STREAM HABITAT INVESTIGATIONS AND ASSISTANCE
PROJECT SUMMARY

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STREAM HABITAT INVESTIGATIONS AND ASSISTANCE
PROJECT SUMMARY

Period Covered: July 1, 2020 through June 30, 2021

PROJECT OBJECTIVE:

To advance the science of stream restoration for the benefit of sportfish management and native species conservation in Colorado; to collect data and conduct experiments for the evaluation of stream restoration and fish passage projects; to provide technical assistance in support of project assessment, design, and evaluation

RESEARCH PRIORITY:

Upper Arkansas River Habitat Restoration Project, Arkansas River

OBJECTIVES

Project objectives were identified in the *Restoration Monitoring and Outreach Plan for the Upper Arkansas River Watershed* (Stratus 2010), including:

1) Increase fish population, fish health, and benthic macroinvertebrate metrics by at least 10% over baseline conditions by year 5
2) Increase riparian vegetation cover by at least 10% over baseline conditions in fenced and replanted areas by year 3
3) Increase habitat quality scores by at least 10% over baseline conditions by year 5
4) Demonstrate that 90% of habitat improvement structures were stable and functional by year 3

INTRODUCTION

The Upper Arkansas River Habitat Restoration Project was implemented to rehabilitate and enhance aquatic habitat for an 11-mile reach of the Arkansas River and Lake Fork near Leadville, Colorado. Funding for the project was obtained under the Natural Resource Damage Assessment (NRDA) provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Damages to natural resources were due to hazardous substances released from the California Gulch Superfund Site and physical disturbance from historic mining and land-use activities. The habitat project was designed to improve fish populations in the Upper Arkansas River (UAR) as partial compensation to the public. Colorado Parks and Wildlife (CPW) was responsible for habitat restoration on approximately five river miles with public fishing access within the Crystal Lakes State Trust Lands (STL), Reddy State Wildlife Area (SWA), and Arkansas Headwaters Recreation Area (AHRA). Restoration activities on the remaining six miles of river occurred on private lands and were implemented in partnership with the Lake County Conservation District, National Resource Conservation Service (NRCS), and individual landowners. Instream construction occurred during summer and fall months from 2012 to 2015.

Project goals were focused on enhancing Brown Trout *Salmo trutta* populations in the UAR, including increased population density and biomass, improved body condition, and improved age and size class structure. Habitat treatments addressed these goals by stabilizing stream banks and promoting diverse stream morphology, reducing erosion and downstream sedimentation, enhancing overhead cover for trout, increasing spawning areas, and providing refugia for juvenile trout (Stratus 2010). Monitoring targets were identified to evaluate project goals and inform adaptive management. Primary monitoring targets were focused on instream habitat structures, riparian vegetation, fish populations, benthic macroinvertebrates, and habitat quality scores. Secondary monitoring targets included water quality and geomorphology.

METHODS

Monitoring targets were identified by project trustees (Stratus 2010) and detailed methods were presented in Richer et al. (2017). A brief summary of primary monitoring targets and methods was provided below.

Fish Populations:
Fish population monitoring was conducted at 14 sites on the Arkansas River and Lake Fork to evaluate the effects of habitat restoration on Brown Trout density, biomass and quality using a Before-After-Control-Impact (BACI) study design. Fish population estimates for each site included Brown Trout density (#/hectare), biomass (kg/hectare), and quality (# ≥ 356 mm/hectare). Relative weights for individual fish were also evaluated at each site as index of fish condition. Site-specific changes in fish metrics were analyzed with a combination of parametric (t-test) and nonparametric (Wilcoxon Rank Sum test) methods, and the BACI study design was tested with a repeated measures ANOVA (RM ANOVA). Creel surveys were also conducted to evaluate trends in angler use.

Benthic Macroinvertebrates:
Dr. Will Clements with the Department of Fish, Wildlife and Conservation Biology at Colorado State University (CSU) was responsible for monitoring benthic macroinvertebrates. Restoration goals included a 10% increase in benthic macroinvertebrates metrics over baseline conditions by 2018 (Stratus 2010). Primary monitoring objectives were to evaluate if improvements in water quality, habitat quality, and riparian vegetation led to improved macroinvertebrate and prey resources for Brown Trout in the upper Arkansas River. Monitoring targets included water quality, benthic macroinvertebrate abundance, adult emergence, inputs of terrestrial and adult aquatic insects, and Brown Trout diets.

Riparian Vegetation:
Dr. Dan Baker with the Department of Civil & Environmental Engineering at CSU was responsible for monitoring riparian vegetation. The final monitoring event for vegetation surveys was conducted in August 2019, following baseline surveys in 2012, implementation surveys in 2015, and effectiveness surveys in 2017. Monitoring targets included vegetation plots and greenline surveys. The methods for greenline and vegetation surveys were outlined in Kulchawik and Bledsoe (2012).

Habitat Quality:
Three indices of habitat quality were used to evaluate changes following restoration: Weighted Usable Area (WUA), Foraging Positions (FP), and habitat heterogeneity. Detailed methods for habitat modeling were provided in Richer et al. (2017, 2019).

Instream Habitat Structures:
Instream habitat structures were surveyed in 2020 in accordance with the monitoring schedule developed in Stratus (2010). Annual assessments during 2014-2018 and 2020 were used to determine if at least 90% of all habitat improvement structures were stable and functional. Surveys utilized a rapid field assessment procedure developed by Miller and Kochel (2012) to evaluate integrity, erosion, and deposition at each structure.

RESULTS AND DISCUSSION

Progress towards project goals for primary monitoring targets was summarized in Table 1 and brief descriptions of monitoring results for fish populations, benthic macroinvertebrates, riparian vegetation, habitat quality, and instream habitat structures were provided below. Select before and after photos were presented in Figures 1-3.

Table 1. Primary monitoring targets for the Upper Arkansas River Habitat Restoration Project including a progress update for 2020-2021.

Monitoring Target	Goal	Progress Update
Fish populations	Increase fish population and fish health metrics by at least 10% over baseline conditions by 2018	Analyses found significant increases in trout density (10%), biomass (17%), and fish condition (2.4%) across all sites. The change in biomass at impact sites (21%) was greater than control sites (12%).
Benthic macroinvertebrates	Increase benthic macroinvertebrate metrics by at least 10% over baseline conditions by 2018	Metrics initially declined due to construction. The density of benthic macroinvertebrates subsequently increased (8%), but adult emergence, terrestrial inputs, and prey biomass did not.
Riparian vegetation	Increase riparian vegetation by at least 10% over baseline in fenced and replanted areas by 2018	Vegetation cover at plots did not change following restoration, but willow cover (8%) and height of willows both increased significantly. Greenline surveys documented vegetation encroachment and increased bank stability.
Habitat quality	Increase habitat quality scores by at least 10% over baseline conditions by 2018	Spawning habitat increased by 53%, depth heterogeneity increased by 15%, and residual pool depth increased by 49%.
Instream habitat structures	At least 90% of the habitat improvement	82% of habitat structures were stable and functional in 2020, which declined from

	structures were stable and functional by 2016	92% in 2018 and was attributed to flooding that occurred in 2019.

Fish Populations:
Results from fish population monitoring were summarized in Richer (2021) and a manuscript has been accepted for publication in the North American Journal of Fisheries Management (Richer et al. *In press*). In summary, significant improvements in Brown Trout biomass were observed at treatment sites. Trout density increased across all sites, but the change in density did not differ between control and treatment sites. Fish health (as indicated by the relative weight) also improved significantly following restoration. Overall improvements in fish population metrics within the California Gulch Superfund Site indicate that ecosystem health continues to improve.

Creel surveys were conducted within multiple reaches in 2020 to evaluate trends in angler use. Results indicate the angler use increased by more than 300% over the past 12 years (Table 2). The two reaches within the restoration project, Upper Hayden Flats and Reddy SWA, received the heaviest use. The largest changes in use occurred between 2008 and 2012, when the number of anglers increased by 184%. Anglers increased by 17% between 2012 and 2017 and 31% from 2017 to 2020. In 2016, the average angler spent $130 per trip (Southwick 2018), which suggests that the 15,546 anglers from the 2020 creel surveys contributed over $2,020,000 in local economic impact.

