STREAM HABITAT INVESTIGATIONS AND ASSISTANCE PROJECT SUMMARY

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STREAM HABITAT INVESTIGATIONS AND ASSISTANCE PROJECT SUMMARY

Period Covered: July 1, 2019 through June 30, 2020

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 and monitoring 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). Instream construction activities began in July 2013 and were completed in August 2014.

Project goals were focused on enhancing the Brown Trout *Salmo trutta* population 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 Sign-Rank) methods, and the BACI study design was tested with a Repeated Measures Mixed Effects ANOVA.

Benthic Macroinvertebrates:
Dr. Will Clements with the Department of Fish, Wildlife and Conservation Biology at Colorado State University (CSU) is responsible for monitoring benthic macroinvertebrates. Monitoring was designed to evaluate if improvements in water quality, habitat quality, and riparian vegetation resulted in improved macroinvertebrate and prey resources for Brown Trout in the UAR. Similar to fish populations, a BACI study design was selected to investigate changes in water quality, benthic macroinvertebrates, the number of Heptageniidae mayflies, adult insect 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 is 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 annually during 2014-2018 were to determine if at least 90% of all habitat improvement structures were stable and functional. Structure assessment utilized a rapid field assessment procedure developed by Miller and Kochel (2012) that included

evaluations of structural integrity and function, unintended erosion, and unintended deposition. The final rapid assessment survey for the project was conducted in 2020.

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.

Table 1. Primary monitoring targets for the Upper Arkansas River Habitat Restoration Project including a preliminary progress update for 2019-2020.

Monitoring Target	Goal	Progress Update
Fish populations	Increase fish population and fish health metrics by at least 10% over baseline conditions by 2018	No monitoring surveys were conducted in 2019 for fish populations, but additional analyses found increases in trout density (15%) at all sites and increases in trout biomass at control (12%) and impact (21%) sites following restoration. Fish condition also improved (2%) across all sites.
Benthic macroinvertebrates	Increase benthic macroinvertebrate metrics by at least 10% over baseline conditions by 2018	In 2018, benthic macroinvertebrate abundance had increased by 4%, the number of prey items in trout diets increased by 17%, and the number of sensitive mayflies increased by 62%. However, adult insect emergence and terrestrial inputs decreased by -21% and -60%, respectively.
Riparian vegetation	Increase riparian vegetation by at least 10% over baseline in fenced and replanted areas by 2018	In 2019, vegetation cover had decreased at impact sites by 1-4% and increased at control sites by 4%. Desirable willow species increased by 9-13% and greenline surveys documented vegetation encroachment and increased bank stability.
Habitat quality	Increase habitat quality scores by at least 10% over baseline conditions by 2018	Preliminary analysis of 2018 habitat models indicated that previously reported trends for habitat quality have not changed. Detailed results were published in a peer-review manuscript.
Instream habitat structures	At least 90% of the habitat improvement structures were stable and functional by 2016	In 2018, 88% of habitat structures were stable and functional. Maintenance and restoration activities are planned for 2020.

Fish Populations:

Results from fish population monitoring were summarized in Richer (2020) and a manuscript is being prepared for submission to a peer-review journal. In summary, significant improvements in Brown Trout density and biomass were observed, but declines in quality trout could be indicative of increased competition and may suggest that the current harvest regulation (i.e., one fish under 12 in) should be reconsidered. Fish health (as indicated by the relative weight) has also improved significantly following restoration. Overall improvements in fish population metrics within the California Gulch Superfund Site indicate that ecosystem health continues to improve.

Benthic Macroinvertebrates:

Prior to the habitat restoration project, benthic macroinvertebrate communities had improved significantly in response to improved water quality (Clements et al. 2010). Preliminary results from the post-restoration evaluation of benthic macroinvertebrates have already been published (Pomeranz 2015; Wolff et al. 2019), and two additional publications are anticipated as part of Brian Wolff's doctoral dissertation. Processing and analysis of samples collected in 2018 was completed during 2019, and those data were used to update results for all benthic macroinvertebrate metrics (Table 2). Although the number of emerging adults (-21%) and terrestrial inputs (-60%) have declined, the abundance of benthic macroinvertebrates (4%) and number of prey items inside trout stomachs (17%) have both increased. This suggests that prey resources for Brown Trout may have improved following restoration, as benthic macroinvertebrates were more abundant and the number being consumed by Brown Trout has increased. The number of Heptageniidae, a sensitive family of mayflies, has increased by 62%, which could be indicative of improved water quality.

Table 2. Preliminary results for benthic macroinvertebrate monitoring associated with the Upper Arkansas River Habitat Restoration Project. The average for macroinvertebrate metrics during before and after periods was presented, along with the percent change.

Metric	**Before**	**After**	**Change**
Benthic Macroinvertebrates (#/Hess sample)	1,127	1,167	4%
Heptageniidae (#/Hess sample)	16	25	62%
Adult Emergence (#/net)	77	61	-21%
Terrestrial/Adult Inputs (#/trap)	906	365	-60%
Brown Trout Diets (#prey/fish)	48	56	17%

Benthic macroinvertebrate abundance, adult emergence, and terrestrial inputs all appeared to decline in 2013 or 2014. These declines could be attributed to streambed disturbance during construction activities, high runoff that mobilized bedload sediment, or issues with water quality. These potential explanations will be investigated further as part of the integrated watershed analysis. The integrated watershed analysis is being conducted by Dr. Chris Kotalik and Dr. Will Clements at CSU to investigate interactions between the various monitoring targets and inform adaptive management for the project.

Riparian Vegetation:

In general, changes in vegetation cover from 2012 to 2019 fell short of project goals (i.e., 10% increase), but more desirable riparian species appear to be displacing grasses (Baker et al. 2020). Two issues complicated the application of percent cover as a primary metric. First, most plots had established vegetation at baseline, 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 closer to a state of equilibrium, which is another indicator of ecosystem health. These results will be incorporated into a final report for riparian vegetation monitoring, as well as a peer-review publication.

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 (habitat heterogeneity, spawning habitat) demonstrated improvements over time. Preliminary analysis of 2018 models provided additional support for the results presented in Richer et al. (2019), which suggests that additional habitat modeling may not be 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 are not currently planned for 2020, but results from 2013-2018 models will be used to investigate changes in fish population metrics as part of the integrated watershed analysis.

Instream Habitat Structures:

Instream habitat structures were not surveyed during 2019 in accordance with the monitoring schedule (Stratus 2010; Richer et al. 2017). The final rapid assessment survey for the project was conducted in July 2020, and will be used to inform the maintenance activities scheduled for the fall of 2020. Results from 2014-2018 surveys were presented in the 2018 Annual Site Assessment (Richer 2019), and indicated that 88% of instream habitat structures were stable and functioning. Additional analysis of the rapid assessment data will be incorporated into a manuscript for submission to a peer-review journal.

ACKNOWLEDGEMENTS

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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 in 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 have been providing technical design assistance to Stillwater Sciences throughout the ongoing design process.

Results from the PIT-tagged tracer rock study were presented in Richer and Allgeier (2020). Tracer rocks will be resurveyed during the fall of 2020, after which the tracer rock data will be integrated with 2D sediment transport modeling results and incorporated into a peer-review manuscript. In general, the preliminary tracer rock data suggests that sediment in the Colorado River does not move with sufficient frequency to maintain benthic habitat for macroinvertebrates and Mottled Sculpin. The tracer rock data will also be used to investigate flushing flows for the project reach, which will in turn be used to inform the final proposed dimensions for the restored channel.

ACKNOWLEDGEMENTS

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. 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:

Habitat Restoration and Rainbow Trout Stocking Evaluation, Yampa River

OBJECTIVES

Evaluate the survival of Hofer×Harrison (H×H) Rainbow Trout (*Oncorhynchus mykiss*) in the Yampa River through a range of habitat conditions, manipulations of a resident Brown Trout population, and stocking strategies.

1) Determine if there is a length-specific effect on survival due to river habitat condition (restored versus unrestored reaches). To accomplish this objective, the annual apparent survival rates of catchable and fingerling-size *M. cerebralis* resistant Rainbow Trout will be estimated for fish stocked into both restored and unrestored reaches of the Yampa River.

2) Determine if large-scale brown trout removal will affect annual apparent survival rates of both catchable (competition) and fingerling-size (competition and predation) rainbow trout. To accomplish this objective, Brown Trout (*Salmo trutta*) will be removed from the Yampa River, on an annual basis during the study period.

3) Determine if a reduced stocking density results in similar annual survival rates in fingerling-size rainbow trout, with potential implications for hatchery management. To meet this objective, the fingerling Rainbow Trout stocking density will be reduced in the third year to less than half of what had been stocked in the two years previous.

INTRODUCTION

With some of the highest trout densities and biomass anywhere in Colorado, the Yampa River downstream of Stagecoach Reservoir is one of the most popular tailwater trout fishing destinations in the United States. A large-scale research project began in 2017 with the goal of evaluating survival of Hofer×Harrison (H×H) Rainbow Trout in the Yampa River through a range of habitat conditions, manipulations of a resident Brown Trout population, and stocking strategies. As part of this study, five distinct reaches were identified to represent the range of habitat conditions present within the entire 7.7-mile stream segment between Stagecoach Reservoir and Lake Catamount (Figure 1). From upstream to downstream, the first reach Stagecoach State Park property, which extends from Stagecoach Dam downstream approximately 0.25 miles (Tailwater Section), was historically degraded but restored in 2013. The second reach is located on private land (Wellar Ranch) extending approximately 1.0 mile. The stream condition is severely degraded (over-widened channel devoid of riparian plant species with active lateral bank erosion) with ongoing land management problems. The third reach, comprised of approximately 0.75 miles, is situated on the Service Creek SWA. This reach has been historically impaired from past land use management activities. It is currently characterized as having vertical bank instability (accelerated bank erosion) and excessive sediment supply as well as rapidly evolving channel form. The fourth reach is located on BLM land extending approximately 1.0 mile. This stream segment has been impacted as a result of excessive sediment supply from upstream erosion, including a major tributary channel (Service Creek) as well as development of an adjacent roadway. The fifth and final reach is located on private land known as Green Creek Ranch and is approximately 0.5 miles upstream of Lake Catamount extending approximately 2.0 miles upstream. This segment is actively being restored through restoration activities. The purpose of the recent habitat improvement projects (Stagecoach Tailwater Habitat Project and Green Creek Ranch Habitat Project) within the larger study reach is to restore the stream by creating a pattern, dimension and profile more appropriate to match the existing modified hydrology (based on upstream reservoir operations) and address historic, anthropogenic impairments. Specific restoration goals include a reduction in the rate of lateral bank erosion and overall sediment supply, fish habitat enhancement, as well as an increase in overall aquatic ecosystem function. Instream structures were constructed to enhance pool and riffle function, reduce the rate of lateral bank erosion and over-widening of the stream channel. Ultimately, results from this study will inform the management goal of re-establishing a wild Rainbow Trout fishery in the larger 7.7-mile channel reach between Lake Catamount and Stagecoach Reservoir. Details regarding the history of whirling disease, fish stocking, and development of whirling disease-resistant Rainbow Trout can be found in Fetherman and Schisler (2018).

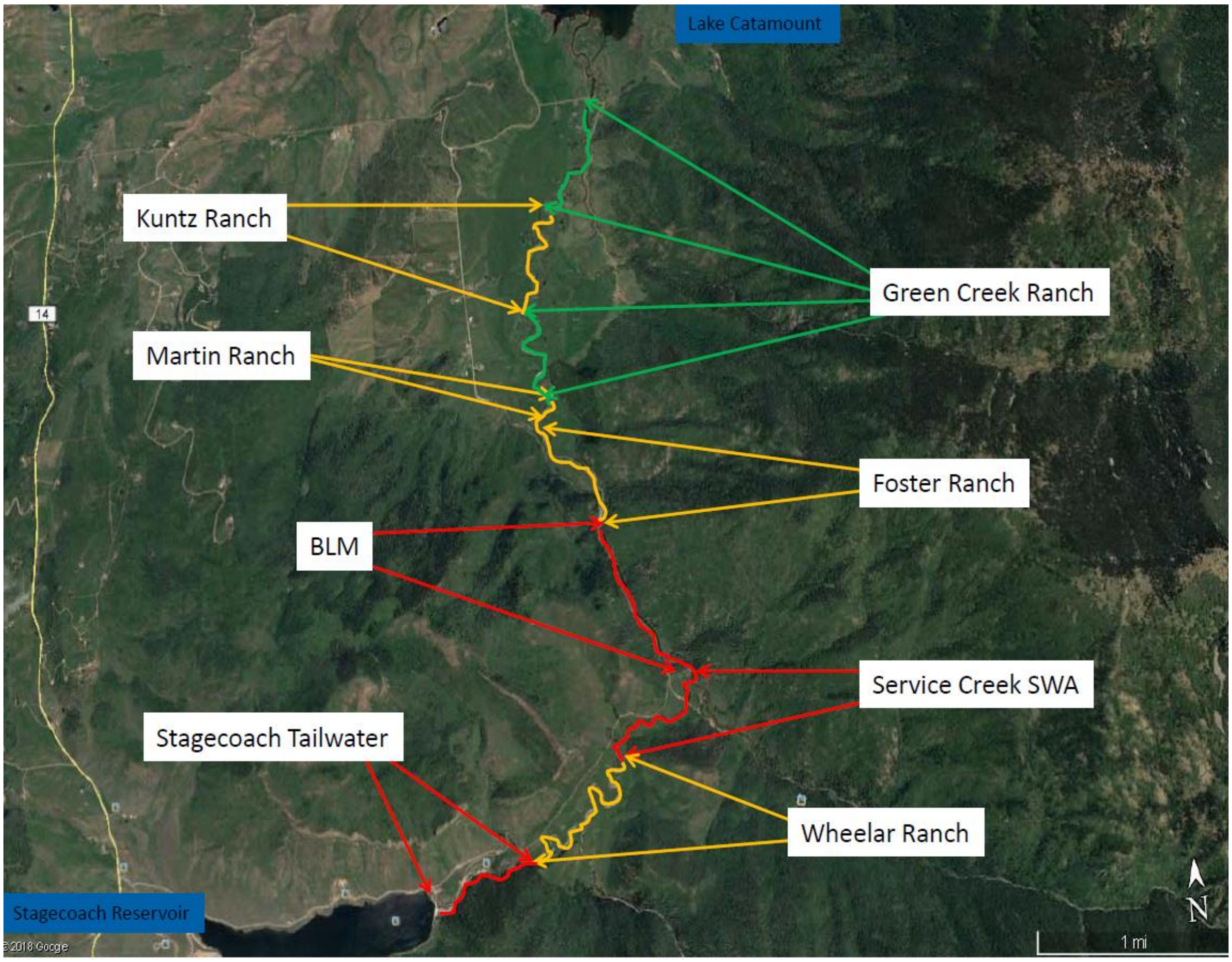

Figure 1. Study area located on a 7.7 mile river reach between Stagecoach Reservoir (upstream) and Lake Catamount (downstream) including the 5 distinct study sites including (from upstream to downstream): 1) Stagecoach Tailwater, 2) Wellar Ranch, 3) Service Creek SWA, 4) BLM, and 5) Green Creek Ranch.

