COLORADO RIVER RECOVERY PROGRAM
FY 2016 ANNUAL PROJECT REPORT

RECOVERY PROGRAM
PROJECT NUMBER: C-28a

I. Project Title: Stationary PIT detection system in the Green River Canal, Green River, UT

II. USU Cooperative Agreement Number: R11AC40005
Lead Agency: U.S. Bureau of Reclamation

III. Principal Investigators:

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Date: December 26, 2016

IV. Abstract:

The goal of this project is to evaluate entrainment of native fish (PIT-tagged non-listed and endangered individuals) in the Green River Canal (near Green River, Utah) using a passive interrogation array (PIA). The PIA includes two locations, named the flume and siphon locations, of two antennas each. In 2016, 243 individual fish were detected in the Green River Canal during the irrigation season (April – November), which represents the lowest total since antennas were installed in 2013. Of these, 151 were identified through Species Tagging, Research and Monitoring System (STReaMS; streamsystem.org) and were comprised of 126 razorback sucker, 7 bonytail, 15 Colorado pikeminnow, 2 humpback chub, and 1 flannelmouth/razorback hybrid.

V. Study schedule: FY13-FY16

VI. Relationship to RIPRAP:

Green River Action Plan

II.	Restore habitat
II.B.2	Screen Tusher Wash diversion to prevent endangered fish entrainment, if warranted
II.B.2.b	Design.
II.B.2.c	Construct.

VII. Accomplishment during FY 2016: Tasks and Deliverables, Discussion of Initial Findings and Shortcomings:

Task 1: March-November 16, 2016 (irrigation season): Activate and operate system; download antennae data, perform diagnostics, repair system if necessary; system shut-down. The antennas operated from April 1st to November 16th, 2016, with a single outage occurring between April 7 and April 28 on antenna four.

Prior to the onset of the 2016 irrigation season, we consulted with canal company representative on proper placement of antenna cables and/or antenna loops and made adjustments to not interfere with canal dredging operations. System was activated prior to the onset of the 2016 irrigation season (April 2016).

Task 2: December: Annual report.

Findings from the antennas from 2013-2016 are provided in the attached report, but are subject to change as data are further analyzed.

VIII. Recommendations:

- Continue to analyze data to determine entrainment characteristics (species, timing).
- Continue to pursue a remedy for entrainment under Project C28. Use entrainment data collected under this project to assist in the design of the entrainment solution. Use data on antenna performance to assist in the design of antenna locations as part of entrainment solution.

IX. Project Status: Ongoing

X. FY 2016 Budget Status

A.	Funds Provided:	$ 6,025
B.	Funds Expended as of September 30, 2016:	$ 6,025
C.	Difference:	$0

D. Percent of the FY 2016 work completed, and projected costs to complete: 100%.
E. Recovery Program funds spent for publication charges: $0

XI. Status of Data Submission (where applicable): Entrainment data from April through November 16, 2016 has been submitted to STReaMS.

Signed: /s/ Dave Speas December 26, 2016
Principal Investigator

Appendix A:
Preliminary results of entrainment in the Green River Canal, 2013-2016.

J.Stahli & K. McAbee (USFWS), D. Speas (USBOR), P. McKinnon (USU), T. Jones (USFWS).

Entrainment in irrigation canals is believed to be a substantial source of mortality for endangered fishes in the Upper Colorado basin. As a result, the Upper Colorado Endangered Fish Recovery Program (Recovery Program) has installed screens at multiple irrigation canals in the Grand Valley of Colorado. The Green River Canal on the west side of Tusher Diversion near Green River, Utah has also been a location the Recovery Program has considered screening. However, the large hydropower water right and other physical constraints have made installation of a screen cost prohibitive. While other entrainment prevention options were being investigated, the Recovery Program decided that more fully understanding the entrainment risk at the Green River Canal was warranted.