Table 2. Number of anglers estimated from creel surveys on the Arkansas River, 2008-2010.

Reach	Description	2008	2012	2017	2020
1	Granite SWA to Ball Town	862	2,680	2,380	3,149
2	Hayden Flats	1,897	5,156	6,805	8,850
2a	Lower Hayden Flats	NA	1,562	2,798	3,153
2b	Upper Hayden Flats	NA	3,594	4,007	5,697
3	Reddy SWA and Crystal Lake STL	NA	NA	2,247	3,547

Benthic Macroinvertebrates:
Limited increases in abundance of benthic macroinvertebrates, and reductions in adult aquatic insects and terrestrial invertebrates occurred after restoration. There was an overall reduction in abundance during and immediately after treatment, followed by either no recovery or a gradual return to pre-treatment conditions. Although the modest (8.8%) increase in total density after treatments approached the restoration goal of a 10% increase in benthic macroinvertebrates (Stratus 2010), this increase resulted primarily from a large decrease immediately after treatment completion. The prey biomass in trout diets also decreased, suggesting that trout shifted their foraging patterns after restoration and that available prey-subsidies may be limiting. There are several potential explanations for the limited responses to restoration, but we believe that increased predation resulting from the increase in Brown Trout density likely dampened effects on benthic communities and depleted aquatic adult and terrestrial prey subsidies.

Figure 1. Before and after photos of wood toe treatment and fluvial tailings remediation.

Figure 2. Before and after photos of an eroding bank that was stabilized with a riparian bench.

Figure 3. Before and after photos showing log vanes, habitat boulders, and channel narrowing.

Results suggest that the effectiveness of remediation (Clements et al. 2010) and restoration differed between benthic macroinvertebrates and fish. Benthic macroinvertebrates were more dependent on water quality improvements that occurred primarily at the watershed-scale, whereas Brown Trout populations responded to both improvements in water quality and reach-scale improvements in habitat. These differences demonstrate the challenges of achieving specific restoration goals because of potential feedbacks between ecological processes. As the upper Arkansas River has a long history of metals exposure, and because water chemistry continues to change due to ongoing treatment and climate change, the ability of the system to recover from future perturbations is uncertain. This study also demonstrated the critical role of riparian vegetation in providing prey subsidies for Brown Trout populations. Both terrestrial invertebrates and adult aquatic insects are critical prey resource for Brown Trout and efforts to sustain and promote riparian vegetation has the potential to increase the production and availability of these prey resources.

There remains considerable uncertainty regarding the responses of aquatic and terrestrial invertebrates to habitat restoration. This uncertainty is largely a result of natural temporal and spatial variation, a highly variable flow regime, and the complex interactions between resource subsidies (i.e., invertebrates) and trout populations. Continued monitoring is recommended to elucidate the influence of highly variable stream flow, interactions between resource subsidies and trout populations, and other sources of variability on the long-term success of restoration in this system. This study has resulted in the publication of a Master's thesis (Pomeranz 2015), peer-review manuscripts (Wolff et al. 2019; Wolff et al. 2021), and final report (Clements et al. 2021). Additional publications are currently in preparation (Wolff et al. *In preparation*; Kotalik et al. *In preparation*).

Riparian Vegetation:

Results from vegetation analyses were summarized in a peer-review manuscript that has been accepted for publication in River Research and Applications (Cubley et al. *In press*), as well as a final report (Baker and Cubley 2021). Results from the study are briefly summarized here. In general, changes in vegetation cover from 2012 to 2019 fell short of project goals (i.e., 10% increase), but more desirable riparian species (willows) appear to be displacing grasses. Two issues complicated the application of percent cover as a primary metric. First, most plots had established vegetation at baseline (mean = 92%), and second, the unvegetated area of plots appeared to persist over the 7-year monitoring period. It is unclear if the persistence of unvegetated areas was due to a lack of seed availability/dispersal or possibly physically or chemically unsuitable conditions for vegetation growth. There was clear qualitative and quantitative evidence that woody species, particularly willows, are thriving. The increase in woody species should provide long-term benefits for aquatic and riparian habitat. Furthermore, bank migration appears to be moving towards a state of equilibrium, as encroachment of riparian vegetation has outpaced bank erosion, which is another indicator of improving ecosystem health.

Habitat Quality:

Results from 2013-2016 habitat modeling were published in Richer et al. (2019), and indicated that some metrics (WUA, FP) improved following restoration and then subsequently declined, while other metrics (depth heterogeneity, spawning habitat) demonstrated improvements over time. Analysis of 2018 models provided additional support for the results presented in Richer et al. (2019), which suggests that additional habitat modeling was not warranted. However, comparison of habitat indices to fish population metrics would inform future monitoring efforts by evaluating the utility of intensive habitat modeling methods. Habitat modeling surveys were not conducted in 2020, and are not currently planned for future monitoring. As results from habitat evaluation have previously been reported, they are not described in detail for this report.

Instream Habitat Structures:
Detailed results from 2014-2020 have been included in Richer (2021), including photos for individual structures, and will be incorporated into a manuscript for submission to a peer-review journal. Rapid assessment surveys indicated that structure integrity had declined to 82% in 2020, down from 92% in 2018, likely due to the large magnitude (35-year return interval) flood that occurred in 2019. Although structural integrity and function declined below the 90% target in 2020, additional maintenance activities may not be warranted. No additional surveys for instream structures are planned at this time.

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RESEARCH PRIORITY:

Kemp-Breeze State Wildlife Area Habitat Project, Colorado River

OBJECTIVES

1) Increase sediment transport capacity and competence by manipulating channel dimensions
2) Decrease the prevalence of fine sediment and reduce embeddedness within riffle habitats
3) Increase the frequency of flushing flow events in riffle habitats under the future flow regime by manipulating channel dimensions
4) Activate floodplains with a frequency of 1-3 years under the future flow regime
5) Increase the density of native riparian vegetation along streambanks and floodplains to increase flood resilience and improve wildlife habitat
6) Increase the density of Mottled Sculpin and Salmonflies within the project reach
7) Increase trout population biomass (lbs/acre) and quality (# of fish > 14"/acre)
8) Increase Rainbow Trout reproduction (fry density) and recruitment (adult density)
9) Increase habitat suitability and diversity for Rainbow Trout, Brown Trout, and Mottled Sculpin by improving instream hydraulics
10) Increase the abundance, distribution, and diversity of benthic macroinvertebrates

INTRODUCTION

The Upper Colorado River Habitat Project (Habitat Project) was developed in coordination with the Municipal Subdistrict, Northern Colorado Water Conservancy District (Subdistrict) and Denver Water to address concerns raised by Colorado Parks and Wildlife (CPW) and other stakeholders regarding conditions of the aquatic ecosystem in the Colorado River downstream of Windy Gap Reservoir (Subdistrict 2011). CPW, formerly the Colorado Division of Wildlife (CDOW), documented declines in populations of Salmonfly *Pteronarcys californica*, which was historically a major source of food for trout in the Colorado River (Nehring et al. 2011). Mottled Sculpin *Cottus bairdii* are a native fish that are important food sources for trout, occupy similar habitat niches as Salmonflies, and have also shown population declines. Riffle habitats below Windy Gap Reservoir were altered by changes in flow regime, water depletions, sedimentation, and armoring of the channel bed (Nehring et al. 2011). Trout populations between Windy Gap and Kremmling have also declined. In particular, Rainbow Trout *Oncorhynchus mykiss* populations in the Colorado River have decreased significantly due to the prevalence of whirling disease, which has been exacerbated by favorable conditions for whirling disease within Windy Gap Reservoir.

The goal of the Habitat Project is to design and implement a stream restoration program to improve the existing aquatic environment in the Colorado River from the Windy Gap Diversion to the lower terminus of the Kemp-Breeze State Wildlife Area (SWA) by returning the river to a more functional system considering current and future hydrology. The large-scale Habitat Project includes a study area of approximately 16.7 miles, but Phase 1 of the project will focus on habitat restoration for a 1.5-mile reach within the Kemp-Breeze SWA. The Kemp-Breeze project is being used as funding match for a Natural Resources Conservation Service (NRCS) Regional Conservation Partnership Program (RCPP) award received by Trout Unlimited for the Colorado River Headwater Project (CRHP). The CRHP includes three separate projects: the Kemp-Breeze habitat project, the Colorado River Connectivity Channel project at Windy Gap Reservoir to restore fish passage and sediment transport, and the Irrigated Lands in Vicinity of Kremmling (ILVK) project. To fulfill requirements for the NRCS RCPP grant, the Kemp-Breeze project will be implemented within a five to six year timeframe that began in 2017.