METHODS

Rainbow Trout Survival and Population Estimation:
This project has three primary objectives. The first is to determine if there is a length-specific effect on survival due to river habitat condition (restored versus impaired reaches). To accomplish this objective, the annual apparent survival rates of catchable and fingerling-size *M. cerebralis*-resistant Rainbow Trout will be estimated for fish stocked into both restored and impaired reaches of the Yampa River. The second objective of this study is to determine if large-scale Brown Trout removal will affect annual apparent survival rates of both catchable (competition) and fingerling (competition and predation) Rainbow Trout. To accomplish this objective, Brown Trout will be removed from the Yampa River on an annual basis during the study period. The third objective of this study is to determine if a reduced stocking density results in similar annual survival rates in fingerling Rainbow Trout, with potential implications for hatchery management. To meet this objective, the fingerling Rainbow Trout stocking density will be reduced in the third year of the study to less than half of what had been stocked in the two years previous. Fish stocking began in 2017 and was completed in 2019. Fish surveys (electrofishing) began in 2017 and will continue until the fall of 2020. For additional details regarding our fish stocking, brown trout removal, and electrofishing surveys used to generate survival and population estimates as well as preliminary fish survey results, see Fetherman and Schisler (2018).

Habitat Assessment and Attribute Measurements:
Habitat conditions present within each of the five reaches were characterized using detailed topographic surveys conducted using GPS topographic survey gear during the fall of 2018. Pebble counts were conducted using Wolman pebble count procedures to characterize bed materials and document proportion of fine sediments. Redd count surveys were completed to identify specific spawning locations and sediment characteristics. Riparian habitat assessment ratings were made to characterize differences in plant communities, cover elements such as large wood, and indirectly assess bank stability associated with vegetation types. Finally, aquatic insect collections were made as an indirect measure of habitat quality. All of these measurements were collected at sampling sites located within each of the five study reaches. Sampling sites were selected based on how representative they were of the overall habitat conditions found within the larger study reach (one through five).

Topographic surveys consisted of collecting stream geomorphic data such as longitudinal profiles, cross sections, and pebble counts. Longitudinal profiles will be used to generate estimates of channel length, stream and valley slope, sinuosity, identify bedform features, and measure residual pool depths across the five study reaches. Cross sections will be used to compare average bankfull widths, average bankfull depths, average width to depth ratios, bankfull cross sectional area, and average entrenchment ratios across all reaches. Pebble counts will be used to characterize bed materials, especially the percentage of fines in each of the five reaches. Additional habitat assessments were completed to monitor riparian vegetation condition, concentration of large wood, presence of various cover types, conduct stream classification (stream and valley types), monitor active bank erosion, compare baseflow to bankfull discharge ratios, and measure the degree of vertical and lateral connectivity (related to bed incision or aggradation respectively). Topographic survey data for the project were presented in Kondratieff and Richer (2019). Historical land use and practices within the study segment (that contains the five study reaches) will be researched in order to understand underlying causes of stream impairment documented through various habitat assessments. Pre- and post-construction survey data from these restored reaches will be analyzed, as well as baseline survey data that was collected from the impaired reaches to form potential correlations between habitat attributes, or lack thereof, and retention of tagged fish. Habitat attributes (riffle to pool ratio, width/depth ratios, percent bank cover, and pool characteristics), as well as limiting factors will be assessed by reach to better formulate correlations. A stage-discharge relationship will be generated to characterize the hydrology within reaches for the extent of the study period. Thermographs may be deployed throughout the system in an effort to monitor potential temperature variations over the course of the study. Further details about this larger-scale study are found in Fetherman and Schisler (2018). Data collection for this study including fisheries metrics and habitat associations are ongoing.

RESULTS AND DISCUSSION

The results from this experiment are expected to help biologists and researchers understand the effects of river restoration activities and Brown Trout removal on the retention and survival of Rainbow Trout. Unique to this study will be the knowledge gained regarding the length-specific effects of restoration activities on apparent survival of stocked fish (i.e., if restoration activities are more of a benefit to larger or smaller fish, or benefit both equally). Additionally, the effects of manipulating stocking densities on Rainbow Trout populations will be evaluated. Stocking density effects on survival will be used to determine if biologists could lower fish requests to obtain similar returns, thereby reducing the pressure of high-density culture and potential issues with disease that come with high-density culture in Colorado hatcheries. Results for this study including data analyses from fish and habitat surveys and habitat associations are ongoing.

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RESEARCH PRIORITY:

Badger Basin State Wildlife Area Habitat Restoration Project, South Platte River

OBJECTIVES

Evaluate the response of trout populations and pool depths to the addition of large wood through the installation of toewood treatments within lateral scour pools.

INTRODUCTION

Overwinter habitat has been identified as a limiting factor for Brown Trout *Salmo trutta* populations in the Middle Fork of the South Platte River near Hartsel, CO (Kondratieff 2011). In response to this assessment, a 2.1 mile habitat restoration project was initiated within a portion of the degraded watershed with the purpose of converting shallow, over-widened pools into deeper, larger-volume pools to improve overwinter habitat from 2007-2011. The hypothesis was that the creation of deeper, larger pools would attract and hold adult fish year-round and that they would reside in the project reach instead of migrating downstream to overwinter in a nearby reservoir. Initial results from a reach-wide BACI study examining the response of trout populations to wood-treated versus boulder-treated restoration approaches (Kondratieff and Richer 2019) provided the motivation to conduct a smaller-scale study to examine the relative value of incorporating wood into lateral scour pools (run-pool-glide complexes).

Pools were constructed in one of three ways:

1) Excavation of a deep pool and construction of a point bar (Figure 2; no wood)
2) Excavation of a deep pool, construction of a point bar, and introduction of large wood placed at the bank toe of the outside bend in a haphazard manner (Figures 3 and 4; Type 1)
3) Excavation of a deep pool, construction of a point bar, and introduction of large wood intentionally placed at the bank toe of the outside bend to function as an undercut bank (Figures 5 and 6; Type 2)

The study was designed to answer the following questions:

1) Given the hypothesis that deep pools were limiting to brown trout populations (lack of overwinter habitat), which of the three treatment types were most effective in maintaining the deepest pools?
2) What was the response of Brown Trout populations to introduction of large wood?
3) What was the response of Brown Trout populations to Type 1 and Type 2 toewood treatments? Is there evidence that one method confers a greater benefit than another (Type 1 vs Type 2)?
4) Is there evidence that toewood treatments create “sucker holes” that have an unintended consequence of enhancing White Sucker *Catostomus commersonii* populations?
5) What is the capture probability of trout and suckers when electrofishing in toewood treated vs non-toewood treated pools?

METHODS

Pool habitat measurements and fish population monitoring occurred eight years post-construction during a two week period in October 2019 when stream baseflows and temperatures were relatively stable and any potential changes in fish behavior due to temporal changes were expected to be minimized due to the very short sampling time period. An as-built survey of the entire 2.1-mile reach was used to classify every lateral scour pool within the restoration reach as Type 1, Type 2, and no wood (Kondratieff and Richer 2015). Note that only lateral scour pools were included within the study and all other pool types (i.e., convergence scour pools, step-pools, or pools formed downstream of tributary junctions) were excluded from the study. Once pools were classified, three pools were randomly selected from each treatment group category. For each individual study pool (lateral scour pool consisting of a run-pool-glide complex), habitat measurements and fish population monitoring was conducted. Fish populations within individual pools were surveyed using multi-pass depletion electrofishing techniques with block nets (upstream and downstream) to satisfy the assumption of closure. All individual fish sampled within study pools were identified to species and measured (lengths and weights). Project effectiveness monitoring was based on data for Brown Trout as it is a wild and self-sustaining population (not stocked), a popular game species, and less sensitive to confounding variables such as whirling disease, metals toxicity, and water pollution. In addition to trout, White Sucker populations were studied since they have been identified as an undesirable nuisance species and potential competitor with certain trout life stages when found living in sympatry. Interviews with fish managers and anglers suggested that there was concern that the placement of large wood into streams to enhance trout habitat might have the unintended consequence of creating more sucker habitat (i.e., "sucker holes"). Part of our monitoring study was devoted to determining if there was evidence supporting this claim.

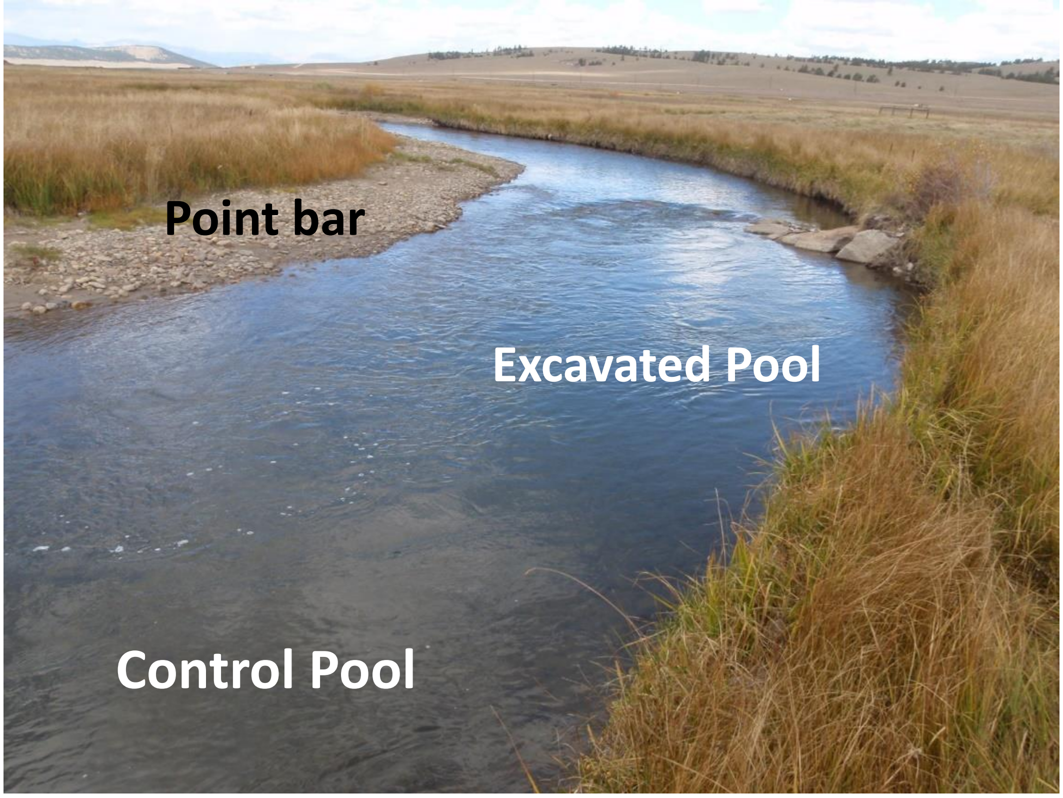

Figure 2. Control pool consisting of an excavated pool and constructed point bar. No wood was intentionally placed within these pools.

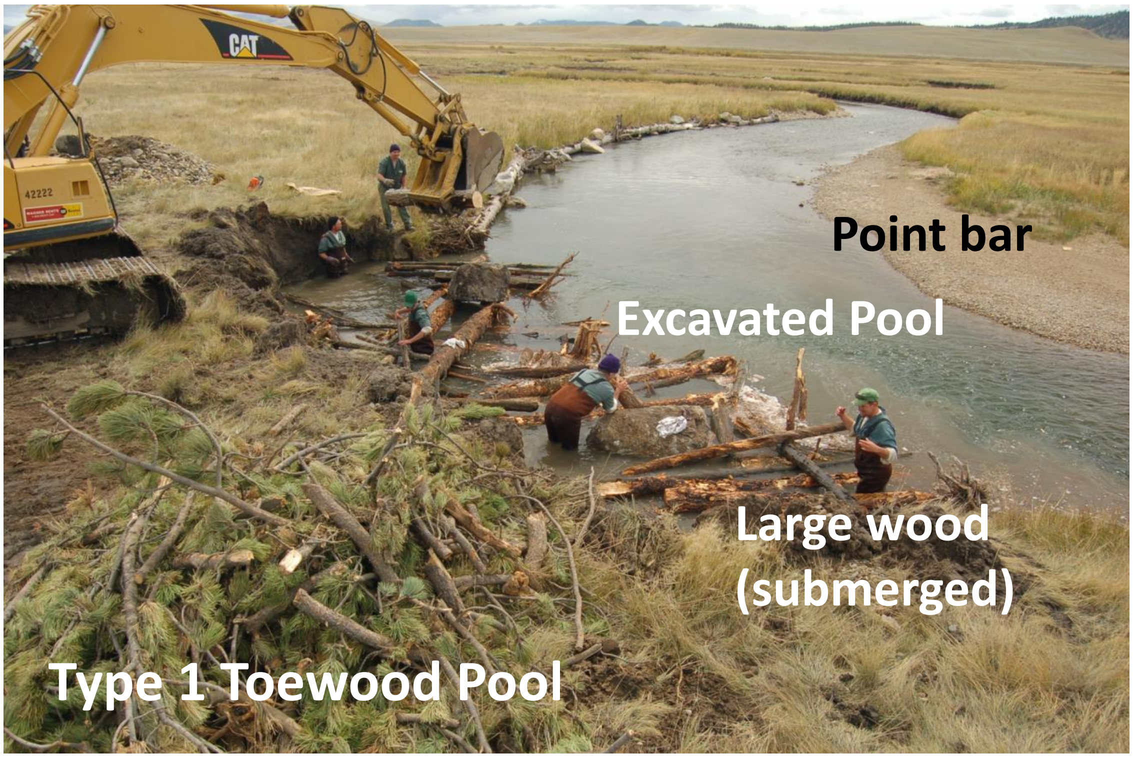

Figure 3. Type 1 toewood pool during construction, consisting of an excavated pool, constructed point bar and introduction of large wood placed at the bank toe of in a haphazard manner.