The Tusher Diversion provides water to many facilities on both the east and west sides of the river. On the west side of the river, an open channel "raceway" conveys up to 700 cfs to the Green River Canal (up to 85 cfs), Thayn Hydropower (up to 600 cfs), and Thayn irrigation (up to 35 cfs). At the end of the raceway, both Thayn hydropower and irrigation enter into a screened hydropower facility, where power is generated and irrigation water is pumped uphill. The remaining water enters into the unscreened Green River Canal. Large bodied fish cannot enter the hydropower facility, so the hypothesis is that the Green River Canal likely entrains fish at as much as 10 times its water use.

In 2013, the Recovery Program installed a passive interrogation array (PIA) consisting of two pass through antennas in the Green River Canal to assess potential entrainment in the canal by detecting the presence of passive integrated transponder (PIT) tags. This PIA was located just downstream of the water flume that measures the intake of the canal (Figure 1). 2013 results demonstrated large scale entrainment (Table 1), which was very worrisome to the Recovery Program. However, stakeholders felt that detections at the flume antennas did not necessary indicate mortalities, because large bodied fish could swim upstream back the river unimpeded. So in 2014, another dual-antenna PIA was installed on the downstream side of an underground canal siphon (Figure 1). It is believed that upstream passage through the siphon is much more problematic for fish, so detection at this PIA likely indicates high entrainment mortality

Historic runoff in the spring of 2011 greatly stressed the 100+ year old Tusher Diversion in the Green River, making it less effective at providing water and more difficult for fish to pass over during the base flow period. Beginning after irrigation season 2015, the Tusher Diversion was completely rehabilitated to provide a more consistent water supply to all the water users. Therefore, it is important to consider this diversion replacement when considered entrainment rates pre- and post-2015.

Since installation (2013-2016 irrigation seasons), 1604 tagged individuals have been detected by at least one antenna in the canal. The most commonly detected species is razorback sucker *Xyrauchen texanus* (69%), followed by Colorado pikeminnow *Ptychocheilus lucius* (9%) and bonytail *Gila elegans* (7%). Other minimally represented species include humpback chub *Gila cypha*, flannelmouth sucker *Catostomus latipinnis*, a hybrid between flannelmouth and razorback

sucker, and individuals currently unidentified within the Species Tagging, Research and Monitoring System (STReaMS; streamsystem.org) (Table 1). At least one individual of each of the four endangered species has been detected in each year of operation. The number of individuals detected in the canals has decreased every year of operation, which may be related to flows in the Green River.

Antenna Effectiveness

Because the antennas installed at the Green River Canal are pass-through antennas offering complete coverage of the irrigation channel, it was expected that all fish swimming through the antennas would be detected. However, electrical 'noise' in field locations, fish swimming behaviors, PIT tag orientation, and antenna age are all known to impact antenna performance. Antennas have been installed in pairs to reduce detection failure at a given location, which can occur if a fish swims too far away from the edges of the antenna (which can occur at the top of the water column in a ditch system) or if a fish swims around small gaps between the antenna and the banks or bottom of the canal. We therefore analyzed detection rates on individual antennas and antenna pairs in order to determine if antenna performance was adequate to provide a thorough understanding of entrainment and to provide other information, such as movement.

The first two antennas installed in the Green River Canal flume were 4' by 16' pass through antennas, originally installed in the Maybell Ditch (which were removed after the Maybell entrainment study was completed). In March 2014, two siphon antennas were installed consisting of upgraded components (2 Biomark IS1001 antenna nodes with master controller and 2, 20' "stout" pass-by antennas). In March of 2015, the flume PIA was upgraded to the same equipment (2 Biomark IS1001 antenna nodes and 20' stout pass-by antennas), making the entire system up-to-date.