METHODS

In support of the Kemp-Breeze SWA Habitat Project, we conducted a site assessment and developed a conceptual restoration design. The assessment included evaluations of hydrology, hydraulics, geomorphology, and biology for the project reach. Detailed methods for the site assessment and design analysis were presented in Richer et al. (2019). We also conducted a sediment transport evaluation using PIT-tagged tracer rocks. Methods for the tracer rock study were described in detail by Richer and Allgeier (2020).

RESULTS AND DISCUSSION

Results from the site assessment were used to develop a conceptual design that was presented in Richer et al. (2019). The major project elements include channel narrowing, restoration of riffle habitats, enhanced bedform and habitat diversity, riparian vegetation, large woody material, and other habitat structures. The assessment was also used to prioritize reaches for restoration treatments, and a design consultant (Stillwater Sciences) was hired to take the conceptual design to a final, construction-ready plan set. We provided technical design assistance to Stillwater Sciences throughout the design process and the final design was completed in March 2021.

Preliminary results from the PIT-tagged tracer rock study were presented in Richer and Allgeier (2020). Tracer rocks were resurveyed during the fall of 2020, and results were used to investigate flushing flows for the project reach and inform the proposed dimensions for the restored channel. In general, the preliminary tracer rock suggested that sediment in the Colorado River does not move with sufficient frequency to maintain benthic habitat for macroinvertebrates and Mottled Sculpin and the 2020 tracer rock data supported this observation. The average distance moved for tracer rocks was 0.86 ft in 2019, compared to 0.28 ft in 2020 (Table 3). The decline in distance moved that was observed in 2020 was due to the lower peak flow observed that year. Additional analysis of tracer rock data will be combined with 2D sediment transport modeling with the intention of publishing those results in the peer-review manuscript. Tracer rock surveys will also be conducted following construction to evaluate the effectiveness of the stream restoration project.

Table 3. Summary statistics for tracer rock movement and maximum average daily flow at the Kemp-Breeze SWA, Colorado River.

Summary Statistic	**Distance Moved (ft)**	
	2019	**2020**
Maximum	11.3	3.1
Average	0.9	0.3
Median	0.3	0.1
Minimum	0.0	0.0
Standard Deviation	1.7	0.4
Maximum flow (cfs)	2,348	1,498

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We would like to acknowledge Barry Nehring for his work documenting changes in benthic macroinvertebrates, Mottled Sculpin, and trout populations following construction of Windy Gap Reservoir that ultimately led to the development of the greater Habitat Project on the Colorado River. We also thank the various collaborators and technicians that have contributed to the data collection and analysis, including Jon Ewert, Eric Fetherman, and Dan Kowalski. We are grateful for the assistance with tracer rock surveys that was provided by Johannes Beeby and Travis Stroth with Stillwater Sciences. Finally, we would like to thank George Schisler, Lori Martin, Karlyn Armstrong, Ken Kehmeier, and Sherman Hebein for their contributions to development and implementation of the fish and wildlife mitigation and enhancement plans for the Colorado River.

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RESEARCH PRIORITY:

Efficacy of Installed Fish Passage Designs along the Northern Colorado Front Range, Cache la Poudre and St. Vrain Rivers

OBJECTIVES

To assess the passage success of the resident fishes at a variety of fish passage structures to better understand how structure design and type affect efforts to restore river connectivity through: (1) long-term monitoring with stationary PIT tag antenna arrays detecting a free-ranging community of PIT-tagged fishes; (2) short-term enclosure studies to allow rapid assessment of passage success of selected members of the regional fish fauna; and (3) determine how fish navigating a fish passage structure interact with the adjacent diversion and irrigation canals to track movement patterns of tagged fish from the main stem river and estimate fish entrainment rates.

INTRODUCTION

Instream barriers can fragment fish populations by restricting access to habitats crucial to survival including access to areas for reproduction, feeding, and refugia. This project seeks to evaluate the efficacy of recently installed (post-flood of 2013) fish passage types including several that incorporate design parameters specifically optimized for small bodied plains and transition zone fish in Colorado. Additionally, it addresses the concern of whether fish passage designs created in laboratory conditions are still effective when installed in natural rivers by restoring connectivity to the surrounding river ecosystem. An expanding understanding of the swimming capacities of representative Great Plains fishes (Billman and Pyron 2005; Ficke et al. 2011) as well as the parameters for gradient, velocity and curvature (Swarr 2018) has enabled designs specific to successful Great Plains fish passage. This crucial information has informed the design of several of the fishways in this study, but it is critical that monitoring occur once the passage is constructed to field validate the laboratory-derived designs. A secondary goal is to monitor and estimate rates of fish entrainment into associated ditches at one of the study sites. Additional background on Great Plains fishes, fish passage, and entrainment can be found in Jones and Myrick (2019).

METHODS

A total of three study sites have been selected for inclusion in this study. Short-term enclosure studies will occur at all three study sites including: (1) Fossil Creek Inlet Diversion (FCRID), Cache la Poudre River*; (2) Dickens Farm Natural Area, St. Vrain River*; and (3) Rough and Ready/Palmerton Diversion, St. Vrain River. Long-term monitoring of fish movements will take place at two locations (see sites marked with "*"). Due to the difficulty in gaining access and approvals from land managers from Boulder, the Green Ditch Diversion on Boulder Creek was eliminated from our original study design.

Study Sites:

<u>Fossil Creek Reservoir Inlet Diversion (FCRID), Cache la Poudre River-Rock Ramp Fishway:</u>
The Fossil Creek Reservoir Inlet Diversion (FCRID) is located east of Fort Collins, Colorado, well into the transition zone for the Cache la Poudre River. It consists of a low-head concrete dam structure that maintains head pressure for diverting water into Fossil Creek Ditch, serving both to fill Fossil Creek Reservoir and as a dilution source for a nearby municipal wastewater treatment facility. The structure was severely damaged in the 2013 flooding, creating the opportunity for the incorporation of a fish passage structure. Based on suggestions from Colorado Parks and Wildlife (CPW), a 10-foot rock ramp was installed on the east side of the structure with a trapezoidal cross-section and arrangeable roughness elements. Due to observations from an evaluation of the structure in 2016, the ramp was extended in an additional 20 feet downstream in 2018 to improve hydraulic conditions at the fishway entrance (Richer et al. 2020). This rock ramp is 30 feet long with a 5% slope and maximum depth of 1.6 feet. Long-term monitoring was conducted in the fishway with antenna placement mirroring the original placement for the 2016 testing performed by CPW (Richer et al. 2018) for the top 10 feet of the fishway. Monitoring this site is somewhat complicated by the presence of a radial gate on the opposite side of the river channel that is often raised during high river flows to reduce strain on the diversion structure. When open, the radial gate provides an additional fish passage route. While the status of the radial gate was noted during the extent of the study period, there is a high probability that some fish are negotiating the structure

through the gate entrance and were not detected by the rock ramp antenna array. The large quantity of metal at the gate precludes the installation of an additional antenna to monitor fish use of this potential passage route. Fortunately, the radial gate was closed nearly the entire time that we conducted the long-term monitoring. Adjacent to the structure is Fossil Creek Ditch. This was the only site used to study fish entrainment as the ditch receives year-round discharges from the wastewater treatment plant, providing flow regardless of water diverted for the reservoir.