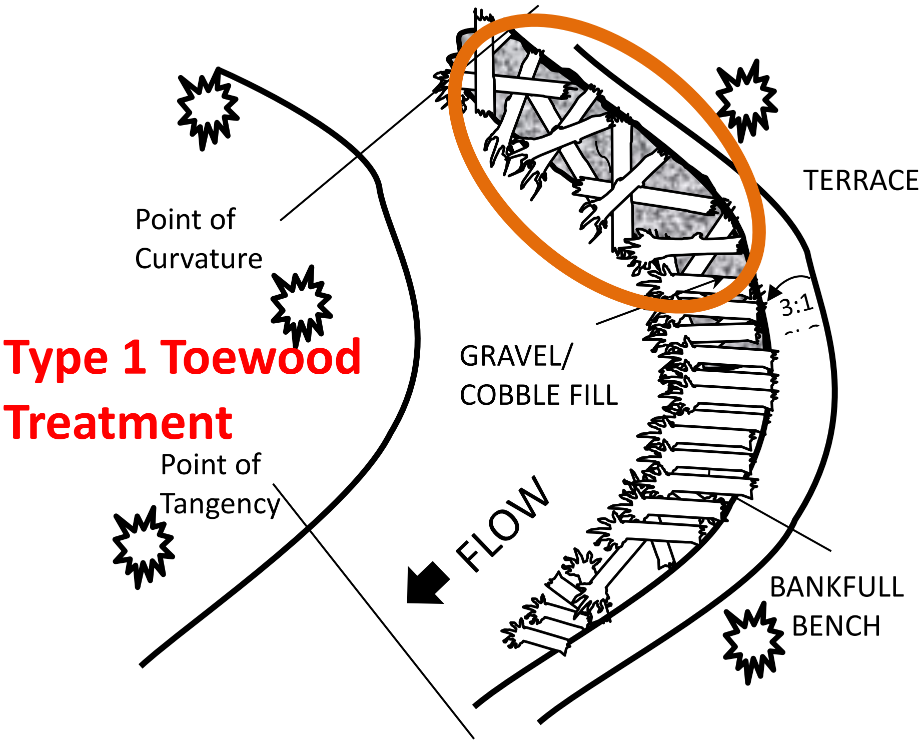

Figure 4. Plan view of the Type 1 toewood treatment concept (circled in orange) and haphazard arrangement of large wood with attached root wads. Sod mats would normally be placed on top of the large wood, brush (not shown) and top soil layers (not shown).

Figure 5. Type 2 toewood treatment during construction, consisting of an excavated pool, constructed point bar introduction of large wood at the bank toe to function as an undercut bank.

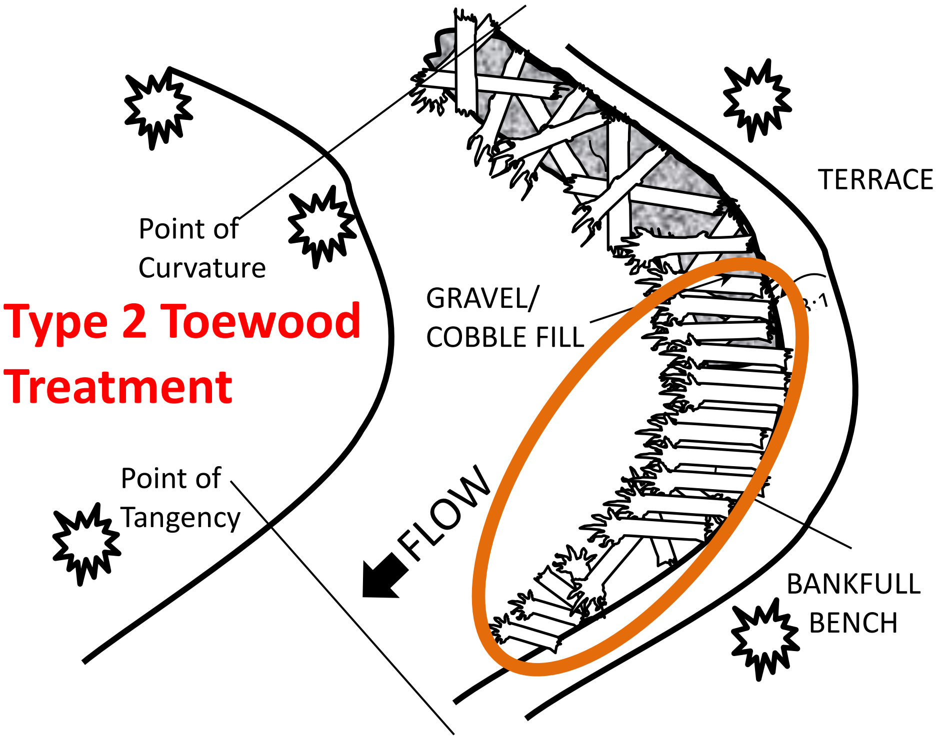

Figure 6. Plan view of the Type 2 toewood treatment concept (circled in orange) and introduction of large wood intentionally placed at the bank toe of the outside bend to function as an undercut bank. Sod mats would normally be placed on top of the large wood, brush (not shown) and top soil layers (not shown).

Fish population monitoring consisted of estimating Brown Trout abundance (number/100 ft of pool), quality Brown Trout abundance (>14" TL/ 100 ft of pool), and Brown Trout biomass (lbs/100 ft of pool), as well as White Sucker abundance and biomass. Pool habitat characteristic measurements included pool type (Type 1, Type 2, or no wood), pool length, maximum pool depth, and length of upstream riffles. Analyses were conducted to determine which treatment types were most effective at maintaining deep pools, the response of Brown Trout and White Sucker populations to the introduction of large wood, which treatment type conferred the greatest benefit to Brown Trout populations, and the capture probability of trout and suckers when electrofishing in toewood treated pools.

RESULTS AND DISCUSSION

Maximum Pool Depth:

Providing deep pools as overwinter habitat and holding cover for adult trout was one of the primary goals of the habitat restoration project. This followed from an assessment of habitat conditions that identified overwinter habitat as a limiting factor for Brown Trout populations. Maximum pools depths were measured for individual pools that were included as part of this study. Maximum pool depths were defined as the location within a lateral scour pool run-pool-glide complex that had the greatest difference between the water surface and streambed surface elevations. As stream discharge was nearly constant during the short duration of the study, water surface could be used as a reliable indicator for determining maximum pool depth within pools. If discharge had been variable during the study duration, water surface would not be a good indicator of pool depth. Instead, the pool tail crest (for residual pool depth) or bankfull elevation could be used as alternative indicator to water surface for determining maximum pool depth. 95% confidence intervals (CI) for maximum pool depths associated with Type 1 and Type 2 toewood-treated pools do not overlap with 95% CI for non-wood treated pools (Control; Figure 7), suggesting that wood-treated pools maintained significantly deeper maximum pool depths than non-wood treated pools. However, the 95% CI for Type 1 and Type 2 wood-treated pools overlap suggesting no advantage in maintaining deeper pools between the two toewood techniques. Non-wood treated (Control) pools averaged a maximum depth of 3.2 ft. Type 1 and Type 2 pools were deeper on average than non-wood Control pools (4.4 ft and 5.2 ft, respectively). Treating lateral scour bends using toewood techniques helps maintain significantly deeper maximum pool depths over time than simply treating pools by excavating them and shaping point bars alone. Since there was no difference between Type 1 and Type 2 maximum pool depths (95% CI overlap), we combined all maximum pool depths from wood-treated toewood pools for comparison with the non-wood Control treatment (Figure 8). Wood-treated toewood pools averaged 1.6 ft deeper than maximum depths from non-wood treated Control pools (a 33% increase in maximum pool depth) and this difference was statistically significant (95% CI non-overlapping).

Brown Trout Abundance and Biomass:

One of the benefits of in-channel large wood is that it can increase micro-habitat complexity and result in improved habitat quality for trout. Brown Trout abundance (density or number/ft) and biomass (lbs/ft) can function as indicators of habitat quality for trout populations. If habitat is degraded, trout abundance and biomass will often be reduced compared to locations where habitat conditions are favorable. Estimates of Brown Trout abundance and biomass were generated for each individual study pool. In order to account for differences in pool volume or length, trout metrics were standardized across sites by dividing abundance and biomass estimates by the total length of the lateral scour pool (run-pool-glide complex) in feet. Therefore, abundance and

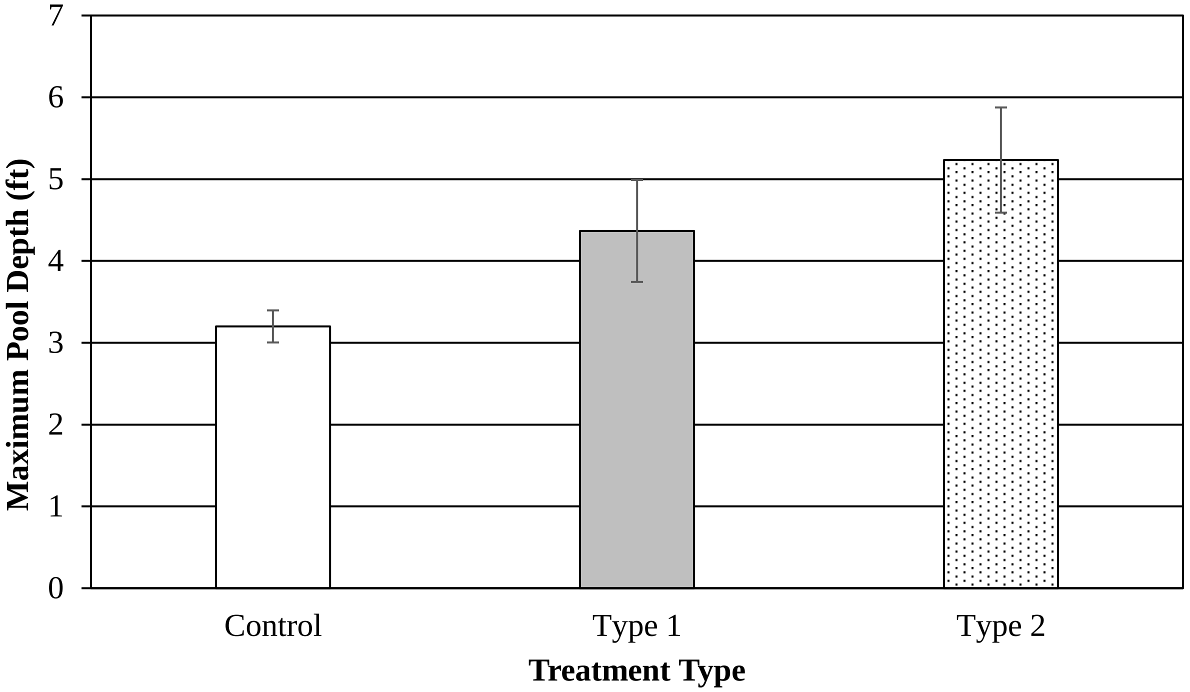

Figure 7. Average maximum pool depths (in feet) and 95% CI from Control (non-wood treated; n=3), Type 1 (haphazard toewood; n=3) and Type 2 (undercut toewood; n=3) treated lateral scour pools. Maximum pool depths were measured as the maximum difference between the streambed and water surface elevations in the vertical plane.