During the first four years of operation, the effectiveness of the antenna closest to the raceway is approximately 50% (Table 2); that is 50% of all detected fish passed through the first antenna without being detected. The two flume antennas together detected just over 80% of all fish, indicating that about 20% of all detected fish were not detected at the first antenna pair. This analysis is based on examining only the first detection in any given year for each individual fish, assuming that individuals could not survive the winter in the canal itself and that each individual must come from the raceway. By multiplying the probability a fish is not detected by either of the first two antennas (19%) by itself, we can calculate a total efficiency of all four antennas of approximately 96%. That is, the chance that a fish is not detected by either of the first two antennas (19%), times the chance that it is not detected by either of the second two antennas (19%), is the chance that a fish could swim through all four antennas and not be detected (3.6%). This indicates that 96% of PIT-tagged individuals who passed over all four antennas would be detected at one or more of the antennas (which also suggests that around 64 PIT-tagged individuals in the canals were not detected over a 4 year period).

Some species specific differences in detection effectiveness can also be seen. The species most likely to be detected on the first antenna (64%) and the first pair of antennas (90%) was the Colorado pikeminnow (Table 2). Increased detection probability may be because of large body size or the location in the water column in which they are likely to swim. The least likely species to be detected on the first antenna (20%) or the first pair of antennas (49%) is the bonytail.

Twenty-five percent of all bonytails detected in the canal were first detected on the fourth antenna. The cause of decreased detection probabilities is unknown. Current theories include: position in the water column as they are likely to swim on the top of the water, the ability/desire to swim into small spaces like the areas between the antenna and the substrate of the canal, or possibly the PIT tag placement in the fish during stocking events. Inserting the PIT tag perpendicular to the fish instead of parallel is known to decrease detection probabilities (Peter MacKinnon, personal communication).

Effects of Entrainment

Recovery Program participants have long debated the estimated mortality rates in the Green River Canal because the siphon is the only upstream barrier to return to the river and because few large bodied fish are found during autumn canal salvage (Ahrens and Jones, 2016). Long-term, multi-location PIT tag datasets allow us to determine individual fish locations after being present in the canal and assess if individual fish are surviving post-entrainment. In the Green River Canal, approximately 20% of individuals are only seen at the flume antennas, where 80% swim through the siphon to the siphon antennas (Table 3). About 18% of individuals detected in the canal are detected or captured elsewhere in the system subsequently, indicating canal escapement. However, 88% of those fish were only detected at the flume antenna. Of 177 individuals only detected at the flume, 152 were detected again outside the canal (~86%), whereas of the 777 individuals detected at the siphon antennas, only 21 (2.7%) have been encountered outside of the canal subsequently. This indicates that entrainment into the Green River Canal is not fatal unless individuals swim through the siphon, but that entrainment past the siphon is likely to result in mortality. Note that the above calculations only include data from 2014-2016 because the siphon antennas were not installed in 2013.

Individuals encountered after the canal have been detected as close as the Tusher Diversion (almost adjacent to the canal), and as far away as the White and Colorado Rivers. Multiple Colorado pikeminnow and a single bonytail have been captured in the Green and Colorado Rivers after detections in the canal, indicating trans-basin movement. Of the 21 individuals that were encountered outside of the canal after being detected at the siphon PIA, the majority of identified fish (five) were Colorado pikeminnow, indicating strong swimming ability may be required to escape the siphon. Eleven of the 21 fish are unidentified fish in the STReaMS systems, but the majority were captured multiple times in the Price River indicating these may be fish tagged during three species work.

Timing and Flow Relationships

Determining a statistical relationship between flow and timing of entrainment is unlikely, but some patterns can be determined by graphing both flow in the Green River and the percentage of Green River Flow diverted into the raceway against the number of fish entering the canal in any given week. It is important to note that the canal is only open during irrigation season, so the antennas are also off from December to February (or later) of each year.