<u>Dickens Farm Natural Area, St. Vrain River-Wingwall Bypass Fishway:</u>
Running directly through the heart of Longmont, CO and adjacent to the intersection of CO-119 and US-287, the Dickens Farm Natural Area on the St. Vrain River consists of a series of grouted, boulder-lined pools and riffles surrounded by trails and open areas created for public recreation. The recreation–focused design was conceived of prior to the 2013 flooding, but due to flood damage, the plan was altered to include flood control measures and bank stabilization. Work began on the project in early 2017 and was completed during fall 2019. Though a Recreational in Channel Diversion (RICD) was obtained in 2004 for enhancing recreation, instream flows and gradient are insufficient to provide the desired whitewater experience, leading the city to dispense with labeling the park as such. Nevertheless, because river recreation was still a main goal of the construction, the channel was altered to provide drops and higher velocity water for tubing and kayaking recreation activities (City of Longmont 2014). Since the St. Vrain River still supports high numbers of native fishes compared to other transition zone rivers along the Front Range, wingwall bypass passage structures were installed at the lateral margins of each drop to provide lower velocity passageways and maintain longitudinal connectivity. Created through the placement of grouted boulders, the channels are characterized with a complexity of different flow pathways, interstitial spaces and numerous exits for fish and water alike. The lowermost drop structure was chosen for study, as it falls to the east of Martin Street, and thus outside of the primary public access area, and though separated by a final pool and low-grade flow control structure from the less altered downstream reach of the St. Vrain, it is presumed to see greater fish populations and movement. The slope of the wingwall bypass was 2% over 50 feet.

<u>Rough and Ready/Palmerton Ditch Diversion, St. Vrain River-Pool-Weir with Orifice Slots:</u>
The Rough and Ready/Palmerton Ditch Diversion sits closer to the foothills near Lyons, and as such has a different species assemblage due to generally cooler water temperatures, with trout making up the largest portion of the overall fish community. Following damage in the flood, integrating a fish passage into the structure was proposed but concern over the legal standing of such construction resulted in a passage created through retrofitting a sediment sluice with weir plates to create a pool-and-weir style passage, requiring adequate jumping capacity to ascend the passage. The slope of the structure varied from 9-12% over 70 feet. Working limitations placed by the ditch company and the presence of the thick metal plates restrict the site to use only in the enclosure portion of this study, with temporary antennas constructed on substitute weir plates cut from marine grade plywood.

Long-Term Fishway Monitoring:
To better understand the efficacy of existing fish passage structures, the FCRID and Dickens Farm sites underwent long term monitoring evaluations. Fish movements at each site were tracked using PIT tag antenna arrays installed within each fishway. To provide directionality of movement and at least a coarse assessment of passage, each fishway was installed with four custom-designed half-

duplex (HDX) antennas—one at the downstream entrance, another at the upstream exit, and two additional antennas placed in between. Following installation, a comprehensive set of baseline detection distances were taken for each antenna at a variety of locations, with three orientations (vertical, horizontal, and 45 degrees) and with two tag directions (perpendicular and parallel to the antenna) with both 32-mm and 12-mm HDX tags. This will provide both information on the "cloud" of detection surrounding each antenna, from which can be inferred how effectively each antenna will detect fish at different water levels, fish orientations, etc., as well as an indication of when an antenna is malfunctioning or out of tune because of a decrease in expected read range. Maintenance on the antennas compared real time detection distances at a set location on each antenna with baseline measurements, which indicated if the system required adjustment or tuning. Maintenance activities were completed routinely throughout the course of the study at bi-weekly intervals. Additional maintenance activities consisted of inspecting antennas for damage and uploading fish movement data from the readers.

Fish Tagging for Long-Term Study:
Construction and installation of multiple PIT tag antennas at each site allowed us to measure directionality and percent passage success. The success of the long-term monitoring study is increased by having a large population of tagged fish in the vicinity of the fishways. Therefore, we collected and tagged the greatest number of species and individuals possible from the surrounding area. Sampling relied largely on backpack electrofishing. Tagging occurred between July-October 2019 and May-September 2020. Captured fish were placed into live pens prior to processing during which we recorded the following for each individual fish: species identification, total length (mm) and weight (to the nearest gram). As the entire assemblage of species in the surrounding area are of interest for the purposes of this study, all fish that met the 80-mm TL size criteria were tagged with a PIT tag. Following tagging, all fish were released downstream of the fishway to capitalize on any homing instinct that might encourage upstream navigation of the fishway (Fox et al. 2016). The majority of tags used were 12-mm x 2-mm HDX tags, though some larger individuals were fitted with either 23-mm x 3.6-mm or 32-mm x 3.6-mm tags. While there may be some flexibility based on individual body condition, in general, fish between 80 to 175-mm received a 12-mm tag, those between 175 to 250-mm received 23-mm tags, and 32-mm tags were used for any fish greater than 250-mm. Since larger tags have superior read range, we used them whenever possible. Fish were anesthetized (25 - 50 mg/L MS-222, buffered to neutral pH or 30 ppm of AQUI-S) prior to tagging. A surgical incision into the abdomen was followed by tag insertion and gentle massaging to guide the tag within abdominal cavity was used since this procedure produced the highest retention and survivability of fish compared to tag injection (Ficke et al. 2012). Information provided by Swarr (2018) suggested that suturing small fish did not dramatically increase tag retention but rather increased the likelihood of additional accidental injuries during the process. Since suturing did not appear to improve tag retention or influence survival, fish used in this study were not sutured following tag insertion. We collected long-term data continuously for 23 months at the FCRID site and 20 months at Dicken's Farm.

Short-Term Enclosure Studies:
To assess whether any of the given sites are physically passable, short-term enclosure studies were conducted during the summer and fall. These consisted of short-duration, two-day trials where small enclosures were installed at the upstream and downstream ends of a fishway. PIT-tagged species of interest and untagged individuals of smaller species (e.g., Plains Topminnow) were

placed in the lower enclosure and allowed to voluntarily navigate the fishway. Four antennas installed along the length of the fishway recorded each individual's progress; the presence of fish in the upper enclosure also indicated successful passage. Trials ran for 22-24 hours to incorporate a full photoperiod. Two successive 24-hour trial periods were conducted at each site. The species selected for the enclosure trials are not the full assemblage of fish at each site but rather represented a range of swimming types and abilities, plus specific additions of some species of concern. Some species of interest formerly inhabited these river stretches but have been extirpated for a variety of reasons (Fausch and Bestgen 1997). In these cases, individuals were brought in from other locations within the South Platte drainage to supplement the experiment under the guidance of CPW collaborators. These species included Common Shiner *Luxilus cornutus*, Stonecat *Noturus flavus* or Creek Chub *Semotilus atromaculatus*. All fish used in the study were tagged prior to the actual enclosure trial, as the healing time for non-sutured fish found by Swarr (2018) fell between 3-5 days. Fish transported from other sites were held in pens in the river, along with local tagged individuals for 12-24 hours to allow some acclimation to local conditions. Individuals were fed frozen bloodworms or other appropriate feed types while in the pen to maintain physical health (Ficke et al. 2012; Ficke 2015). Following the study, any locally captured fish were released back into the river. Enclosure boxes were constructed from either metal or plastic screening over PVC frames that could be mounted with T-posts as near as possible to the entrance and exit of the fishways or allowed to float in the case of higher water. Lengths of woven nylon netting connected the boxes to the fishway, providing a runway, and in the case of any more natural structures like Dickens Farm, closing off additional escape routes. Cover elements in the form of PVC tubing or cinder blocks were provided within the enclosure for the creation of resting areas for fish trying to ascend or recovering at the top. Fish movements were actively monitored both visually and through the submerged antennas. Small fish that were not tagged, but were measured prior to the trial, were removed at intervals from the top enclosure should they ascend. These individuals were measured once more and counted as a successful passage from their species. The lack of PIT tags will prohibit the collection of partial success information from such individuals, as well as individual identifiers, thus the testing of smaller fish will instead focus solely on whether full completed journeys were achieved and their associated sizes.

Entrainment:

Entrainment of both native fish and invasive fish species into agricultural ditches has been broadly documented with concern as to its role in mortality rates of some species (Carlson and Rahel 2007). As a large number of PIT tagged fish were already traversing the river adjacent to several ditches, the entrainment portion of this study is an offshoot of the long-term monitoring of the fish passage structures. Possible entrainment was monitored at the Fossil Creek Division because it has an unscreened ditch receiving water from near the fishway. Dickens Farm in Longmont was excluded from this portion of the study because water at this location is diverted through screened pipes and pumps that should pose less of a chronic entrainment risk. The entrainment study was monitored using PIT tag antenna arrays and readers similar to those used for the fish passage monitoring. Unlike the fish passage sites, the entrainment study used only two antennas installed within the ditch (but near the entrance) to determine directionality of movement.

