Establishing a baseline to assess impact of restoration actions reconnecting Bear Lake tributaries to increase resilience and abundance of native fishes

Progress Report to the Utah Division of Forestry, Fire, and State Lands and the Janet Quinney Lawson Institute for Land, Water, and Air at Utah State University

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Executive Summary

Stream fragmentation due to the construction of dams, diversions, and road crossing culverts have limited the ability of native migratory fishes to access the distinct habitats required to complete their life history, contributing to widespread declines in abundance and distribution. The Bear Lake Cutthroat Trout (*Oncorhynchus virginalis spp.,* recently reclassified from *O. clarkii*), represent a unique adfluvial life history variant, living in the lake and migrating up tributary streams to spawn. However, development of water resources and construction of roads in the valley surrounding Bear Lake reduced their ability to access their historic spawning grounds, leading to the near extirpation of the species from the lake by the 1950s. Recent efforts to reestablish connectivity between the lake and its tributaries has resulted in substantial increases in recruitment of wild Cutthroat Trout to the population, such that wild individuals accounted for the majority of the population in a recent annual lake monitoring survey. As such, further increasing connectivity to tributary streams may increase the production and resilience of the wild Cutthroat Trout population in Bear Lake.

North Eden Creek, on Bear Lake's eastern shore, is home to a relict population of Bear Lake Cutthroat Trout that are isolated in the headwaters. Adfluvial Cutthroat Trout enter the stream during their spawning migration, but are blocked from ascending upstream of the intersection with North Cisco Road by an impassable culvert. Trout Unlimited and partners are planning to replace the culvert in Fall of 2025 to allow adfluvial spawners to access the additional spawning habitats upstream of the road crossing. To understand how this planned restoration action ultimately impacts the Cutthroat Trout population of North Eden Creek, we conducted a review of historical documents and data collection efforts, and designed and implemented a monitoring plan to assess the physical habitat, fish assemblage, and aquatic invertebrate community along an elevational gradient of North Eden Creek, including sites both below and above the culvert.

Cutthroat Trout and non-native Brook Trout (*Salvelinus fontinalis*) were the only two species of fish captured upstream of the culvert at North Cisco Road, while two additional native fishes (Utah Chub *Gila atraria* and speckled dace *Rhinichthys osculus*) were also captured downstream of the culvert. An additional native species (Utah Sucker *Catostomus ardens*) has also been observed downstream of the culvert in recent years, but was not captured in our samples. Brook Trout were found at all sites inhabited by Cutthroat Trout, and represent potential competitors for resources and predators of juvenile Cutthroat Trout. Importantly, fish were restricted to headwater habitats and to habitats downstream of the culvert, being absent throughout the middle and low elevation reaches upstream of the culvert.

Physical habitat conditions demonstrated clear elevational patterns along North Eden Creek. Riparian vegetation was most abundant in lower elevation sites both upstream and downstream of the culvert, and was very limited in middle and high elevation reaches. The low elevation sites maintaining riparian vegetation cover do not experience cattle grazing, while the upper and

middle elevation reaches do. Undercut bank habitat was abundant in high elevation sites, but very limited in middle and low elevation sites. Gravel substrates were more abundant in high elevation sites, while cobble substrates were most available in low elevation sites, and middle elevation sites were dominated by silty substrates. Stream temperatures were highest in middle elevation reaches, where temperatures exceeded 7-day incipient lethal temperatures for at least part of the summer. Headwater and low elevation temperatures never exceeded this thermal limit, and were generally lower than in middle elevation sites, demonstrating complex, nonlinear thermal patterns along the length of the river.

Aquatic invertebrates were most abundant at the low and high elevation sites, and much less abundant in middle elevation reaches. Additionally, the proportional contribution of sensitive taxa (Ephemeroptera, Trichoptera, Plecoptera) was greatest in high and low elevation reaches, and lower in middle elevation reaches. Taken together, the physical habitat and aquatic invertebrate data suggest middle elevation reaches are suboptimal and even unsuitable at specific times of the year, thus limiting the distribution of both native and non-native trout. As such, while we expect reestablishing connectivity for adfluvial Cutthroat Trout to increase the availability of spawning habitat and the production of juvenile Cutthroat Trout, the middle elevation reaches of the stream are unlikely to support large increases in abundance of trout without further habitat restoration efforts.

We recommend repeating the monitoring surveys presented in this report, alongside additional efforts to monitor the abundance of spawning adfluvial trout entering the stream each year to assess the population level response of Cutthroat Trout to the planned culvert replacement. We provide a description of the monitoring protocol in an appendix. If surveys are repeated every 1-3 years, managers and stakeholders will be able to determine the effects of culvert replacement and any subsequent habitat restoration efforts on both the adfluvial and resident populations of Cutthroat Trout in North Eden Creek.