Daily flow averages for the Green River (USGS 09315000) were obtained from the USGS gage at Green River Utah[1]. Flow in the Green River seems to have little impact on the number of fish entrained in any given week, but more individuals were entrained when flows were low in 2013 than in other years (Figure 2). Some species specific indicators are present in multiple years. For example, the majority of Colorado pikeminnow typically do not enter the canal until the descending limb of spring flows, indicating they are more likely to enter the canal when swimming downstream after spawning. Additional trends in entrainment are discussed in the species specific trends below.

We also compared initial entrainment date to the percentage of the river being diverted into the raceway. In order to calculate the percentage, Green River data were used in conjunction with information from the water rights that are diverting water from the river. Daily average flow values for the Green River Eastside Canal (GRC East), Green River Canal Company (GRC) and the Green River Thayns Diversion (Thayns) were obtained from the Utah Division of Water Resources[2]. The percentage of flow in the raceway was calculated using the following formula:

$$\text{Raceway \%} = \frac{\text{hydro plant (assumed 600 cfs)} + \text{Thayns Diversion} + \text{GRC}}{\text{Green River} + \text{hydro plant} + \text{Thayns} + \text{GRC} + \text{GRC East}}$$

In 2013, low flows in the river caused a higher percentage of flow to be diverted into the raceway above the Green River Canal (Figure 3). The highest percentage of flow was diverted into the raceway during the winter of 2013-2014, which would have had little impact on individual fish as the canal was shut during that time period. During August 2013, about 35% of the river was diverted into the canal, and corresponding increases in entrainment were seen in Colorado pikeminnow and unidentified fish.

An examination of hourly trends indicates that neither initial entrainment nor number of detections is strongly effected by hour.

Species Specific Trends

Humpback chub

Only 5 humpback chub were detected in the canal between 2013 and 2016, none of which have been detected or captured since being present in the canal. All individuals were initially tagged as part of Desolation-Gray Canyons population estimates and moved downstream. Three have canal detections far removed from known sampling, but two individuals were detected in the canal within two days of being captured more than once in the Green River (9/24/15 and 9/23/14). Although detections of humpback chub are rare, they are important because they demonstrate emigration between core population areas. Humpback chub have high site fidelity and are not often encountered outside of core populations, such as Desolation & Gray Canyons.

Bonytail

1 https://waterdata.usgs.gov/ut/nwis/uv?site_no=09315000
2 https://www.waterrights.utah.gov/distinfo/realtime_info.asp

All bonytail detected in 2013 and 2014 were stocked in the same year in either the Green River or the White River. Over 75% of bonytail detected in the canal in 2014 were stocked in a single event on the White River by WAHWEAP in May; they were subsequently detected in the canal between August and October.

In contrast, the data from 2015 and 2016 indicate that bonytail are surviving over at least one winter in the river. Thirty-three bonytail detected in 2015 were stocked in 2014, and 26 of those were stocked on a single day (August 29, 2014) at mile 120 in the Green River by Ouray NFH. Mile 120 is about 10 miles downstream of the canal and the associated Tusher Diversion structure. Therefore, all of these fish moved upstream over the structure before it was rebuilt. All individuals detected from this stocking event were above 260 mm in total length (TL) at the time of stocking. All 7 of the individuals detected in the canal in 2016 were stocked in 2015, with no discernable patterns in stocking date or location. All individuals were above 240 mm TL at the time of stocking. The majority of the fish entered the canal during the spring and were last detected at the siphon antennas which may indicate mortality (Figure 4). Although a single individual detected in 2016 was detected last at the siphon antennas but detected two months later using the fish passage on the Tusher Diversion (8/22/16) indicating less than 100% mortality of bonytail detected at the siphon.

Colorado pikeminnow

Colorado pikeminnow are the second most common species detected in the canal and are the most likely to be detected/captured after being in the canal with approximately 20% proven survival after entrainment. Current theories as to why include the fact that they are strong swimmers and can swim out of the canal effectively or the long distance of travel makes them more likely to cross a PIA. Individuals have been captured or detected in the Green, White, Colorado, and Price rivers after being detected in the canal.