Hydrology Monitoring:

In the interest of understanding how local flow conditions may affect fish passage, stream staff gages (enamel finished 4-foot plates marked in feet and tenths) were installed at each long-term site if not already present. Water depth was recorded during each bi-weekly antenna check and hourly during the enclosure studies to provide a baseline. These measurements were compared with nearby steam gages to develop a correlation between staff gage readings and stream gage values:

- Cache la Poudre River USGS 06752260 at Fort Collins and USGS 06752280 near Timnath for the FCRID site
- Colorado Division of Water Resources SVCLOPCO for St. Vrain Creek below Ken Pratt Blvd at Longmont for the Dickens Farm Site

Additionally, a pair of HOBO U2 Water Level Data Loggers, one stationed above water and another installed near the mouth of each fishway, recorded hourly data on water depth and temperature. Flow monitoring occurred at Rough and Ready/Palmerton Ditches only during the enclosure study through Colorado Division of Water Resources SVCLYOCO29 for St. Vrain Creek at Lyons and with temporarily emplaced HOBO loggers and a staff gage. These more constant methods were supplemented with periodic cross-sectional discharge profiles taken at the mouth and within the fishways, and in the main channel either above the fishway (FCRID) or alongside the fishway (Dickens Farm Park). Measurements were made with a Hach FH950 Portable Velocity Meter or similar instrument and wading rod. Within each fishway, a series of point measurements for depth and velocity were taken to reflect differences in the water's movement through the structure. These consisted of cross-sections taken at least four stations along the fishway, with each cross-section point within those stations recording a bottom, top, and depth-average flow measurement. These point velocity measurements represent the average velocity over a 10-second interval.

Data Analyses:

PIT tag antenna detections were the primary form of data collected in this study, though if fish were recaptured above the fishway despite a downstream release, these were considered as a successful passage. During the enclosure study, there was an added physical element, as the top enclosure allows fish to be observed and their tag numbers documented. Information collected during the long-term monitoring included: species, length, weight, PIT tag ID, capture/tagging date, antenna ID, antennas crossed, number of hits per antenna, time of detection, and length of time between antennas. Additionally, during the enclosure portion, water temperature and flow were recorded through the use of HOBO loggers, and trial start and stop times were tracked. The flow data from the nearest permanent gauging station, the HOBO pressure transducers, and the instream measurements were collected to determine any possible correlations with recorded fish movements.

Fish movement data were analyzed with a mark-recapture model in program MARK, using a Cormack-Jolly-Seber (CJS) model or a multi-state mark-recapture (MSMR). The original model was modified for antenna detection data by redefining the survival coefficient (ϕi) as the probability of being "recaptured" by an antenna and thus an estimate of passage probability. Detection by a PIT tag antenna will stand in for the "sampling effort" component needed by the model (p). This type of model manipulation has been effective in modeling the movement of PIT tagged trout (Horton et al. 2011; Fetherman et al. 2015).

Some assumptions of the model were modified somewhat, such as the likely need to add a "timing covariate" to the model. Typically, the assumption in a mark-recapture study holds that tagging is an instantaneous process and all animals are released at the start of a time period (Williams et al. 2012). Given that tagging efforts will be ongoing throughout the project with the intention of distributing as many tags in the passage structure's vicinity as possible, marked fish will be free in the system for varying lengths of time. As this difference in time length may affect the survival, detection and transition probabilities, a timing covariate that classifies fish into different time periods of marking may be used to address this problem (Williams et al. 2012).

Another concern will be missed, partial or ghost detections, that could arise from several different causes, listed below:

- Fish may trigger one antenna but due to the timing cycle of several antennas on a multiplexor, they may escape detection on adjacent antennas, leaving the question as to whether the fish continued on, or aborted its movement through the fishway.
- Although antennas were designed to give the greatest detection cloud possible, the combination of smaller PIT tags and high water may allow fish to transit the structures outside of the detection range for an antenna at certain times of the year. It is likely that during high flow events, fish will be using lower velocity areas, such as the bottom or margins of a fishway, to traverse the passage but missed detections will still occur.
- Multiple fish crossing the antenna at once may create interference in reading their tags (i.e., tag collisions), or they may cross the antenna in a less-ideal orientation, lowering their chance of detection. This may be particularly prevalent during the enclosure studies where the density of fish is higher.

Using models such as the CJS approach will assist in calculating passage probabilities with these concerns in mind. Additional analyses may explore the failure rate (e.g., looking at movement patterns within each fishway to determine if there are "bottlenecks" or critical points where fish fail to transit), and may look at the possibility of declining passage performance with repeated passage attempts, possibly indicating physiological fatigue.

In addition to the MARK analysis, raw data from fish detections were used to re-construct individual fish "journeys" and "completed journeys." A "journey" is defined as a fish movement detected by two antennas in succession. A "completed journey" is defined as a detection on an end point antenna through the course of their journey. A completed journey might consist of an encounter history that misses one or more detections on antennas located along the path it used to ascend the fishway, but all completed journeys must include the end point antenna to be classified as a "completed journey." Detections and journeys were sorted by a variety of environmental factors (including time of day, year, flow, temperature, etc.) to create a more complete picture of fish movement in fishways.

Data will be used to develop recommendations on the most effective fish passage designs for the assemblage of species along the Colorado Front Range. For each design in the study, the number of species tagged and then passed, number of natives versus nonnatives, size of individuals with successful passage, and timing of fish movement (both diel and seasonally) will be used to quantify the efficacy of each design. Behavioral data collected as well as flow data will also be used where applicable.

RESULTS AND DISCUSSION

Data analyses for this project are ongoing, but preliminary results for this project were included in Jones and Myrick (2019) and described below.

<u>FCRID: Rock Ramp Fishway Short-Term Enclosure:</u>
Two enclosure trials were conducted at the FCRID during 2019 and 2020. The 2019 trial was largely unsuccessful due to wildly fluctuating flows and temperature shifts during the trial period. Flows during the 2020 trail were higher than desired, likely prohibiting the recovery and potentially the passage of any of the 126 untagged fish in that trial. Nonetheless, eight species and a total of 123 tagged fish were used in the 2020 short-term enclosure trial (Table 4).

Table 4. Fish used in FCRID short-term enclosure trial including species, count, and minimum/maximum total lengths (mm) for individual fish. Species names in *italics* are non-native species that were included in the study.

Species	**Count**	**Min Length (mm)**	**Max Length (mm)**
Creek Chub	3	86	100
Common Shiner	6	139	203
Fathead Minnow	1	81	81
Longnose Sucker	38	97	280
Longnose Dace	27	80	100
Brown Trout	6	99	116
Green Sunfish	29	80	138
White Sucker	13	92	126
Total	123	--	--

All detection data from short-term enclosure trials were used to estimate transition probabilities (φ) and individual antenna detection probabilities (p) using CJS live recaptures function in Program MARK. Models incorporated each species individually with length as a covariate and variation by antenna. Overall fishway efficiency was modelled using all species combined and including length and antenna as covariates. Top models were determined using AIC and then averaged to produce robust estimates. Total fishway efficiencies were calculated using the product of φ and p estimates for a given species or fishway. See Table 5 for results of FCRID enclosure trial and estimated transition probabilities. Brown Trout performed particularly poorly in this enclosure trial, likely due to the small size of individual fish caught for use in the trial (less than 116 mm TL) and the time of year (low motivation to move upstream).

Raw data from fish detections were used to re-construct individual fish "journeys" and "completed journeys" for fish during the FCRID short-term enclosure trial. A "journey" is defined as a fish movement detected by two antennas in succession. A "completed journey" is defined as a detection on an end point antenna through the course of their journey. A completed journey might consist of an encounter history that misses one or more detections on antennas located along the path it used to ascend the fishway, but all completed journeys must include the end point antenna to be classified as a "completed journey." Results for the detection history analyses using successful journeys and completed journeys for the short-term enclosure trial at the FCRID are included in Table 6.

Table 5. Estimates of probability of movement (φ) and individual antenna detections (*p*) generated by Program MARK using CJS live recaptures model for FCRID short-term enclosure trials.