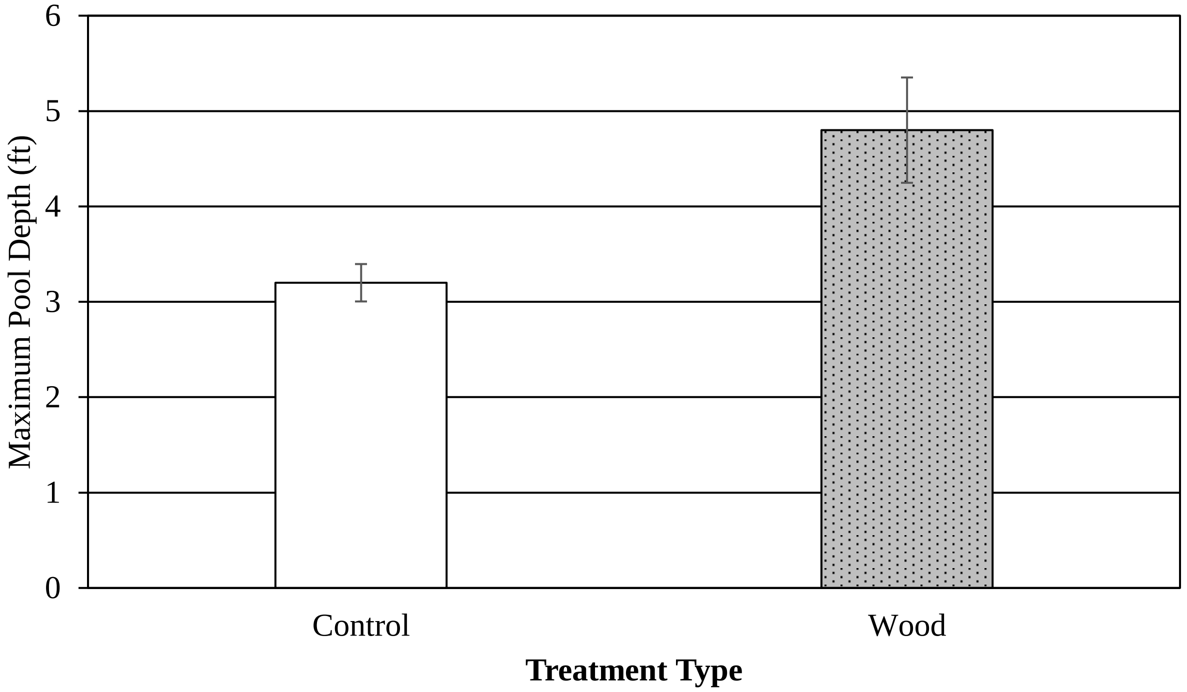

Figure 8. Average maximum pool depths (in feet) and 95% CI from Control (non-wood treated; n=3) and Wood (combined Type 1 and Type 2 toewood-treated; n=6) treated lateral scour pools. Maximum pool depths were measured as the maximum difference between the streambed and water surface elevations in the vertical plane.

biomass are reported in a per 100 ft-of-pool basis. Reporting abundance and biomass in this way may help improve our understanding of how stream habitat quality for fish measured in a functional foot scale can be useful as a unit of measure under the Colorado Stream Quantification Tool for stream mitigation projects.

Brown Trout abundance in Type 1 and Type 2 toewood treated pools was estimated to be higher (77 and 69 trout/100 ft of pool, respectively) than the non-wood treated Control pools (21 trout/100 ft of pool). However, only the trout abundance from the Type 2 treatment was significantly higher compared to the Control treatment (Figure 9; 95% CI non-overlapping). Brown Trout abundance in Type 1 (haphazard toewood technique) and Type 2 (undercut toewood technique) were not different (95% CI overlap). Since there was no difference between Type 1 and Type 2, Brown Trout abundance (95% CI overlap), all Brown Trout abundance estimates from wood-treated toewood pools were combined to compare with the non-wood Control pool estimates (Figure 10). Wood-treated toewood pools held on average 2.4 times more Brown Trout than non-wood treated Control pools and this difference was statistically significant (95% CIs non-overlapping).

Brown Trout biomass in Type 1 and Type 2 toewood treated pools was estimated to be higher (20.8 lbs trout/100 ft of pool and 23.2 lbs trout/100 ft of pool, respectively) than the non-wood treated Control pools (2.0 lbs trout/100 ft of pool). However, only the trout biomass from the Type 2 treatment was significantly higher compared to the Control treatment (Figure 11; 95% CI non-overlapping). Brown Trout biomass estimates in Type 1 (haphazard toewood technique) and Type 2 (undercut toewood technique) were not different (95% CI overlap). As there was no difference between Type 1 and Type 2 Brown Trout biomass (95% CI overlap) from wood-treated pools, all Brown Trout biomass estimates were combined for comparison with the non-wood Control pool estimates (Figure 12). Wood-treated toewood pools held on average 9.9 times more biomass of Brown Trout than non-wood treated Control pools and this difference was statistically significant (95% CI non-overlapping; Figure 12).

Quality Brown Trout:

The abundance of quality-sized Brown Trout (adult trout ≥ 14” TL) is important to estimate because quality-sized trout are desirable for anglers and they represent a portion of sexually mature individuals within a trout population. High quality habitats for wild trout will often have a diverse range of age classes represented, including large, sexually mature individuals. Quality Brown Trout abundance in Type 1 and Type 2 toewood treated pools was estimated to be higher (8 and 12 quality trout/100 ft of pool, respectively) than the non-wood treated Control pools (0.3 quality trout/100 ft of pool). All wood-treated toewood pools had quality Brown Trout present (range = 2-24 quality trout/100 ft of pool). However, only one of the three non-wood control pools had quality-sized Brown Trout present (range = 0-1 quality trout/100 ft of pool). The number of quality size Brown Trout found in individual study pools was highly variable for Type 1 and Type 2 toewood treated pools as is reflected in very wide 95% CI for abundance estimates (Figure 13). No significant differences between treatment types were detected. Since there was no difference between Type 1 and Type 2 quality Brown Trout abundance (95% CI overlap), all abundance estimates from wood-treated toewood pools were combined for comparison with the non-wood Control pool estimates (Figure 14). Wood-treated toewood pools held on average 28 times more Brown Trout than non-wood treated Control pools and this difference was statistically significant (95% CI non-overlapping).

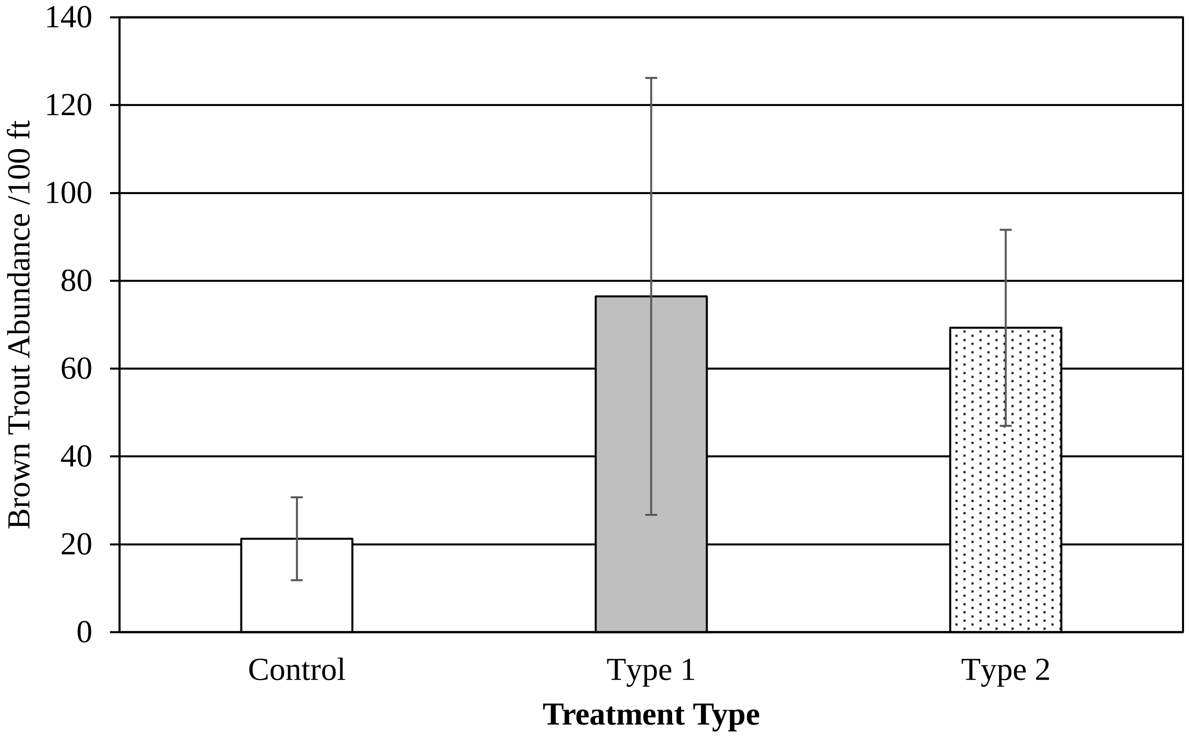

Figure 9. Average Brown Trout abundance (number of trout/100 ft of pool) and 95% CI from Control (non-wood treated; n=3), Type 1 (haphazard toewood; n=3) and Type 2 (undercut toewood; n=3) treated lateral scour pools.

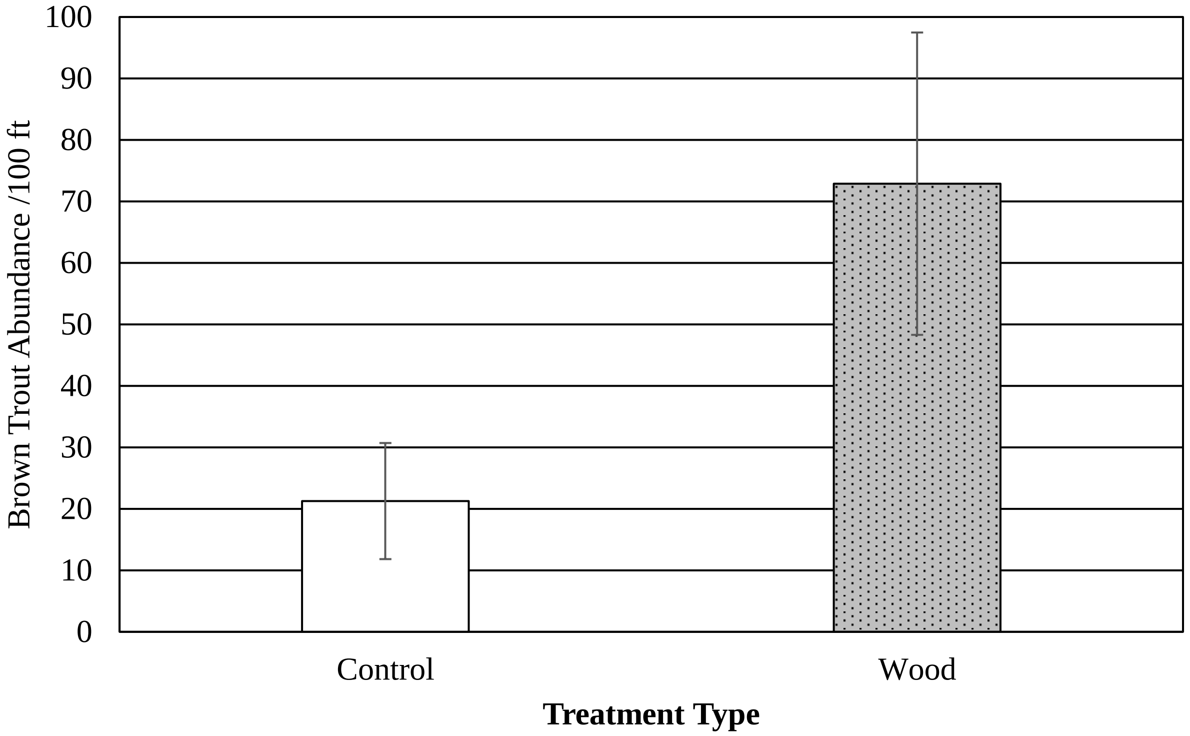

Figure 10. Average Brown Trout abundance (number of trout/100 ft of pool) and 95% CI from Control (non-wood treated; n=3) and Wood (combined Type 1 and Type 2 toewood-treated; n=6) treated lateral scour pools.

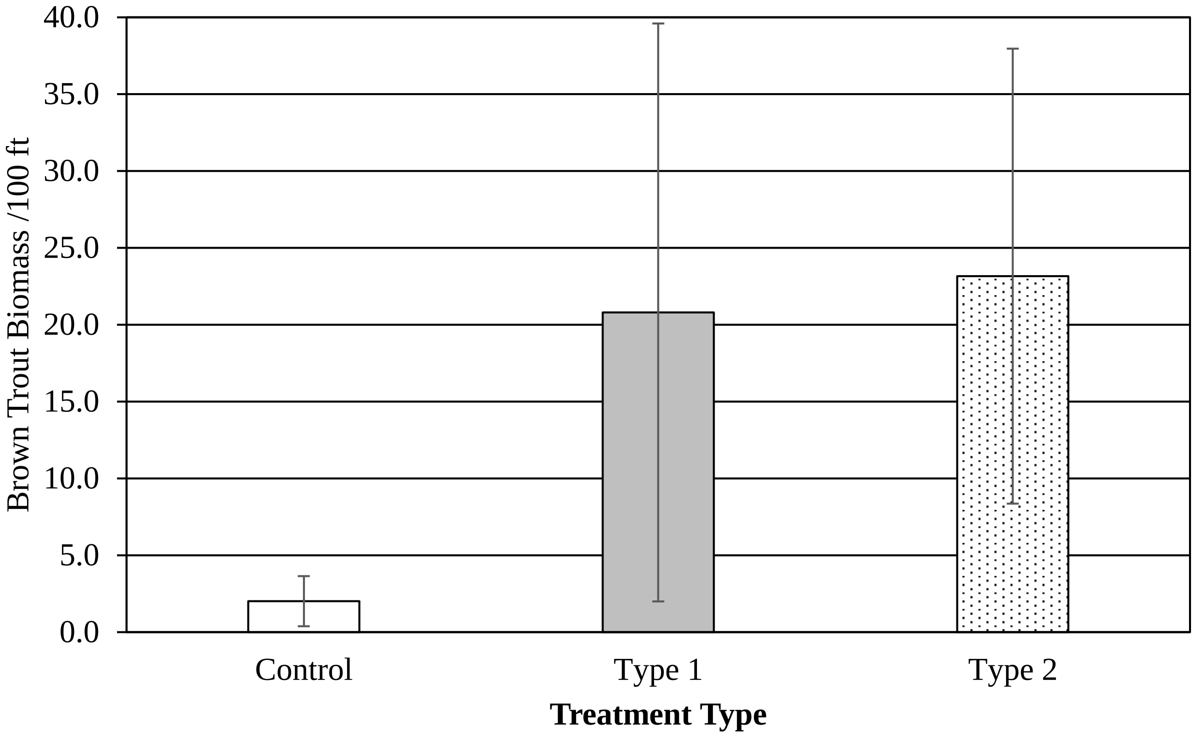

Figure 11. Average Brown Trout biomass (lbs of trout/100 ft of pool) and 95% CI from Control (non-wood treated; n=3), Type 1 (haphazard toewood; n=3) and Type 2 (undercut toewood; n=3) treated lateral scour pools.