As noted above, Colorado pikeminnow are more likely to enter the canal on the descending limb of high flows, typically while moving downstream. The vast majority of the fish seen in the canal were also seen in the Green River, but many others have been seen throughout the Upper Colorado basin, in the Green, White, Yampa, Colorado, Price, San Rafael and Gunnison rivers over 16 years of sampling. During most of those 16 years, PIA locations did not exist, providing an incomplete picture of movement. As more PIA locations are brought online across the basin, more documentations of consistent long-range movement of Colorado pikeminnow are likely.

Razorback sucker

Razorback sucker are the most common species detected in the canal, but the number of individuals detected in a given year has been decreasing over time (531 in 2013 to 126 in 2016, Table 1). Individual razorback suckers enter the canal throughout the irrigation season, with the highest per day additions entering during peak flow periods. The majority of fish are last detected at the siphon and have not been seen again, which could indicate mortality, but a few of the exceptions offer interesting patterns. Twenty-nine razorback suckers have been detected in the canal in more than one year. Twenty-eight of those were detected in the same month of two given years. The two most common months for this phenomenon are July and September. For example, one razorback sucker (3D91C2C5D0460) was stocked in September of 2009 about 10

miles below the diversion dam. The same fish was detected in the canal for two days during September of 2014, and then again over three days during September of 2015. In fact, 21 of the 28 fish seen in multiple years were stocked in September of varying years between 2009 and 2012 at the same river mile (Green River, 120).

Conclusion

In summary, the data from the four antennas indicate that entrainment into canals can be a substantial sink for the endangered species of the Upper Colorado River basin, and is likely to be higher in years when the canals are taking a large percentage of the river for irrigation. All four endangered species were detected in the canal in all four years of data with additional representation from flannelmouth suckers and a hybrid sucker. Anecdotal data indicate that fish are at higher entrainment risk when swimming downstream, rather than upstream, which is logical given the orientation of the raceway entry. The data also suggest that entrainment mortality is not certain, as some individuals are detected or captured after being entrained in the canal. Permanent entrainment is much more likely once an individual reaches the siphon antennas. Species specific trends are beginning to emerge from the data and may provide the Recovery Program with possible questions to query further, but need additional research to be significantly valid.

The data from the Green River Canal also illuminates the power of a single database with records from the entire Upper Colorado River basin to link records of specific fish together. Additional data work will be needed to fill in some of the data holes, specifically the records of unidentified species. The system also becomes stronger with the addition of antennas where possible. Each antenna adds a tremendous amount of data inaccessible from sampling and stocking alone.

Figure 1. Locations of PIAs in relationship to the Green River Canal (GRC) and the Green River.