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Introduction

In response to the degradation of riverine habitats and consequent declines of native species driven by human land use and water development activities, stream restoration has become a common management goal over the past several decades (Bernhardt et al. 2007; Wohl et al. 2015). In theory, by restoring the structural complexity of in-stream habitats, channel form, hydrographs, reestablishing connectivity between upstream and downstream habitats and between in-channel and floodplain habitats, or improving the condition of riparian vegetation, restored streams will demonstrate improved function and support levels of ecosystem services more reflective of historical conditions. However, while stream restoration is widely implemented and practitioners can highlight successful impacts on habitat and in some cases on native biota (e.g., Duda et al. 2021; Clark et al. 2020; Pess et al. 2024), many projects either do not elicit the desired response or are simply not monitored adequately and/or for sufficiently long periods to assess restoration success (Bernhardt et al. 2007; Foote et al. 2020; Bilby et al. 2024). Effectively assessing the ecological outcomes of restoration actions requires both a robust understanding of the baseline conditions prior to restoration, and consistent post-restoration monitoring to characterize any realized changes to the system.

Migratory species are particularly susceptible to the negative impacts of stream degradation, as fragmentation by dams, diversions, and culverts at road crossings limit their ability to access habitats necessary to complete their life history (McIntyre et al. 2016; Gido et al. 2016). Migratory salmonids are the targets of a vast amount of stream restoration and conservation actions (Katz et al. 2007; McIntyre et al. 2016; Bilby et al. 2024), owing to their widespread declines over the past century and their ecological, economic, and cultural importance. Some of the most successful, and best monitored, restoration projects involve reestablishing habitat connectivity via the removal of migration barriers, whether at large scales through the removal of hydroelectric dams (Duda et al. 2021; Pess et al. 2024) or at smaller scales restoring connectivity to small tributaries by removing road crossing culverts (Anderson et al. 2019; Clark et al. 2020). Given the frequent success of barrier removals, managers and conservation groups routinely assess the potential benefits of removing or redesigning migration barriers to improve fish passage.

Bear Lake (Utah and Idaho, USA) supports a distinctive native fish assemblage, including three endemic species of whitefish (*Prosopium gemmifer, P. abyssicola, P. spilonotus*), Bear Lake Sculpin (historically considered a unique species *Cottus extensus*, though recent molecular evidence suggests it is a lacustrine life history variant of the regionally widespread *C. semiscaber*; Young et al. 2022), and a unique adfluvial population of Bear River strain Rocky Mountain Cutthroat Trout (*Oncorhynchus virginalis spp.,* recently reclassified from *O. clarkii*) commonly referred to as the Bear Lake Cutthroat Trout (hereafter, “Cutthroat Trout”). However, starting in the late 19th century, the lake and its surrounding watershed underwent a series of major changes that impacted the unique fish assemblage. Dams and diversions were constructed on many of the lake's tributaries, degrading and fragmenting tributary habitats from the lake. Road construction to connect towns in the valley to each other and to surrounding communities further reduced tributary connectivity, as impassable culverts limited the ability of adfluvial trout to access upstream spawning habitats. Livestock grazing degraded riparian vegetation, compromised stream bank stability widening stream beds and increasing siltation, reduced stream habitat quality and diminished remaining habitat suitability for spawning migratory and resident fishes. Finally, the introduction of a suite of non-native fishes to support sport fishing altered the food web structure in the lake and its tributaries, increasing the competition for prey resources for native fishes, as well as presenting novel sources of predation. Due to these changes, the population of Cutthroat Trout in the lake declined substantially throughout the twentieth century and was considered to be nearly extinct by the 1950s. The population was subsequently maintained primarily through artificial propagation, as adfluvial adults could not access sufficient tributary habitat to support natural production of wild fish.

Beginning in the 2000s, agencies and conservation groups began to identify opportunities to reestablish connectivity between tributary habitats and Bear Lake for adfluvial Cutthroat Trout and their offspring (Heller et al. 2022). Through the removal of migration barriers and installation of fish screens on irrigation diversions in three historical spawning tributaries on the lake's western shore, agency and conservation partners have been able to successfully increase the abundance of spawning adfluvial trout, and wild fish accounted for the majority of the population for the first time in decades (Heller et al. 2022). Given these successes, stakeholders have continued to look for new opportunities to further increase tributary spawning access on the remaining tributaries.