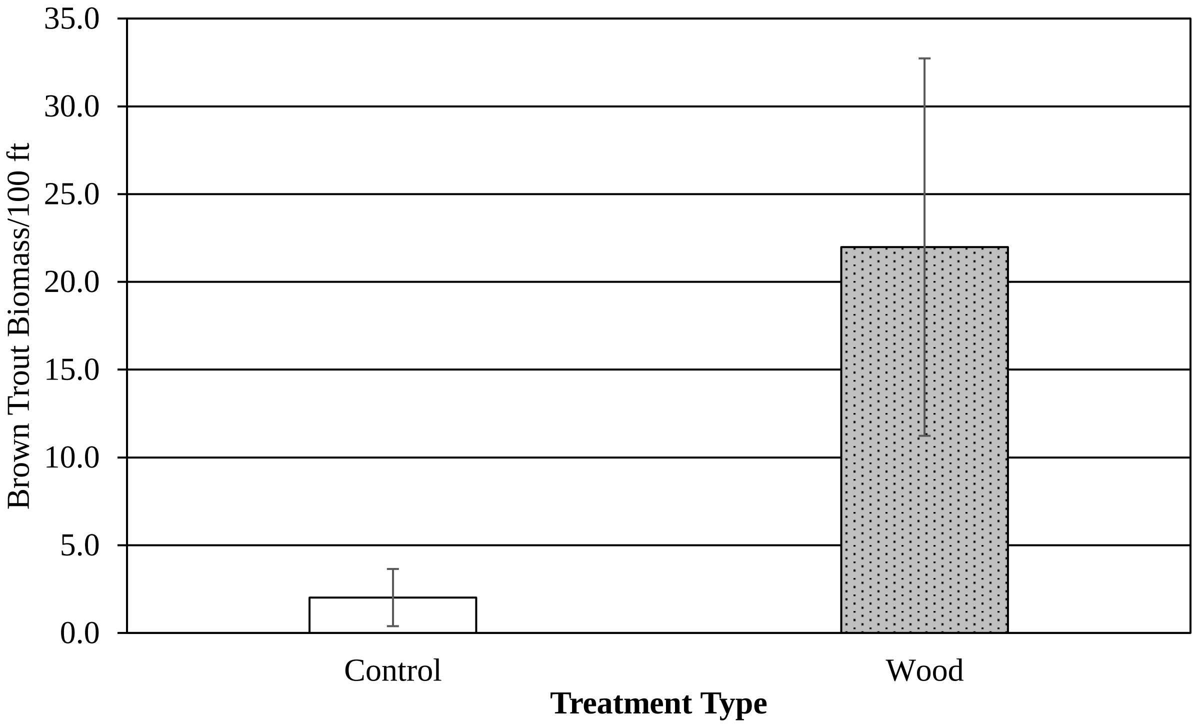

Figure 12. Average Brown Trout biomass (lbs of trout/100 ft of pool) and 95% CI from Control (non-wood treated; n=3) and Wood (combined Type 1 and Type 2 toewood-treated; n=6) treated lateral scour pools

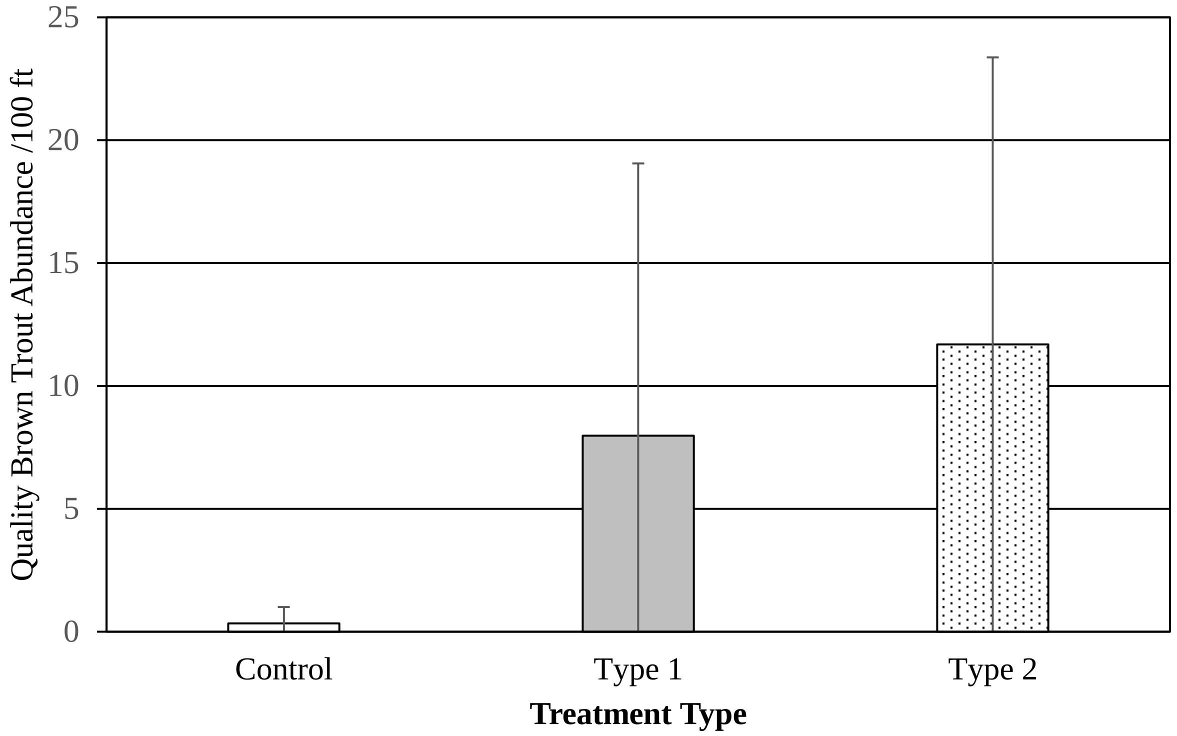

Figure 13. Average Quality Brown Trout (TL ≥14”TL) abundance (number of quality trout/100 ft of pool) and 95% CI from Control (non-wood treated; n=3), Type 1 (haphazard toewood; n=3) and Type 2 (undercut toewood; n=3) treated lateral scour pools.

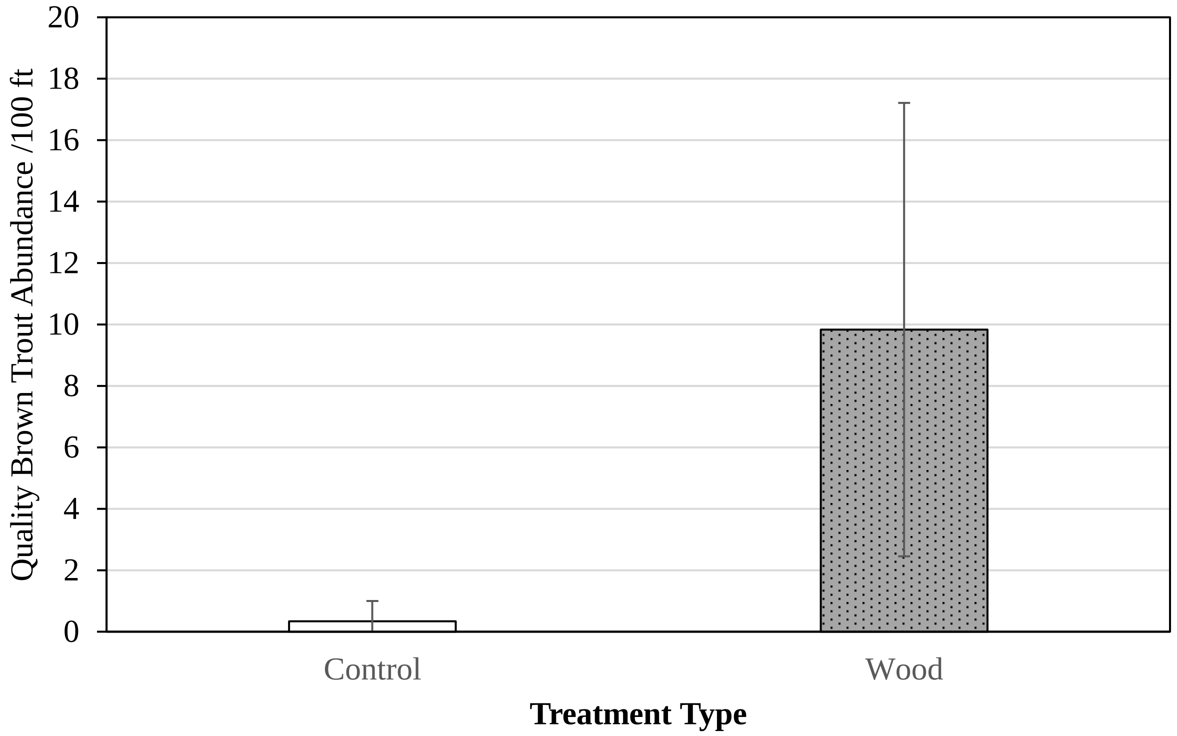

Figure 14. Average Quality Brown Trout (TL ≥14”TL) abundance (number of quality trout/100 ft of pool) and 95% CI from Control (non-wood treated; n=3) and Wood (combined Type 1 and Type 2 toewood-treated; n=6) treated lateral scour pools.

In summary, toewood treated pools were most effective at maintaining the deepest pools, averaging 1.6 feet or 33% deeper pools than non-wood treated pools. There was not sufficient evidence to suggest that either Type 1 or 2 toewood treatment methods were more effective at maintaining deeper pools. Brown Trout abundance and biomass were both higher in toewood treated pools than non-wood treated pools (2.4 times higher abundance and 9.9 times higher biomass, respectively). However, when comparing Brown Trout abundance and biomass from Type 1 and Type 2 toewood-treated pools, there did not appear to be an advantage of one type over another. Brown Trout biomass and abundance were not significantly different when comparing Type 1 and 2 toewood treatment types. Quality-sized Brown Trout abundance was 28 times higher in toewood treated pools than non-wood treated pools. The abundance of quality-sized Brown Trout within toewood treated pools was highly variable (range = 2-24 quality trout/100 ft of pool). Quality-sized Brown Trout abundance was not significantly different when comparing Type 1 and 2 toewood treatment types.

Remaining aspects of the study including whether there evidence that toewood treatments create “sucker holes” that have an unintended consequence of enhancing white sucker populations and estimation of capture probabilities of trout and suckers when electrofishing in toewood treated vs non-toewood treated pools. Data analyses for these study questions are ongoing.

ACKNOWLEDGEMENTS

We would like to thank the many CPW aquatic biologists, researchers, and technicians that have contributed to the resource management, data collection, and analysis. In particular, Jeff Spohn, Paul Winkle, Tyler Swarr, and Ryan Fitzpatrick were instrumental in assisting with major portions of this project. We would also like to thank the Vocational Heavy Construction Technology program for helping us with construction of this habitat restoration project and our CPW property technician Bill Rivale for managing the Badger Basin SWA fences and relations with adjacent landowners to exclude grazing cattle out of the project reach.

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RESEARCH PRIORITY:

Twin Tunnels Habitat Restoration Project, Clear Creek

OBJECTIVES

Evaluate the trout population response to the conversion of a channelized, riprapped, disconnected floodplain stream reach to a moderately-confined, non-riprapped stream with a functional floodplain

INTRODUCTION

Many Colorado streams have been channelized to convey floods, protect infrastructure, and maximize crop production over the past two centuries. A good representative example of this kind of stream channel modification is found on Clear Creek near Idaho Springs, Colorado. The stream is generally confined along most of the stream corridor between a major Interstate highway (I-70) on one side and a historic railway grade on the other. As most of Clear Creek has been channelized and armored with riprap to protect infrastructure, there are very few locations with functional floodplains resembling historic natural conditions. The Twin Tunnels construction project was initiated by the Colorado Department of Transportation (CDOT). Once construction of the new tunnels was completed, a temporary frontage road was removed, providing a unique opportunity for riparian restoration within the I-70 corridor. The 0.4-mile riparian restoration and instream habitat project was completed in April 2015.

We report on a study assessing the effects of converting a highly-confined, channelized and riprapped, single-stage Rosgen F-stream (confinement ratio = 1.2; channel slope < 2%) to a moderately-confined, three-stage Rosgen Bc-stream (confinement ratio = 2.0; channel slope = 0.9%) on trout populations. Primary treatments within the high-intensity segment consisted of removal of riprap and excess bank material to create a new floodplain and shape a new active channel that aligned with current bankfull discharge. Response of trout population abundance from the high-intensity segment were compared to low-intensity and control stream segments. Channel cross-sectional geometry was not altered in the low-intensity segment (pre- and post-construction average confinement = 1.2). The low-intensity segment remained highly confined, riprapped, and constrained between two roadways. Pre-construction baseline data were collected at the high-intensity (two years), low-intensity (three years), and control (one year) segments. Post-construction fish population monitoring continued for a total of five years, evaluating fish population composition, density (number/mile), and biomass (lbs/acre) for populations within the three segments. Project effectiveness monitoring was based on data for Brown Trout *Salmo trutta* only as they are a wild and self-sustaining population (not stocked), a popular game species, and less sensitive to confounding variables such as whirling disease, metals toxicity, and water pollution.

METHODS

Physical habitat characteristics were documented, mapped, and measured before and after the project was completed using survey grade GPS equipment. Pre-project habitat characteristics were compared to habitat characteristics documented in the as-built survey to make detailed comparisons of channel conversion changes. Representative reaches within the low- and high-intensity segments were selected for stream classification (Rosgen 1994) and estimating fish population response. As-built surveys were also used to locate, inventory, and describe treatment actions and the extent of treatment actions within each project reach. Detailed results of the physical habitat treatments and project reach can be found in Kondratieff and Richer (2019).