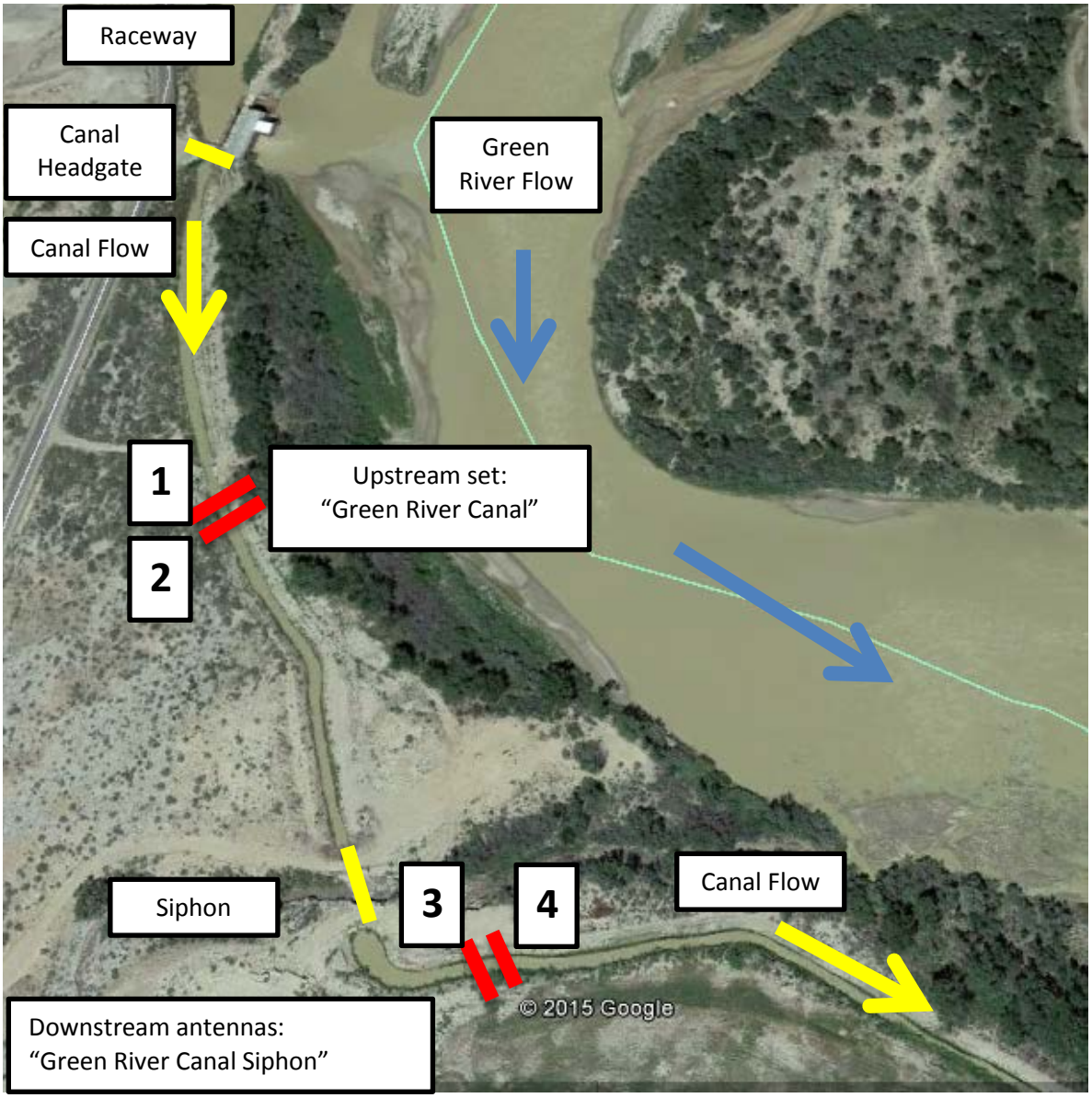

Table 1. Total individuals detected by species during each year of operation. Totals indicate individuals captured during all years (summing years does not equal totals as some individuals were seen in multiple years).

Species	2013	2014	2015	2016	Total
flannelmouth sucker	7	6	2		14
FM x RB	1	1		1	3
humpback chub	1	1	1	2	5
bonytail	8	26	77	7	116
Colorado pikeminnow	102	21	18	15	149
unidentified	45	59	25	92	214
razorback sucker	531	302	182	126	1103
Total	695	416	305	243	1604

Table 2. Percentage of first detection in a given year by antenna. Using detection patterns can determine effectiveness of paired arrays.

Species	1	2	3	4
flannelmouth sucker*	53%	13%	20%	13%
FM x RB*	100%	0%	0%	0%
humpback chub*	40%	20%	40%	0%
bonytail	20%	29%	25%	25%
Colorado pikeminnow	64%	26%	8%	2%
unidentified	54%	14%	27%	5%
razorback sucker	50%	36%	11%	3%
Total Effectiveness	50%	31%	14%	5%

Table 3. Individual outcomes after detection at Green River Canal antennas

2014 - 2016	Detected only at Flume		Detected at Siphon		
Species	Not detected after canal	Detected after canal	Not detected after canal	Detected out of canal Made it through/out of the siphon	Grand Total
flannelmouth sucker		1	6	1	8
FMxRB			2		2
humpback chub		1	3		4
bonytail		10	97	1	108
Colorado pikeminnow	15	7	25	5	52
Unidentified	4	13	147	11	175
Razorback sucker	6	120	476	3	605
Grand Total	**25**	**152**	**756**	**21**	**954**

Figure 2. Number of individuals initially entrained in a given week by species in relationship to the flow of the Green River over time.