North Eden Creek, a tributary on Bear Lake's eastern shore, supports a relict population of genetically pure Cutthroat Trout in its headwaters, and historically supported spawning by migratory adfluvial individuals. However, due to the construction of reservoirs and roads, the creek became disconnected from the lake and in-stream habitat became degraded due to an altered hydrograph and intensive grazing. The historical reservoirs have since failed and blown out, reestablishing connectivity between upstream and downstream reaches of North Eden Creek. Yet, a culvert near the mouth of the creek still limits the ability of adfluvial fish from Bear Lake to access potential spawning habitats upstream of the road crossing culvert. Presented with this opportunity to improve spawning opportunities for Cutthroat Trout by restoring connectivity at the road crossing, the culvert is slated for replacement by agency and conservation partners in autumn of 2025. However, our current understanding of the fish assemblage and in-stream habitat of the watershed is limited, as historical fish monitoring surveys have been limited to the headwaters where the resident population has persisted. Understanding the fish assemblage structure and habitat conditions throughout the watershed prior to restoration of connectivity is critical to assessing the ultimate impact of the culvert replacement.

Here, we develop a baseline understanding of the historical and current conditions in North Eden Creek to allow for future assessment of the effectiveness of the proposed culvert removal and any subsequent restoration actions. Specifically, we address the following objectives:

1. Compile and summarize historical information relating to water temperature, water quantity, fish habitat, and fish distribution in North Eden Creek.
2. Design a preliminary monitoring plan to assess the impact of future restoration projects in the North Eden Creek drainage.
3. Characterize the current fish community and habitat quantity and quality throughout the drainage using field surveys and remote sensing.

Methods

North Eden Creek

North Eden Creek drains a 155 km^2 watershed spanning the border of Idaho and Utah, before discharging into Bear Lake approximately 1.3 km south of the Utah-Idaho border (Figure 1). The watershed ranges in elevation from 1807 m at the confluence with Bear Lake to 2349 m at its highest point on the summit of Black Mountain. The watershed contains a mixture of private and public lands, with public lands being managed as Utah State Trust Lands and by the U.S. Bureau of Land Management. Land use in the watershed has a long history of cattle grazing and mining, with public lands also hosting dispersed recreation. The stream is fragmented by a culvert at the crossing of North Cisco Road, near the outlet to Bear Lake.

Figure 1. Map showing the location of the North Eden Creek watershed (green polygon) relative to Bear Lake along the Utah-Idaho border. North Eden Creek is drawn in blue with its tributaries in light blue and the yellow star indicates the location of the impassable culvert.

Historical Information Survey

We gathered information for the historical survey from the Utah Division of Wildlife Resources (UDWR) Bear Lake Field Office, current and former UDWR Bear Lake biologists, Idaho Department of Fish and Game historical records and local North Eden Canyon landowners. Historical imagery of North Eden Canyon was found through the U.S. Geological Survey (usgs.gov). We found additional reference papers through the assistance of the Utah State University library and the American Fisheries Society online Journal Access.

Field Surveys

We established ten sampling reaches 300m in length and distributed along an elevational gradient from below the impassable culvert near the lake (Site 1) to the headwaters (Site 10; Figure 2). Sites 9 and 10 correspond with established sites sampled regularly by UDWR. Our sampling sites ranged in elevation (at their downstream extents) from approximately 1813m - 1943m (Table 1). We sampled all sites between May 28 and July 9, 2024, following the peak of spring runoff. During each sampling event at each site, we surveyed the fish assemblage, physical habitat conditions, and aquatic invertebrate assemblage.

Figure 2. Location of sampling sites within the North Eden Creek watershed.The pink lines indicate each of the 300 meter extents of sampling reaches sites 1-10, and T represent locations of temperature loggers 1-4. The impassible culvert is located at the upstream end of Site 1 near Bear Lake labeled with the yellow star and the Mayfly stream gage is located in the center of Site 2.

We sampled the fish assemblage via single-pass backpack electrofishing, using a Smith-Root LR-24 backpack electrofisher unit (Smith-Root, Inc., Vancouver, WA). Field crews electrofished from the downstream to upstream ends of each sampling reach, removing all captured fish for subsequent processing. All fish captured during surveys were identified to species, measured (total length TL in mm) and weighed (g), before being returned to the stream (except for a subsample of non-native Brook Trout that were euthanized and removed from the stream by UDWR staff). At one site (Site 10), we conducted a two-pass depletion survey, during which block nets were placed at the upstream and downstream ends of the reach, and all fish sampled during the first pass were returned to the stream outside of the bounds of the sampling reach. We estimated the total abundance within this reach from our catch data using the Carle and Strub (1978) method. Given the low abundances of trout in our sampling reaches, we adjusted the lower confidence interval values from the abundance estimator upwards to match the number of individuals captured in our surveys, as we know there were at least that many individuals present. We calculated the body condition of Cutthroat and Brook Trout captured during our surveys using both the Fulton's K method (Ricker 1975) and by calculating the residuals from a length-weight regression for each species. We then compared the size structure and body condition among sites for each species using analysis of variance (ANOVA) and Tukey's HSD test.