Fish populations were estimated using multi-pass depletion electrofishing techniques at representative fish sampling sites. All individual fish sampled within sampling sites were identified to species and measured (lengths and weights). Data collected from fish surveys were used to generate estimates of trout density (number/mile) and biomass (lbs/acre) for making conclusions about trout population response to physical habitat changes.

RESULTS AND DISCUSSION

High-Intensity Treatment Site:

The high-intensity treatment site is an approximately 1,300-ft long stream segment upstream of the Dog House Bridge. Primary treatments within this site consisted of riprap removal and removal of excess bank material to create a new floodplain and shape a new active channel that would align with the current channel-forming discharge (bankfull Q). This involved conversion of the existing highly-confined, channelized and riprapped, single-stage Rosgen F-stream type (confinement ratio < 1.4; channel slope < 2%) to a moderately-confined, three-stage Rosgen Bc stream type (confinement ratio = 1.4-2.2; channel slope = 0.9%). Confinement was defined as the width of the valley at two times the average depth at bankfull (bkf) elevation divided by the bkf channel width. The pre-construction single-stage channel was converted to a post-construction three-stage channel with functional floodplain. The average confinement pre-construction within the high-intensity treatment reach was 1.2. The average confinement post-construction was increased to nearly 2.0 due to the removal of riprap and expansion of floodplain area by removal of fill material. Other treatments within the high-intensity site included: addition of 153 habitat boulders (65% of total for the project or 153 of 234 total), installation of eight boulder structures (J-hooks, boulder half vanes, and cross vanes; 89% of total for the project or eight of nine total), 2,458 linear feet (lf) of boulder toe (91% of total for the project or 2,458 lf of 2,708 lf total), 10 constructed pools (71% of total number of pools for the project or 10 out of 14 total), 5,420 square feet (sf) of point bar development (100% of total for the project), and 18,775 sf of new floodplain (or "riparian bench") development (100% of total for the project).

Low-Intensity Treatment Site:

The low-intensity treatment site consisted of an approximately 650-ft long stream segment located downstream of the Dog House Bridge. Unlike the high-intensity site, the channel geometry was not altered in this reach (no removal of riprap or excess bank material, conversion of single-stage to three-stage channel, point bar development, or riparian bench development). The average confinement for this reach before compared with after the project did not change (1.2). The low-intensity treatment site remained highly confined, riprapped, and constrained between two roadways. Treatments in the low-intensity segment included addition of habitat boulders (35% of total for the project or 81 of 234 total), installation of one boulder structure (cross-vane; 11% of total for the project or one of nine total), 250 lf of boulder toe (9% of total for the project or 250 lf of 2,708 lf total), and four constructed pools of which three were located off the main channel in a side-channel (29% of total number of pools for the project or four out of 14 total). No point bar development or riparian benches were constructed within the low-intensity treatment segment.

Trout Population Response:
Post-project monitoring of Brown Trout populations suggest that habitat treatments have resulted in an increase in Brown Trout density and biomass in both high- and low-intensity treatment segments (Table 3). Within the control reach, Brown Trout density and biomass did not change significantly over the same pre- and post-monitoring period (Table 3, Brown Trout density = 32% increase; Brown Trout biomass = 0.6% increase). The magnitude of change for Brown Trout density within the high-intensity segment (Figure 15; +182%) was higher as compared to the low-intensity segment (Figure 16; +104%). The magnitude of change for Brown Trout biomass increased even more within the high-intensity segment (Figure 17; +422%) as compared to the low-intensity segment (Figure 18; +76%). This suggests that the Brown Trout population within the high-intensity site not only had more fish per linear distance (density increase) than the low-intensity site, but also the population within the high-intensity site experienced a shift toward larger, adult fish within the high-intensity treatment site (much larger increase in total Brown Trout biomass) as compared with the low-intensity treatment site. Our results suggest that the conversion of highly-confined, channelized and riprapped, single-stage streams to a reference-like historic condition can lead to large increases in trout population abundance and biomass.

ACKNOWLEDGEMENTS

We thank Jim Eussen and Francesca Tordonato with the Colorado Department of Transportation (CDOT) for their invitation to work collaboratively on the Twin Tunnels Project and their enthusiastic support to move the stream restoration project forward. We thank Josh Hollon (Senior Project Manager, Atkins) and Cory Engen (River Engineer, Flywater Inc.) for allowing us to assist in directing construction activities and provide input into construction implementation. We thank many of the CPW DWM recruits over the eight year period of the study for assisting with fish annual fish sampling surveys that formed the basis of our fish populations monitoring results. Annual fish sampling for this project served as part of the training they received as part of the DWM training program. We especially thank Paul Winkle, CPW Aquatic Biologist for leading the fish sampling effort and serving as point person for the habitat improvement project for months leading up to implementation of this project and throughout the monitoring study period. We also thank numerous CPW technicians for their support of fieldwork, topographic surveys, and fish sampling.

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Table 3. Summary of Brown Trout density (n ≥ 150 mm TL/mile) and biomass estimates (lbs/acre) and statistics for the high-intensity (Upper Reach), low-intensity (Lower Reach) and control reach of Clear Creek, Twin Tunnels stream restoration project. 95% confidence intervals for density and biomass estimated are shown in parentheses. Pre-construction and post-construction surveys were conducted during fall 2012, 2013, and 2014 and fall 2015, 2016, 2017, 2018 and 2019 respectively. P-values are reported for least square mean estimates comparing pre- and post-habitat improvement treatment periods within each reach.

Year	**High-Intensity: Upper Reach**		**Low-Intensity: Lower Reach**		**Control**	
	Density (n/mile)	**Biomass (lbs/acre)**	**Density (n/mile)**	**Biomass (lbs/acre)**	**Density (n/mile)**	**Biomass (lbs/acre)**
	Pre-Habitat Improvement Treatment Period					
2012	N/A	N/A	846 (773-919)	39.6 (35.3-43.9)	1,261(1,077-1,445)	65.3(54.9-75.8)
2013	275 (265-285)	8.2 (7.6-8.8)	804 (773-835)	29.6 (27.3-31.8)	N/A	N/A
2014	711 (682-740)	13.6 (13.6-16.0)	1,393 (1337-1449)	49.2 (45.3-53.1)	N/A	N/A
Average	**493**	**11.5**	**1,014**	**39.5**	**1,261**	**65.3**
	Post - Habitat Improvement Treatment Period					
2015	1,008 (989-1027)	52.4 (48.7-56.2)	1,399 (1348-1450)	53.2 (48.9-57.5)	N/A	N/A
2016	1,137 (940-1,334)	58.6 (47.8-69.5)	1,099 (1,036-1,162)	43.4 (39.6-47.3)	857 (770-945)	36.1(31.7-40.5)
2017	1,588 (1,221-1,955)	62.0 (47.0-77.0)	2,261 (2,065-2,457)	82.9 (72.5-93.3)	N/A	N/A
2018	1,364 (1,328-1,400)	60.7 (56.5-65.0)	2,410 (2,253-2,567)	71.6 (64.3-78.9)	N/A	N/A
2019	1,850 (1,690-2,010)	66.3 (58.5-74.0)	3,193 (3,029-3,357)	96.0 (87.6-104.4)	2,459 (2,323-2,596)	95.3(86.7-103.9)
Average	**1,389**	**60.0**	**2,072**	**69.4**	**1,658**	**65.7**
% Change (Magnitude)	**+181.7% (+2.8×) p=0.073**	**+421.7% (+5.2×) p=0.006**	**+104.3% (+2.0×) p=0.048**	**+75.7% (+1.8×) p=0.037**	**+31.5% (+1.3×) N/A**	**+0.6% (+1.0×) N/A**

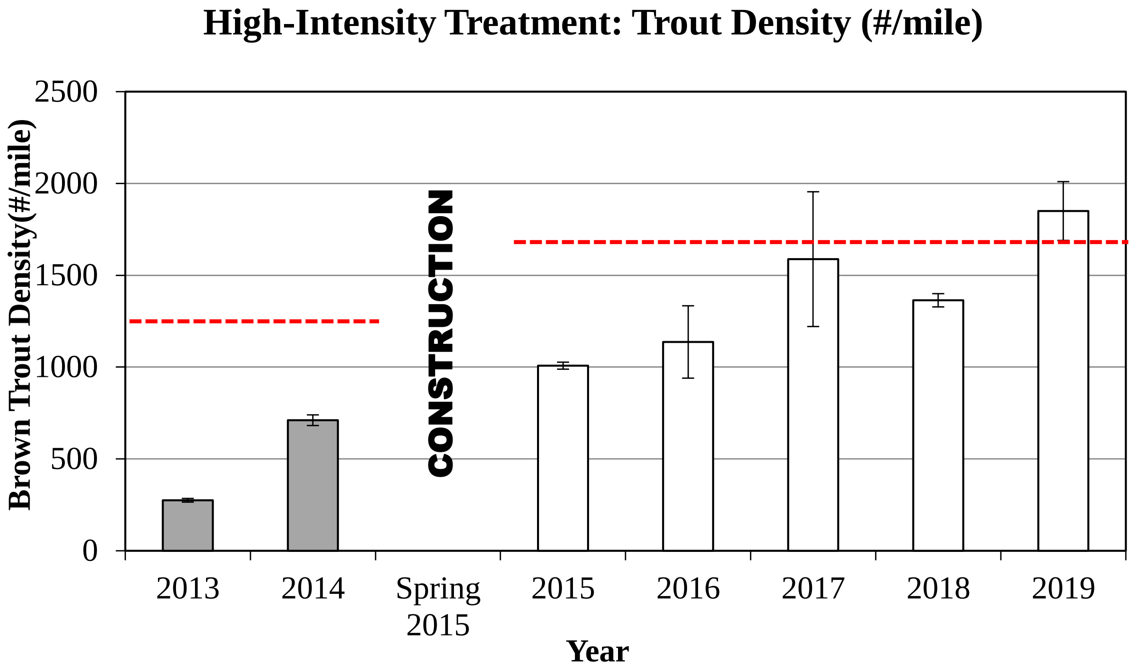

Figure 15. Brown Trout density (number/mile) within the "high-intensity" treatment site for pre- (shaded; 2013-2014) and post- (white; 2015-2019) construction years. Red dashed line represents the average Brown Trout density within the control reach during the pre- and post-construction periods.

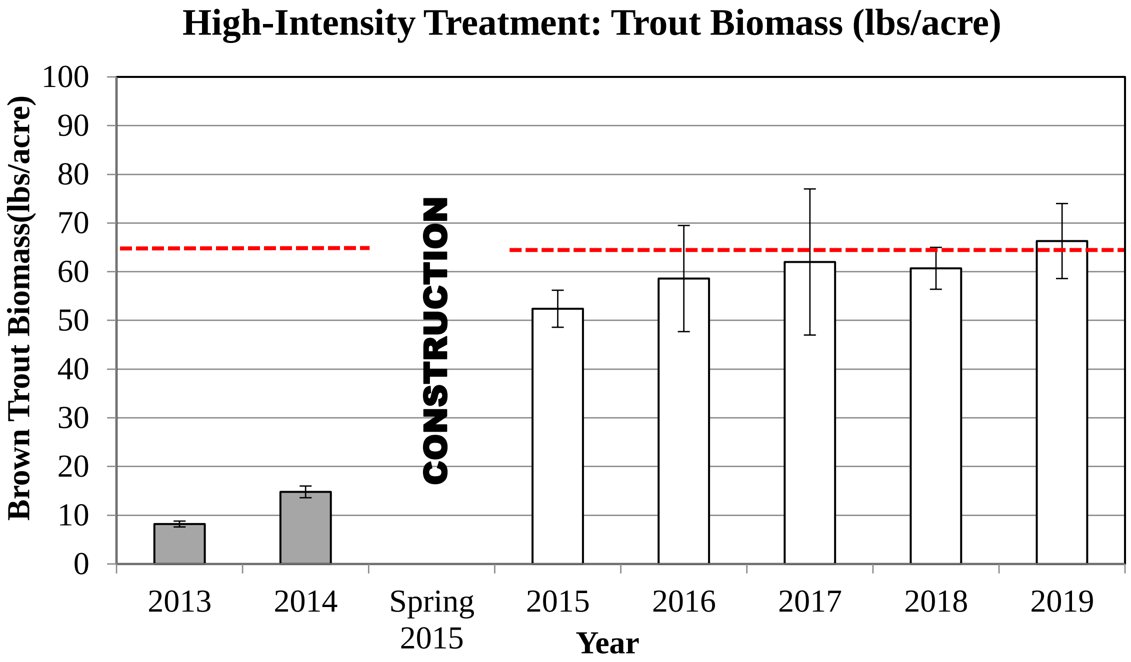

Figure 16. Brown Trout biomass (lbs/acre) within the "high-intensity" treatment site for pre- (shaded; 2013-2014) and post- (white; 2015-2019) construction years. Red dashed line represents the average Brown Trout biomass within the control reach during the pre- and post-construction periods.