Probability of Movement Past an Antenna (φ)					
Species	**Antenna 1**	**Antenna 2**	**Antenna 3**	**Antenna 4**	**Total φ**
Common Shiner	0.75	0.93	0.81	0.96	0.54
Longnose Sucker	0.76	0.95	0.83	0.98	0.59
Longnose Dace	0.99	1.00	1.00	1.00	0.99
Brown Trout	0.60	0.91	0.70	0.97	0.37
Green Sunfish	0.88	0.97	0.91	0.99	0.77
White Sucker	0.66	0.92	0.75	0.97	0.44
Fishway	0.80	0.95	0.90	0.96	0.65
Probability of Detection by an Antenna (*p*)					
Species	**Antenna 1**	**Antenna 2**	**Antenna 3**	**Antenna 4**	**Total *p***
Common Shiner	0.61	0.73	0.82	0.73	0.27
Longnose Sucker	0.73	0.82	0.89	0.83	0.44
Longnose Dace	0.90	0.94	0.97	0.94	0.78
Brown Trout	0.46	0.59	0.72	0.60	0.12
Green Sunfish	0.59	0.71	0.82	0.72	0.25
White Sucker	0.69	0.80	0.87	0.80	0.39
Fishway	0.72	0.84	0.91	0.84	0.47

Table 6. Detection histories from fish included in FCRID enclosure trial experiment including species, number of individuals in trial, number of fish detected, number of journeys, percent success, and total number of completed journeys. Species names in *italics* are non-native species that were included in the study.

Species	**Number in Trial**	**Number Fish Detected**	**Completed 1 Successful Journey**	**Percent Success**	**Total Number of Completed Journeys**
Creek Chub	3	2	0	0	0
Common Shiner	6	5	1	20	1
Fathead Minnow	1	1	0	0	0
Longnose Sucker	38	30	14	47	44
Longnose Dace	27	27	23	82	204
Brown Trout	6	3	0	0	0
Green Sunfish	29	20	6	30	19
White Sucker	13	7	3	43	5
Total	123	96	47	49	273

FCRID: Rock Ramp Fishway Long-Term Passage Rates:

Between August 2019 and August 2020, a total of 828 fish were tagged and released in the vicinity of the FCRID site. A summary of the species, counts, and individual fish total lengths (mm) is included in Table 7. No obvious patterns of movement were associated with patterns of low or high river discharge. However, the lowest rates of upstream movement occurred during the winter months. Of the 828 total tagged and released fish, a total of 330 individual fish were redetected during 23 months of monitoring for a redetection rate of 39%. Of the 330 known fish detected at the FCRID rock ramp fishway, a total of 182 individual fish completed at least one successful journey producing an overall passage rate of 55%.

Table 7. Species, count, and total lengths (mm) of fish included in the long-term fish passage study at the FCRID. Species names in *italics* are non-native species that were included in the study.

Species	**Count**	**Total Length Range (mm)**
Bluegill	2	85-107
Common Carp	14	84-572
Creek Chub	36	80-196
Common Shiner	6	131-178
Fathead Minnow	4	72-81
Longnose Sucker	233	80-306
Largemouth Bass	29	76-168
Longnose Dace	130	80-121
Brown Trout	131	82-457
Rainbow Trout	2	359-390
Green Sunfish	110	76-138
Stonecat	2	115-160
Central Stoneroller	6	93-99
White Sucker	123	84-452
Total	828	--

Dickens Farm Natural Area: Wingwall Bypass Fishway Short-Term Enclosure:

An enclosure trial was conducted at Dickens Farm during 2019. Fishway discharge ranged from 3.3 to 3.6 cfs over the trial period. A total of 10 species and 124 individually tagged fish were used in the short-term enclosure trial (Table 8). A total of 41 untagged Plains Topminnows were released into the system downstream of the fishway and recovered in the upstream enclosure within the first half hour.

All detection data from short-term enclosure trials were used to estimate transition probabilities (φ) and individual antenna detection probabilities (p) using CJS live recaptures function in Program MARK. Models incorporated each species individually with length as a covariate and variation by antenna. Overall fishway efficiency was modelled using all species combined and including length and antenna as covariates. Top models were determined using AIC and then averaged to produce robust estimates. Total fishway efficiencies were calculated using the product of φ and p estimates for a given species or fishway. See Table 9 for results of Dickens Farm enclosure trial and estimated transition probabilities.

Table 8. Fish used in Dickens Farm short-term enclosure trial including species, count, and minimum/maximum total lengths (mm) for individual fish. Species names in *italics* are non-native species that were included in the study.

Species	**Count**	**Min Length (mm)**	**Max Length (mm)**
Bluegill	1	121	
Central Stoneroller	3	87	125
Creek Chub	35	83	168
Common Shiner	10	81	181
Longnose Sucker	2	140	156
Longnose Dace	20	80	110
Brown Trout	5	200	277
Green Sunfish	5	78	116
Stonecat	25	100	185
White Sucker	21	117	312
Total	124	--	--

Table 9. Estimates of probability of movement (φ) and individual antenna detections (*p*) generated by Program MARK using CJS live recaptures model for the Dickens Farm short-term enclosure trial.

Probability of Movement Past an Antenna (φ)					
Species	**Antenna 1**	**Antenna 2**	**Antenna 3**	**Antenna 4**	**Total φ**
Creek Chub	0.83	0.95	0.84	0.98	0.65
Common Shiner	0.97	0.99	0.97	1.00	0.93
Longnose Dace	0.85	0.96	0.86	0.99	0.70
Green Sunfish	0.50	0.80	0.52	0.93	0.19
Stonecat	0.37	0.70	0.38	0.88	0.09
White Sucker	0.50	0.80	0.52	0.93	0.19
Fishway	0.67	0.90	0.77	1.00	0.46
Probability of Detection by an Antenna (*p*)					
Species	**Antenna 1**	**Antenna 2**	**Antenna 3**	**Antenna 4**	**Total *p***
Creek Chub	0.98	1.00	1.00	1.00	0.98
Common Shiner	0.98	1.00	1.00	1.00	0.98
Longnose Dace	0.98	1.00	1.00	1.00	0.98
Green Sunfish	0.99	1.00	1.00	1.00	0.99
Stonecat	0.98	1.00	1.00	1.00	0.98
White Sucker	0.98	1.00	1.00	1.00	0.98
Fishway	0.99	1.00	1.00	1.00	0.98

Raw data from fish detections were used to re-construct individual fish "journeys" and "completed journeys" for fish during the Dickens Farm short-term enclosure trial. A "journey" is defined as a fish movement detected by two antennas in succession. A "completed journey" is defined as a detection on an end point antenna through the course of their journey. A completed journey might consist of an encounter history that misses one or more detections on antennas located along the path it used to ascend the fishway, but all completed journeys must include the end point antenna to be classified as a "completed journey." Results for the detection history analyses using successful journeys and completed journeys for the short-term enclosure trial at Dickens Farm are included in Table 10. Stonecats did not show a great number of completed journeys in the enclosure trial with only one completed trip out of 26 individuals. However, they had the highest number of completed journeys and detections during the long-term monitoring period. This vast difference between the short-term enclosure trial and long-term monitoring might be the result of Stonecats escaping or because they simply were not motivated to move during the short-term trial. Whatever the case, the enclosure trial seems to have understated the success of the Dickens Farm wingwall bypass when compared to the long-term monitoring results. The total fishway model appears to drastically underestimate the structure compared to the species data or the long-term monitoring.

Table 10. Detection histories from fish included in Dickens Farm enclosure trial experiment including species, number of individuals in trial, number of fish detected, number of journeys, percent success, and total number of completed journeys. Species names in *italics* are non-native species that were included in the study.