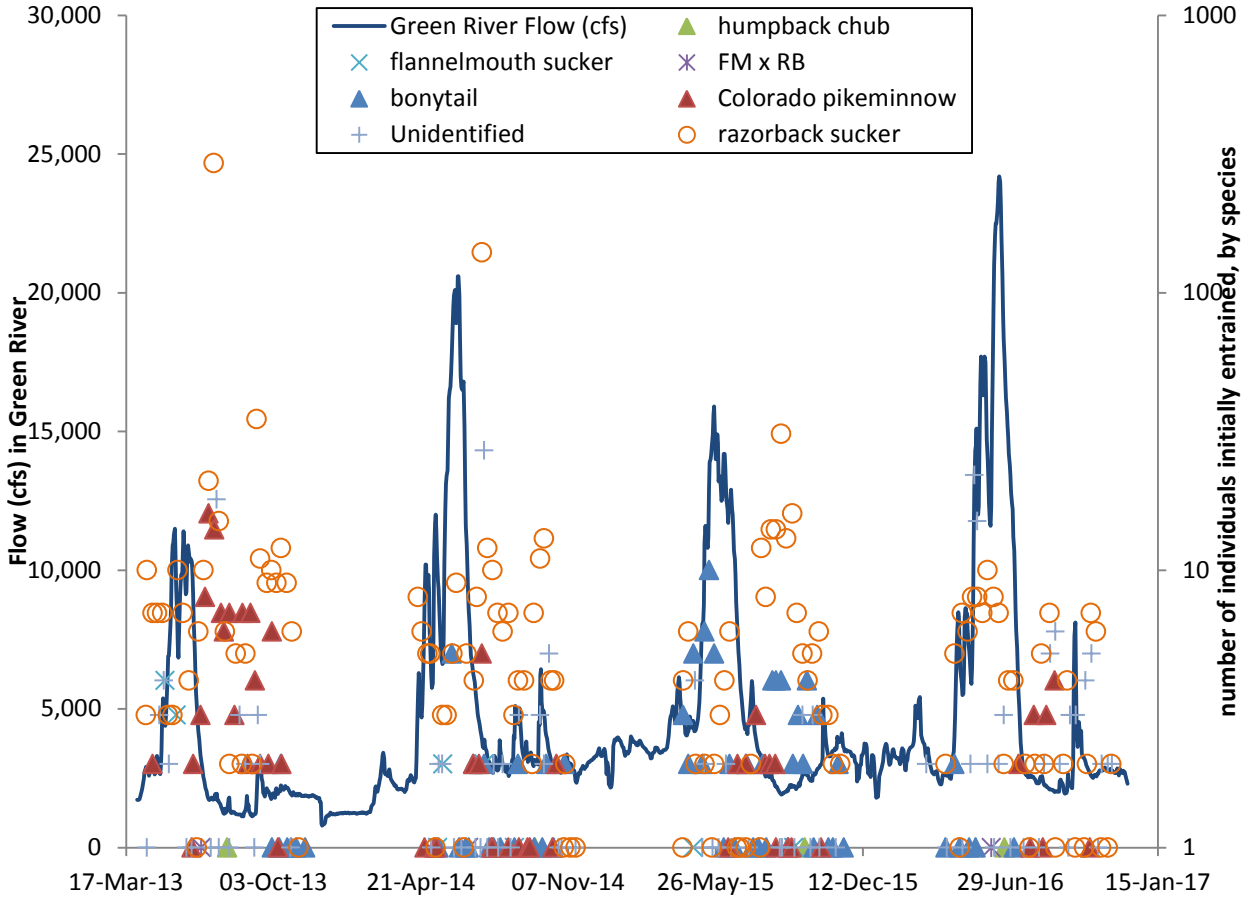

Figure 3. Number of individuals initially entrained in a given week by species in relationship to the percentage of Green River flow diverted into the raceway over time.