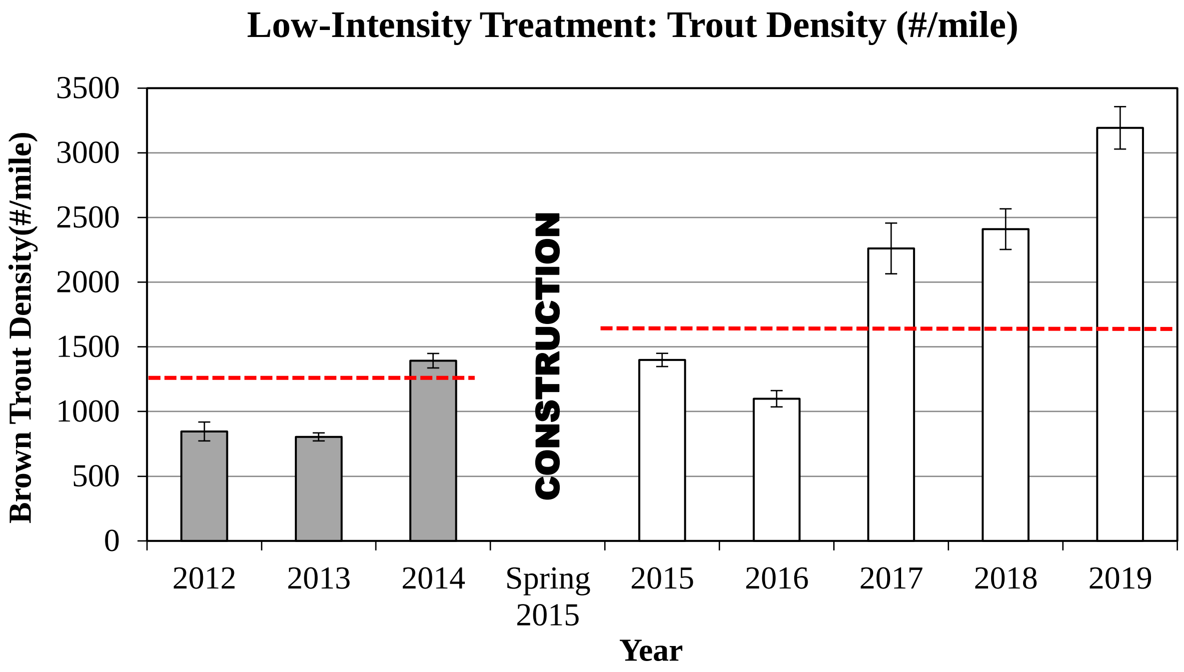

Figure 17. Brown Trout density (number/mile) within the “low-intensity” treatment site for pre- (shaded; 2013-2014) and post- (white; 2015-2019) construction years. Red dashed line represents the average Brown Trout density within the control reach during the pre- and post-construction periods.

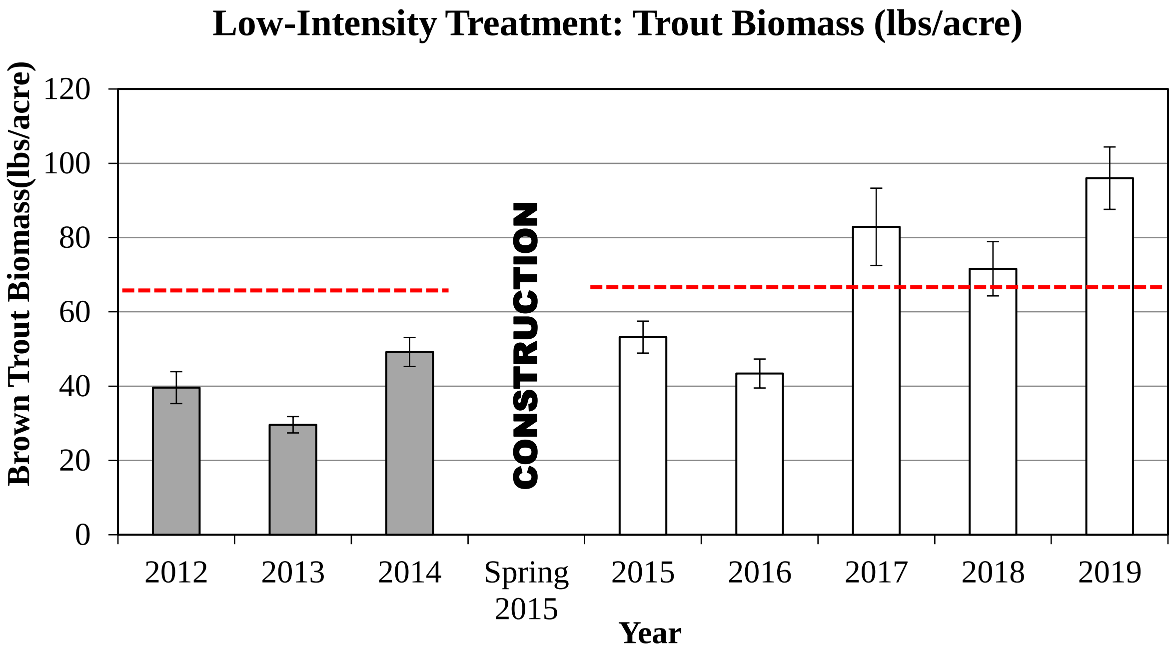

Figure 18. Brown Trout biomass (lbs/acre) within the “low-intensity” treatment site for pre- (shaded; 2013-2014) and post- (white; 2015-2019) construction years. Red dashed line represents the average Brown Trout biomass within the control reach during the pre- and post-construction periods.

RESEARCH PRIORITY:

Windy Gap Connectivity Channel Fish Passage Evaluation, Colorado River

OBJECTIVES

To support the design, construction, and evaluation of a connectivity channel around Windy Gap Reservoir that will restore upstream fish passage and downstream sediment transport.

INTRODUCTION

The Windy Gap Connectivity Channel project was identified in the *Fish and Wildlife Enhancement Plan* for the Windy Gap Firming Project (Subdistrict 2011). CPW has provided technical support for evaluation and design of the connectivity channel, which includes narrowing the existing reservoir, construction of a new water diversion structure, and construction of a 1.5-mile connectivity channel around the modified reservoir. In addition to technical design assistance, we will also be monitoring fish movement in the Colorado River near Windy Gap prior to and following construction of the connectivity channel to evaluate project effectiveness and inform adaptive management.

METHODS

The fish passage evaluation will entail installation of PIT-tag antennas above and below Windy Gap Reservoir. To date, efforts have focused on antenna design and testing to maximize detection probabilities for the stationary arrays, including developed of a solar power system that does not interfere with the antennas. Stationary antennas will be installed during August 2020. Following installation, fish will be collected and PIT-tagged and baseline movements will be monitored for a two-year period prior to construction of the connectivity channel. After the connectivity channel is constructed, additional antennas will be installed on the connectivity channel and fish movement will be evaluated for another two-year period to investigate project effectiveness. Mobile antennas will also be developed and deployed to support evaluation of fish movement and habitat use in the Colorado River. Preliminary methods for the fish movement study were incorporated into a draft monitoring plan, but plans may need to be refined in light of the Covid-19 pandemic and input from other project stakeholders (e.g., landowners).

RESULTS AND DISCUSSION

We have attended numerous meetings and conference calls in support of the project, and have provided comments on the conceptual design package for the connectivity channel to the design team. Antenna installation was initially scheduled for the spring of 2020, but was postponed due to the Covid-19 pandemic. However, development of a prototype antenna site including a solar power supply was completed during the winter of 2019-2020, including detailed detection distance measurements that will help quantify detection probabilities at the stationary antenna sites. Actual data collection on fish movements in the Colorado River will begin after antenna installation and fish tagging are completed.

ACKNOWLEDGEMENTS

We acknowledge Nicholas Salinas, Matt Robinson, and Mallory Allgeier for their work on antenna system development and testing. We are grateful to Brad Neuschwanger and his staff at the CPW Fish Research Hatchery for providing a testing site for our prototype antenna system. We also acknowledge our project partners and funders, including the Municipal Subdistrict, Denver Water, Trout Unlimited, Grand County, and the Natural Resources Conservation Service (NRCS).

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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 surrounding river.

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 efficiency recently installed (post-flood of 2013) fish passage types; several 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 their intended 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 follow-up 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 et al. (2019).

METHODS

A total of three study sites have been selected for inclusion in this study. Long-term monitoring of fish movements will take place at two locations. Short-term enclosure studies will occur at all three sites. Study sites include: (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. Due to the difficulty in gaining access and approvals from land managers from Boulder, the Green Ditch Diversion on Boulder Creek was eliminated for consideration.

Study Sites:

Fossil Creek Reservoir Inlet Diversion (FCRID), Cache la Poudre River:
The Fossil Creek Reservoir Inlet Diversion (FCRID) lays to the east of Fort Collins, Colorado, well into the transition zone for the Cache la Poudre River. Located in Running Deer Natural Area, it is 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. 2018). Long-term monitoring will be conducted in the fishway, with antenna placement mirroring the original placement during 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 west side of the structure that is often raised during high river flows or low ditch flow to reduced strain on the structure's integrity. When open, the radial gate provides an additional route for fish passage. While the status of the radial gate will be noted during work performed at the site, there is a high probability that some fish are negotiating the structure through the gate and will not be detected by the rock ramp antenna array. The metal nature of the gate precludes the installation of an additional antenna to monitor fish use of this potential passage route. Adjacent to the structure is Fossil Creek Ditch. This will be one of the fish entrainment study sites as the ditch receives year-round discharges from the wastewater treatment plant, providing flow regardless of water diverted for the reservoir.

Dickens Farm Natural Area, St. Vrain River:
Running directly through the heart of Longmont, 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 the purpose of 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 (City of Longmont 2014). The St. Vrain still supports high numbers of native fishes compared to other transition zone rivers along the Front Range, so wingwall bypass passage structures were installed at the edge of each drop to provide lower velocity passageways to help maintain longitudinal connectivity. Created through the placement of grouted boulders, the channels are characterized with a complexity of different flow zones, 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.

<u>Rough and Ready/Palmerton Ditch Diversion, St. Vrain River:</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 playing a larger role. 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. 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 will undergo long term monitoring. Fish movements at each site will be 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 will be installed with at least two custom-designed half-duplex (HDX) antennas—one at the downstream entrance and another at the upstream exit. Following installation, a comprehensive set of baseline detection distances will be 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 will compare real time detection distances at a set location on each antenna with baseline measurements, indicating if a system requires adjustment or tuning. This will be done routinely through the months of the study at bi-weekly intervals with antenna sites also being checked for damage and data uploaded from the readers.

Fish Tagging for Long-Term Study:

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, the greatest number of species and individuals possible from the surrounding area will be collected and tagged. Sampling will rely largely on backpack or barge electrofishing. However, seines or fyke nets may also be utilized, especially in ditch habitats. Captured fish will be placed into live pens prior to processing during which each individual will be identified by species with total length (mm) and weights (to the nearest gram) recorded. As the entire assemblage of species in the surrounding area are of interest in this study, all fish that meet the 80-mm TL size criteria will be tagged. Following tagging, all fish will be released downstream of the fishway to capitalize on any homing instinct that might encourage navigation of the fishway (Fox et al. 2016). The majority of tags used will be 12-mm x 2-mm HDX tags, though some larger individuals can be 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 will receive a 12-mm tag, those between 175 to 250-mm will receive 23-mm tags, with 32-mm tags being used for any fish greater than 250-mm. Larger tags have superior read range, and will thus be used when possible, but fish survival is paramount. Fish will be 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 followed by tag insertion and gentle massaging to guide the tag within abdominal cavity has shown 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. Due to all tagging being done in the field, and with little evidence to recommend it, the fish will not be sutured following tag insertion.

Short-Term Enclosure Studies:
To assess whether any of the given sites are physically passable for native species, short-term enclosure studies will be conducted during the summer and fall. These will consist of two-day trials where small enclosures will be 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) will be placed in the lower enclosure and allowed to navigate the fishway. Antennas installed along the length of the fishway will record each individual's progress; the presence of fish in the upper enclosure will also indicate successful passage. Trials will run for 22-24 hours to incorporate a full photoperiod. The species selected for the enclosure trials are not the full assemblage of fish at each site but rather represent 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 may be brought in from other locations within the South Platte drainage to supplement the experiment under the guidance of CPW collaborators. These species may include Common Shiner *Luxilus cornutus*, Stonecat *Noturus flavus* or Creek Chub *Semotilus atromaculatus*, all based on the ability to obtain them prior to the study. All fish used in the study will be 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 will be held in pens in the river, along with local tagged individuals for 12-24 hours to allow some acclimation to local conditions. Individuals will be 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 will be released back into the river. Enclosure boxes will be constructed from either metal or plastic screening over PVC frames that can be either mounted with T-posts (possibly anchored in concrete-filled cinder blocks) or duckbills 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 will connect 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 will be provided within the enclosure for the creation of resting areas for fish trying to ascend or recovering at the top. Fish movement will be actively monitored both

visually and through the submerged antennas. Small fish that were not tagged, but were measured prior to the trial, will be removed at intervals from the top enclosure should they ascend. These individuals will be measured once more and will count 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 success was 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 2007). As a large number of PIT tagged fish will already be 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 will be monitored at the Fossil Creek Division because it has an unscreened ditch receiving water from near the fish passageway. Dickens Farm in Longmont will be excluded from this portion because water at this location is diverted through screened pipes and pumps that should pose less of a chronic entrainment risk. The entrainment study will be monitored with PIT tag antenna arrays and readers similar to those used for the fish passage monitoring. Unlike the fish passage sites, the entrainment study will only use two antennas installed within the ditch (but near the entrance) to provide direction of movement for detected fish.

Hydrology Monitoring:
In the interest of understanding how local flow conditions may affect fish passage, stream staff gauges (enamel finished 4-foot plates marked in feet and tenths) will be installed at each long-term site if not already present. Water depth will be recorded during each bi-weekly antenna check and hourly during the enclosure studies to provide a baseline. These measurements will be compared with nearby steam gauges to develop a correlation between staff gauge readings and stream gauge 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, will record hourly data on water depth and temperature. Flow monitoring will occur 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 gauge. These more constant methods will be 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 will be 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 will be taken to reflect differences in the water's movement through the structure. These will consist 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 will be the primary form of data collected in this study, though if during sampling fish are recaptured above the fishway despite a downstream release, these will be noted as a successful passage. During the enclosure study, there will be 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 will include: species, length, weight, PIT tag ID, capture/tagging date, antenna ID, antennas crossed, number of hits per antenna, and length of time between antennas. Additionally, during the enclosure portion, water temperature and flow will be recorded through the use of HOBO loggers, and trial start and stop times will be tracked. The flow data from the nearest permanent gauging station, the HOBO pressure transducers, and the instream measurements can possibly be correlated with recorded fish movements.