Species	**Number in Trial**	**Number Fish Detected**	**Completed 1 Successful Journey**	**Percent Success**	**Total Number of Completed Journeys**
Bluegill	1	0	0	0	0
Central Stoneroller	4	0	0	0	0
Creek Chub	39	32	24	75	41
Common Shiner	10	9	8	89	31
Longnose Sucker	2	1	1	100	1
Longnose Dace	20	14	10	71	11
Brown Trout	5	0	0	0	0
Green Sunfish	6	2	2	100	2
Stonecat	26	15	1	7	1
White Sucker	21	3	3	100	14
Total	135	76	49	64	101

<u>Dickens Farm: Wingwall Bypass Fishway Long-Term Passage Rates:</u>

Between July 2019 and May 2020, a total of 794 fish were tagged and released in the vicinity of the Dickens Farm fishway. A summary of the species, counts, and individual fish total lengths (mm) is included in Table 11. Similar to the Dickens Farm monitoring results, no obvious patterns of movement were associated with patterns of low or high river discharge. However, the lowest rates of upstream movement occurred during the winter months. Of the 794 total tagged and released fish, a total of 471 individual fish were redetected during 20 months of monitoring for a redetection rate of 59%. Of the 471 known fish detected at the Dickens Farm wingwall bypass fishway, a total of 290 individual fish completed at least one successful journey producing an overall passage rate of 62%.

Table 11. Species, count, and total lengths (mm) of fish included in the long-term fish passage study at Dickens Farm. Species names in *italics* are non-native species that were included in the study.

Species	Count	Total Length Range (mm)
Black Bullhead	4	183-240
Bluegill	3	108-122
Common Carp	3	91-132
Creek Chub	167	81-179
Fathead Minnow	2	78-84
Gizzard Shad	6	106-136
Longnose Sucker	36	80-242
Largemouth Bass	96	80-248
Longnose Dace	151	79-112
Brown Trout	14	99-277
Red Shiner	3	69-81
Sand Shiner	1	80
Green Sunfish	26	75-145
Stonecat	74	88-195
Central Stoneroller	5	87-125
White Sucker	199	81-321
Yellow Perch	3	93-100
Total	794	--

Rough & Ready/Palmerton Diversion: Pool-Weir with Orifice Slots Short-Term Enclosure:
An enclosure trial was conducted at Rough & Ready/Palmerton Diversion during 2020. Plywood weir panels were constructed and installed to temporarily replace steel weir plates. A total of 11 species and 124 individually tagged fish were used in the short-term enclosure trial (Table 12). None of the 90 Plains Topminnows were documented moving upstream past the lowest weir plate.

All detection data from short-term enclosure trials were used to estimate transition probabilities (φ) and individual antenna detection probabilities (p) using CJS live recaptures function in Program MARK. Models incorporated each species individually with length as a covariate and variation by antenna. Overall fishway efficiency was modelled using all species combined and including length and antenna as covariates. Top models were determined using AIC and then averaged to produce robust estimates. Total fishway efficiencies were calculated using the product of φ and p estimates for a given species or fishway. See Table 13 for results of Rough and Ready enclosure trial and estimated transition probabilities. Antenna 3 had the lowest probability of movement past this point, likely because the slope increased from 9 to 12% between antenna 2 and 3, severely limiting fish movement.

Table 12. Fish used in Rough and Ready short-term enclosure trial including species, count, and minimum/maximum total lengths (mm) for individual fish. Species names in *italics* are non-native species that were included in the study.

Species	Count	Min Length (mm)	Max Length (mm)
Bluegill	1	87	
Creek Chub	11	25	124
Common Shiner	4	134	182
Longnose Sucker	53	80	241
Largemouth Bass	6	85	93
Longnose Dace	24	80	115
Brown Trout	14	80	361
Rainbow Trout	1	95	95
Red Shiner	2	67	80
Green Sunfish	6	90	130
Central Stoneroller	1	92	92
Total	124	--	--

Table 13. Estimates of probability of movement (φ) generated by Program MARK using CJS live recaptures model for the Rough and Ready short-term enclosure trial.

Probability of Movement Past an Antenna (φ)					
Species	**Antenna 1**	**Antenna 2**	**Antenna 3**	**Antenna 4**	**Total φ**
Creek Chub	0.95	0.86	0.21	1.00	0.17
Common Shiner	0.15	0.14	0.05	0.43	0.00
Longnose Sucker	0.89	0.70	0.11	1.00	0.07
Largemouth Bass	0.98	0.97	0.69	1.00	0.66
Longnose Dace	0.95	0.83	0.19	1.00	0.15
Brown Trout	0.95	0.83	0.19	1.00	0.15
Green Sunfish	0.93	0.76	0.15	1.00	0.10
Fishway	0.87	0.66	0.18	1.00	0.10

Raw data from fish detections were used to re-construct individual fish “journeys” and “completed journeys” for fish during the Rough and Ready short-term enclosure trial. A “journey” is defined as a fish movement detected by two antennas in succession. A “completed journey” is defined as a detection on an end point antenna through the course of their journey. A completed journey might consist of an encounter history that misses one or more detections on antennas located along the path it used to ascend the fishway, but all completed journeys must include the end point antenna to be classified as a “completed journey.” Results for the detection history analyses using successful journeys and completed journeys for the short-term enclosure trial at the Rough and Ready are included in Table 14. The orifice slots were used by Longnose Dace in particular. A single Longnose Dace made 32 trips up and down the fishway in equal proportion- likely indicating usage of the orifice slots. Largemouth bass, a non-native species, was the only species that had a “good” rate of movement through this fishway type.

Table 14. Detection histories from fish included in Rough and Ready enclosure trial experiment including species, number of individuals in trial, number of journeys, and total number of completed journeys. Species names in *italics* are non-native species that were included in the study.

Species	**Number in Trial**	**Completed 1 Successful Journey**	**Total Number of Completed Journeys**
Bluegill	1	0	0
Creek Chub	11	0	0
Common Shiner	4	0	0
Longnose Sucker	54	5	11
Largemouth Bass	6	3	8
Longnose Dace	24	2	34
Brown Trout	14	7	24
Rainbow Trout	1	0	0
Red Shiner	2	0	0
Green Sunfish	6	0	0
Central Stoneroller	1	0	0
Total	124	17	77

The following conclusions can be made based on the short-term enclosure and long-term monitoring of fish movements at the FCRID, Dickens Farm, and Rough and Ready fishways. Both the rock ramp (FCRID) and wingwall bypass (Dickens Farm) fishways designs are passing fish very effectively, just somewhat differently. The fish using the Dickens Farm wingwall bypass are residing in the fishway using it as habitat such as the Stonecats monitored in the study. As part of the long-term monitoring study, the Stonecats were detected over 35,000 times and made 661 complete journeys through the structure. The rock ramp design at the FCRID was effective at passing fish just as it was intended to function. However, the rock ramp did not provide the same habitat cover and refuge benefits that the bypass fishway at Dickens Farm. Fish utilizing the rock ramp at the FCRID did not reside in the fishway for any extended period of time. The Rough and Ready pool-weir with orifice fishway was the least effective in providing passage for fish and is not recommended for general use in passing our Great Plains fishes, especially the majority of species that are non-jumping. This fishway design concept evolved from earlier versions developed primarily for passing Pacific Northwest salmonids and is not appropriate for passing Great Plains fishes found in our Colorado transition zone streams. The orifice concept seemed like a promising way to provide another passage route for non-jumping fish species, however the ongoing maintenance issues associated with orifice openings clogging with sediment or debris seem to limit the ability of orifice slots to provide any meaningful passage for fish in typical natural river systems.

Some general fish passage recommendations reinforced through this study include: 1) Select a design slope and length of the fishway that will not exceed the swimming capacity of the slowest swimming species in an assemblage. 2) Include components that simulate habitat and either simulate habitat and decrease water velocities OR provide opportunity for the use of behavioral adaptations to overcome higher velocities. For instance, provide large boulders or similar roughness elements with as much surface texture as possible, incorporate Natural Channel Design principles, and provide interstitial spaces to function as resting areas. 3) Complex structures are difficult to monitor, but better for fish passage. Consider including provisions for antenna installation incorporated into the original fishway designs. 4) Species-specific fish passages (i.e., the pool-weir fishway designed for salmonids) are not ideal as they are designed for the highest physical capacity of a species at the exclusion of other species that make up the remainder of the assemblage. 5) Consider managing water around fishways to optimize ideal movement conditions, especially during seasons or hydrologic patterns that are critical to maintaining life histories, such as during spawning seasons or prior to the onset of winter. 6) Finally, both long-term monitoring and short-term enclosure studies provide valuable insights into evaluating new or differing fishway designs. Long-term monitoring is especially valuable for determining the effectiveness of fishway design types, but is much more costly and time-intensive than short-term enclosure studies. Short-term enclosure studies provide a rapid approach to evaluating the relative performance of fishways, but depending on the species and time of year, might falsely indicate poor performance of certain species (e.g., Stonecats). Motivation for fish moving upstream may not be a constant over the course of a season or based on fish maturity/size class. The enclosure process by nature is stressful to fish and is hardest on sensitive or shy species with may be have the highest conservation value.

