	12:35:23	1
166	3	3D9.1C2D3C78B4	13-Jun-10	20:25:37	1
167	1	3D9.1C2D3C78B4	13-Jun-10	21:25:36	1
168	2	3D9.1C2D3C78B4	14-Jun-10	4:54:26	1
169	3	3D9.1C2D3C78B4	14-Jun-10	6:51:09	1