Fish movement data will be analyzed with a mark-recapture model in program MARK, likely using a Cormack-Jolly-Seber (CJS) model or a multi-state mark-recapture (MSMR) (Pollock et al. 1989; Lebreton et al. 1992). The original model can be 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. 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 will be 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 will be 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.

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

Results and data analyses for this project are ongoing. Preliminary results for this project are included in Jones et al. (2019).

ACKNOWLEDGEMENTS

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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) and Richer et al. (*In press*). 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. A discharge measurement section was designed for the upstream-most section of the fishway that was flat and did not included any roughness elements. Hydraulics within the flat section were evaluated to determine if the discharge measurement section met design criteria. As the fishway design included an upper and lower tier to provide more passable conditions across a wider range of flows, hydraulic measurements were summarized by their location on each tier.

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. All three species that have been tagged thus far (i.e., Brown Trout, Longnose Sucker, and Rainbow Trout) exhibited successful passage through the fishway by at least one individual (Table 4). However, 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 = 5). Numerous Brown Trout and Rainbow Trout have successfully passed through the fishway (n = 49), including a wide range of size classes (TL = 124-405 mm), which indicates that the fishway is functioning as intended for these species. No Longnose Dace or White Sucker have been tagged at this time, so additional work in needed to evaluate the efficacy of the Watson fishway for those species, as well as Longnose Sucker.

Table 4. Fish passage summary by species for the Watson Diversion fishway from April 26, 2019 to May 12, 2020, 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)**
Longnose Sucker	5	1	382	382
Brown Trout	50	33	124	364
Rainbow Trout	32	16	215	405
All	85	48	124	405

The stage-discharge relationship for the Watson fishway indicates that the maximum observed fishway capacity was 70.2 cfs, compared to the minimum design capacity of 30 cfs (Figure 19). Depth-average velocity within the flat discharge measurement section was higher than the target design velocity of 3.0 ft/s, and ranged from 3.7-5.1 ft/s. This suggests that the discharge measurement section may impair passage for weaker swimming species and smaller trout under some flows. We recommend that roughness elements be incorporated into the discharge measurement section to reduce velocities and improve passage conditions.

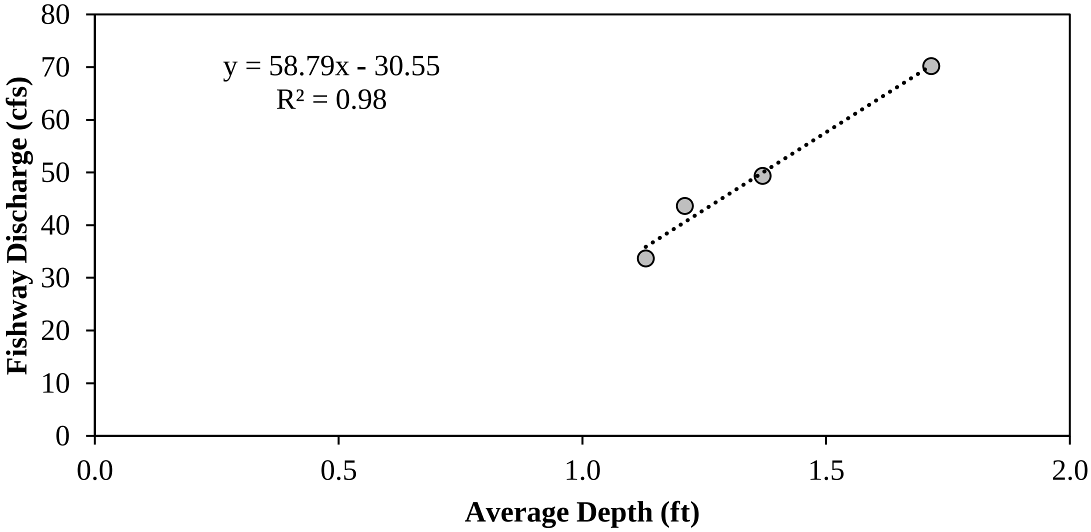

Figure 19. Relationship between average water depth and total fishway discharge at the upstream most section of the Watson Diversion fishway on the Cache la Poudre River.

Due to the high flow capacity of the Watson fishway, hydraulic measurements have been difficult to collect due to safety concerns. As such, the full suite of hydraulic measurement has only been collected on a single occasion. Data from those observations indicate that water depths met the minimum depth criteria and that benthic velocities were typically low (<2 ft/s). Water velocities on the upper tier were lower than velocities on the lower tier, as designed (Figure 20). However, we have observed high velocities (>5 ft/s) on the upper tier in locations where the fishway makes a bend or turn. These areas of elevated velocity indicate that a continuous pathway meeting the design criteria for water velocity is not present on the upper tier. We recommend that 2D or 3D modeling be conducted for future fishway designs to evaluate potential areas of hydraulic complexity that would not be captured by a 1D hydraulic analysis.

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. Additional evaluations are needed to determine the efficacy of the fishway for Longnose Dace, Longnose Sucker, and White Sucker. Hydraulic evaluations across a wider range of flows would also provide useful information on fishway performance and inform the design of new fishways within the watershed. 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.

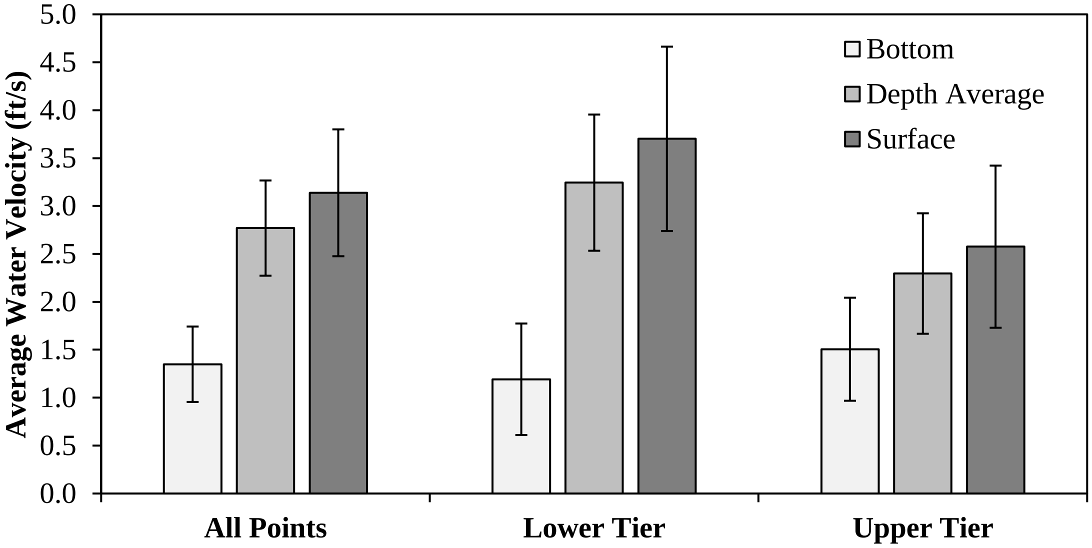

Figure 20. Water velocity results from hydraulic measurements within the Watson Diversion fishway on the Cache la Poudre River at a fishway discharge of 33.6 cfs, including all points, points on the lower tier only, and points on the upper tier only. Error bars represent 95% confidence intervals.

ACKNOWLEDGEMENTS

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Richer, E. E., E. Krone, F. B. Wright III, M. C. Kondratieff, and A. Treble. 2018. Evaluation of a rock ramp fishway at the Fossil Creek Reservoir Inlet Diversion (FCRID) on the Cache la Poudre River. Colorado Parks and Wildlife. 23 pp.

Richer, E. E., E. R. Fetherman, E. A. Krone, F. B. Wright III, and M. C. Kondratieff. *In press*. Multi-species fish passage evaluation at a rock-ramp fishway in a Colorado transition zone stream. North American Journal of Fisheries Management.

RESEARCH PRIORITY:

Fossil Creek Reservoir Inlet Diversion (FCRID) Fish Passage Project, Cache la Poudre River

OBJECTIVES

1) Validate that target fish species could ascend the fishway, including Brassy Minnow *Hybognathus hankinsoni*, Longnose Dace *Rhinichthys cataractae*, Longnose Sucker *Catostomus catostomus*, and Brown Trout *Salmo trutta*
2) Validate that fishway hydraulics met design criteria
3) Determine if fishway efficiency varied by species
4) Investigate the utility of a short-term enclosure method for evaluating fish passage structures

INTRODUCTION

Stream habitat fragmentation caused by manmade structures is ubiquitous in Colorado, creating a need for passage solutions that accommodate multiple fish species. The Fossil Creek Reservoir Inlet Diversion (FCRID) is a water diversion structure on the Cache la Poudre River. The structure was considered a vertical, velocity, and/or depth barrier to upstream fish movement during low to moderate flows, depending on the species in question. During high flows when the diversion structure was completely submerged, a channel-spanning hydraulic wave with elevated velocities formed downstream of diversion crest, which likely inhibited upstream passage for most species. The FCRID was severely damaged during flooding in September 2013. Reconstruction provided an opportunity to incorporate a rock-ramp fishway into the new structure and restore connectivity for 15.6 km of river. We developed a conceptual design for the rock-ramp fishway, provided guidance and oversight during fishway construction, and conducted an evaluation of the fishway that included monitoring fish passage with PIT-tags and a characterization of fishway hydraulics.

METHODS

This study tested the effectiveness of the FCRID fishway to pass nine fish species with a range of swimming abilities. Target species for fishway design included Brassy Minnow *Hybognathus hankinsoni* (weakest swimming), Longnose Dace *Rhinichthys cataractae*, Longnose Sucker *Catostomus catostomus*, and Brown Trout *Salmo trutta* (strongest swimming). Testing included a 46-hour enclosure study and three-month extended study, during which fish passage was evaluated using PIT tags. Hydraulic conditions within the fishway were also evaluated to validate that fishway hydraulics met design criteria. Detailed methods for evaluating the FCRID fishway were previously presented in a report to project stakeholders (Richer et al. 2018). Methods were then revised to include a more robust analysis of encounter histories with Program MARK (White and Burnham 1999). The final methods used for fishway evaluation are described in detail within a manuscript that is currently in press with the North American Journal of Fisheries Management (Richer et al. *In press*).

RESULTS AND DISCUSSION

All species exhibited successful passage through the fishway during the enclosure study, but movement probabilities varied by species. Five species were not detected at the fishway during the extended study, possibly due to issues with attraction flows, entrance conditions, or motivation. Roughness elements maintained a benthic, low-velocity zone across a range of flows, even when surface and depth-averaged velocities surpassed design criteria for the weakest-swimming species. The methods from this study could be replicated at other structures to evaluate design criteria (e.g., slope, capacity, roughness, and configuration) for rock-ramps and the effectiveness of different fishway types for passing a variety of species. Detailed results for the FCRID evaluation are available in Richer et al. (2018) and Richer et al. (*In press*). Additional research investigating fish movement patterns, attraction flows, species-specific behavioral traits, and various design configurations would further optimize the performance of rock-ramp fishways in Colorado.

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Richer, E. E., E. Krone, F. B. Wright III, M. C. Kondratieff, and A. Treble. 2018. Evaluation of a rock ramp fishway at the Fossil Creek Reservoir Inlet Diversion (FCRID) on the Cache la Poudre River. Colorado Parks and Wildlife. 23 pp.

Richer, E. E., E. R. Fetherman, E. A. Krone, F. B. Wright III, and M. C. Kondratieff. *In press*. Multi-species fish passage evaluation at a rock-ramp fishway in a Colorado transition zone stream. North American Journal of Fisheries Management.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement:120-138.

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) Halligan Water Supply EIS, North Fork Cache la Poudre River
4) Bear Creek In-stream Habitat Restoration
5) Fish Passage and Instream Flow Evaluation, Halfmoon Creek
6) Rabbit Creek Conservation/Mitigation Bank
7) Arkansas River Legacy Habitat Improvement Project
8) Trail Creek Ranch Fishery Improvement Project
9) Timnath Reservoir Inlet Fish Passage Project, Cache la Poudre River
10) Niwot Diversion Reconstruction Project, St. Vrain Creek
11) St. Vrain Creek Reach 3 Phase 2 Fish Passage Project

12) Godfrey Ditch Fish Passage Project, South Platte River
13) Florida Canal Diversion Structure Rehabilitation Project
14) Second Creek Channel Re-establishment Project
15) Picnic Rock Boat Launch, Cache la Poudre River
16) Crooked Creek and Little Lime Creek Cutthroat Trout Conservation Barrier Projects
17) Conejos River Stream Habitat Restoration Project, Conejos River
18) Basalt Whitewater Park Maintenance and Construction, Roaring Fork River
19) Linden Street Whitewater Park Feasibility Assessment, Cache la Poudre River
20) CPW guidance letters to the U.S. Army Corps of Engineers (Stream Restoration, Fish Passage, and Bank Stabilization Projects and Whitewater Park Projects)
21) Stream Mitigation Accounting Metrics (US EPA), Technical Team Committee
22) Eagle River Whitewater Park, Eagle River
23) Big South Fork of the Cache la Poudre River Cutthroat Trout Conservation Barrier Project
24) Bobtail and Steelman Cutthroat Trout Conservation Barrier Projects, Williams Fork River
25) Charlie Meyer SWA Stream Enhancement Maintenance Project, South Platte River

We also provided technical assistance to the U.S. Army Corps of Engineers (ACOE) and U.S. Environmental Protection Agency (EPA) as members of the Steering Committee tasked with development of a Stream Quantification Tool (SQT) to support stream mitigation banking in Colorado, including contributions to the SQT Scientific Support document (CSQT SC, 2019a) and User Manual (CSQT SC, 2019b).

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We acknowledge and appreciate Dr. George Schisler for his unwavering support and leadership.

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Colorado Stream Quantification Tool Steering Committee (CSQT SC). 2019a. Scientific Support for the Colorado Stream Quantification Tool, Beta Version. U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds (Contract # EP-C-17-001), Washington, D.C.

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