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RESEARCH PRIORITY:

Watson Lake Fish Passage and Fish Screening Project, Cache la Poudre River

OBJECTIVES

To restore upstream fish passage at the Watson Lake Diversion Structure on the Cache la Poudre River for five fish species, including Brown Trout *Salmo trutta*, Longnose Dace *Rhinichthys cataractae*, Longnose Sucker *Catostomus catostomus*, Rainbow Trout *Oncorhynchus mykiss*, and White Sucker *Catostomus commersonii*.

INTRODUCTION

The Watson Lake Diversion structure on the Cache la Poudre River is operated by Colorado Parks and Wildlife (CPW) to provide water for the Watson Fish Hatchery near Bellvue, Colorado. CPW collaborated with the City of Fort Collins Natural Areas Department, Noosa Yogurt and Morning Fresh Dairy, and Northern Water to design and construct an engineered rock-ramp to restore fish passage at the diversion and reconnect 2.8 miles of habitat. The project also included a cone screen to prevent fish entrainment from the river into the reservoir. This project was the first fish passage and screening project to be implemented at a CPW owned diversion structure. Construction was completed during April 2019, and we have been monitoring fish passage with PIT-tag antennas to evaluate fishway effectiveness and inform the design of similar fishways in the watershed.

METHODS

Fishway evaluation has included monitoring of fish movement with PIT tags, discharge measurements to develop a rating curve for the fishway, and hydraulic measurement within the fishway to validate design criteria, similar to methods used by Richer et al. (2018, 2020). Design criteria included a maximum water velocity of 3.0 ft/s and minimum depth of 0.5 ft. Fish passage evaluation entailed installation of three PIT-tag antennas within the fishway, as well as the collection and tagging of target species. Discharge measurements were collected at the upstream-most section of the fishway and hydraulic measurements (i.e., depth, bottom velocity, depth-average velocity, and surface velocity) were collected at five transects within the fishway.

RESULTS AND DISCUSSION

Detection data from PIT-tag antennas were analyzed to evaluate passage success for the fishway, which was defined as detection of a fish at the upstream-most antenna. Three of the four species that have been tagged thus far exhibited successful passage through the fishway by at least one individual (Table 15). Over 30% of the tagged Brown Trout and Rainbow Trout have successfully ascended the fishway, ranging from 124 to 405 mm in total length (TL). This indicates that the fishway has provided upstream passage for multiple life stages of trout. Only one large Longnose Sucker (TL = 382 mm) has successfully ascended the fishway, but the sample size for tagged Longnose Sucker was relatively small (n = 8). Although five White Suckers were tagged and released as part of this study, no White Suckers have successfully ascended the fishway (Table 15) and only one has been detected within the fishway. No Longnose Dace have been tagged at this time, so additional work in needed to evaluate the efficacy of the Watson fishway for both dace and suckers.

Table 15. Fish passage summary by species for the Watson Diversion fishway from April 26, 2019 to June 30, 2021, including the number of tagged fish that were released, number of fish that passed through the fishway, and range in total length (TL) for fish that successfully ascended the fishway.

Species	**Released (#)**	**Passed (#)**	**Min TL (mm)**	**Max TL (mm)**
Brown Trout	160	50	124	379
Rainbow Trout	62	21	138	405
Longnose Sucker	8	1	382	382
White Sucker	5	0	NA	NA
All	235	72	124	405

Results from hydraulic measurements were presented in Kondratieff and Richer (2020). Additional hydraulic measurements were not conducted during this reporting period due to safety concerns associated with the high flow capacity of the Watson fishway. Alternative measurement methods, such as an Acoustic Doppler Currently Profiler (ADCP), will be explored as a means to evaluate hydraulic conditions within the fishway across a wider range of flows. In general, the Watson Diversion fishway has restored passage for trout and provides a low-velocity benthic pathway that meets design criteria for all target species. However, additional evaluations are needed to determine the efficacy of the fishway for Longnose Dace, Longnose Sucker, and White Sucker. We will continue to monitor fish passage, fishway discharge, and hydraulics at the Watson fishway to provide a more comprehensive understanding of fishway performance and to determine if modifications to the fishway are warranted.

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RESEARCH PRIORITY:

Technical Assistance

OBJECTIVES

Provide at least 10 technical assistance reviews to CPW personnel, NGOs, and Federal agency personnel as requested.

INTRODUCTION

CPW and other state and federal personnel are frequently in need of technical assistance related to stream habitat restoration, fish passage, whitewater park, and post-flood recovery projects. Technical assistance for projects will be provided as needed, including project identification, selection, design, evaluation, and permitting. Technical assistance includes design review for CPW biologists and district wildlife managers (DWMs), site visits to proposed stream restoration locations, consultations with various agencies on stream restoration opportunities associated with highway and bridge improvement projects, project management, consultations and technical support related to stream mitigation work for 404 permits, technical assistance related to fish passage design and construction, and teaching at various technical training sessions for CPW and other state and federal personnel.

METHODS

Technical assistance includes the review of proposed stream habitat restoration, fish passage, and conservation barrier projects, including design, contractor selection, and permitting for CPW and other state and federal personnel as requested. Proposed designs for post-flood road reconstruction and stream restoration will be reviewed for the Colorado Department of Transportation (CDOT) as requested. We will also provide training to CPW and other state and federal personnel on stream restoration techniques and fish passage design criteria, including guidance for permitting.

RESULTS AND DISCUSSION

We provided technical assistance for the following projects:

1) Colorado River Connectivity Channel at Windy Gap
2) Granby Fish Passage and Ditch Diversion Improvement, Fraser River
3) Windy Gap Fish Passage Study, Colorado River
4) Habitat Restoration and Rainbow Trout Stocking Evaluation, Yampa River
5) Niwot Ditch Diversion Reconstruction, St. Vrain Creek

6) Verner SWA Habitat Project, North Platte River
7) Gunnison River SWA Maintenance Project
8) Swan River Restoration Project, Reach B
9) Poudre Valley Canal Fish Passage Project, Cache la Poudre River
10) Wines Ditch Whitewater Park and Conservation Barrier Project, Dolores River
11) Huerfano County Water Conservancy Diversion Structure Fish Passage, Huerfano River
12) North I-25 Express Lanes Project, Cache la Poudre River
13) Halligan Water Supply Project, North Fork Cache la Poudre River
14) Boxelder Creek Mitigation Bank
15) St. Vrain State Park Mitigation Bank, St. Vrain Creek
16) Cheyenne Creek Bridge Project
17) Monument #1 Reservoir Flushing Flows
18) North Michigan Creek Dam Bank Stabilization
19) Request for Proposals, CPW Habitat Projects
20) Adams County Clear Creek Whitewater Park
21) Middle Colorado River Watershed Habitat Modelling
22) McIntyre Spring Rio Grande Sucker and Chub Habitat Project
23) Charlie Meyer SWA Habitat Maintenance Project, South Platte River
24) American Whitewater, RICD statute legislative revision
25) U.S. Army Corps of Engineers Nationwide and General Permit Revisions
26) Ridgway Reservoir Tailwater Habitat Maintenance Repair Project, Uncompahgre River
27) Eagle Whitewater Park Project, Eagle River
28) Crystal River Habitat Enhancement Project, Crystal River
29) Pleasant Valley Habitat Project, Yampa River
30) Sarvis Creek SWA Habitat Enhancement Project, Yampa River
31) Robinson Ditch Diversion Project, Roaring Fork River
32) South Platte Urban Grade Control Project, South Platte River through Denver
33) Canyon Creek Fish Passage Project, Canyon Creek and Interstate 70
34) Roan Creek Cutthroat Trout Conservation Barrier, Roan Creek

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