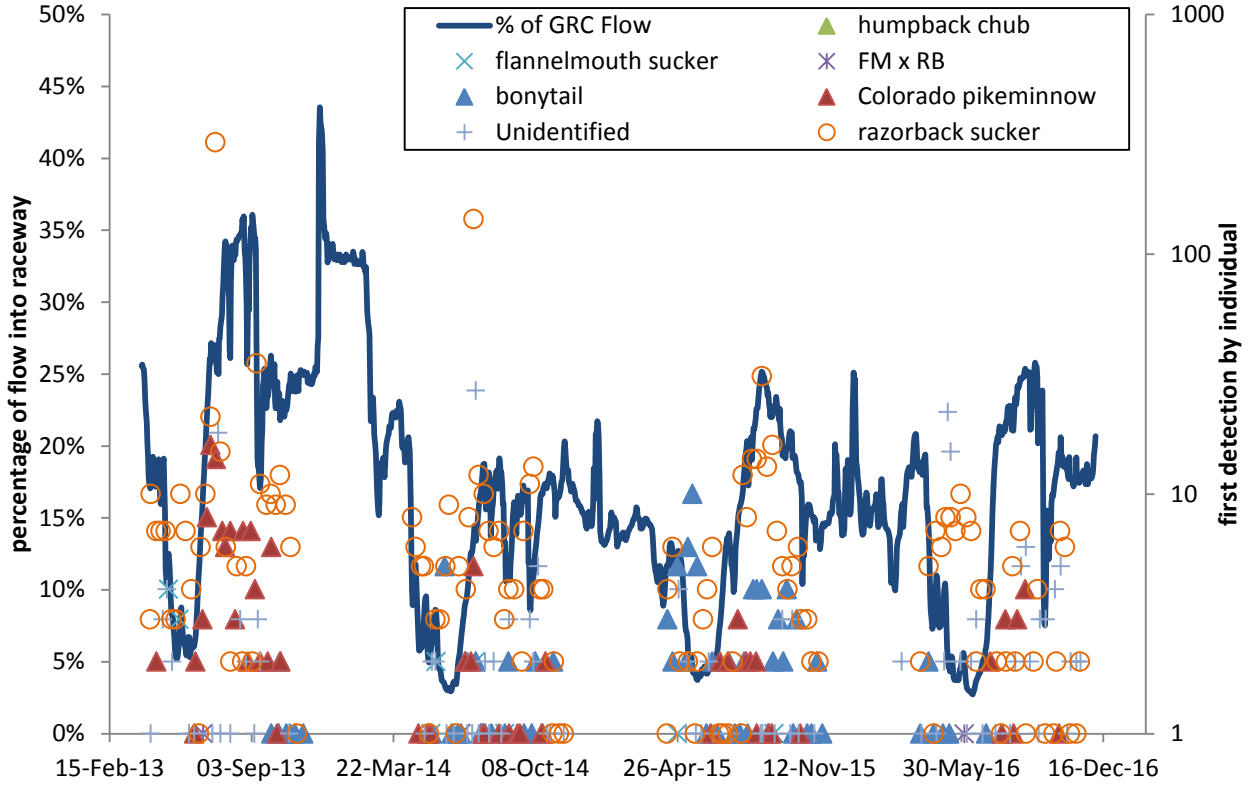

Figure 4. Number of individuals initially entrained in a given week by species in relationship to the flow of the Green River in 2016.