We sampled the aquatic invertebrate community using the kick net method at each of the ten sites (Stark et al. 2001). To collect the samples, we positioned a standard 500 um mesh D-frame kick net within a representative portion of the stream and held the net vertically upright with the base of the frame in contact with the substrate and the open portion of the net facing into the flow. The collector then stood approximately 60 cm upstream of the net and kicked for one minute using a stopwatch. The net was removed from the water and immediately emptied into a tray and rinsed clean to ensure all macroinvertebrates collected were captured before being placed into a jar. Samples were preserved in ethanol and returned to the lab, where all aquatic invertebrates were sorted, identified to order, and counted. We then characterized the relative abundance of different taxa across sites, relative abundance of EPT (Ephemeroptera, Trichoptera, Plecoptera) taxa across sites, and compared the community composition across the elevational gradient of our sites by calculating the Shannon Diversity index at each site and conducting a principal components analysis on the abundances of individual taxa (orders) at each site.

We surveyed a suite of standard in-stream habitat conditions at each site as metrics of habitat quality. At each of ten evenly spaced transects within each site, we measured wetted width, bankfull width, thalweg depth, and dominant substrate type. Substrate types were categorized as silt (< 0.25 mm), sand (0.25 - 1.9 mm), gravel (2 - 64 mm), cobble (65 - 256 mm) and boulders (>256mm), based broadly on categories identified in Wentworth (1922). We also estimated the percent of the banks that were undercut, the percent of the banks that provided vegetative cover to the stream, and the total frequency of woody structures (i.e., sticks, logs > 0.3m length) within the site. We sampled conductivity, temperature, total dissolved solids and salinity within each site during August 2024 using a LaMottee 1749 TRACER pocket tester calibrated to the manufacturer recommendation using a salt calibration standard of 3000 ppm. We compared the physical habitat conditions between sites for those metrics measured at the ten transects using ANOVA and Tukey's HSD test. All statistical tests were conducted in the R Statistical Computing Environment (R Core Team 2024).

Additionally, we installed five temperature loggers along the length of the creek (Table 2) to capture spatio-temporal variation in thermal conditions. While the four higher elevation logger sites consisted of HOBO Tidbit temperature loggers, which recorded temperatures once per hour, the lowest elevation logger site had a Mayfly Environmental Logger installed, which recorded temperature, conductivity and depth at 15 min intervals. The Mayfly logger system was installed in July 2022, sites T1 and T2 were installed in October 2023, site T4 was installed in November 2023, and site T3 was installed in June 2024. For each of these logger sites, we characterized the seasonal temperature changes and calculated the number of hours in which water temperatures exceeded the 7-day incipient lethal temperature threshold for Bonneville Cutthroat Trout of 24.2°C (Johnstone and Rahel 2003) during the monitored period of 2024.

Table 1. Site information for the ten 300-meter sampling reaches in North Eden Creek. Site 1 is nearest to Bear Lake, and the impassible culvert is at the upstream end of Site 1.

Site Number	Downstream Coordinate (UTM)	Upstream Coordinate (UTM)	Downstream Coordinate Elevation (m)	Upstream Coordinate Elevation (m)	Gradient (*Estimated from DEM*)
1	12T 477833.80m 4648467.41m	12T 478096.09m 4648372.22m	1813	1820	2.3%
2	12T 478254.22m 4648343.97m	12T 478530.85m 4648275.96m	1823	1829	2.0%
3	12T 479387.36m 4648328.38m	12T 479647.50m 4648340.95m	1844	1850	2.0%
4	12T 480882.05m 4647837.88m	12T 481137.64m 4647690.64m	1873	1873	0.0%
5	12T 479644.54m 4648349.40m	12T 483268.73m 4648200.47m	1887	1888	0.3%
6	12T 483891.32m 4648415.54m	12T 484055.40m 4648446.25m	1892	1893	0.3%
7	12T 485414.42m 4649111.73m	12T 485630.08m 4649266.73m	1906	1908	0.7%
8	12T 486479.77m 4649223.97m	12T 486509.38m 4649111.78m	1924	1926	0.7%
9	12T 486846.82m 4648848.01m	12T 486969.81m 4648653.22m	1933	1936	1.0%
10	12T 487442.32m 4648358.40m	12T 487526.53m 4648199.48m	1943	1945	0.7%

Table 2. Site information for environmental loggers deployed in North Eden Creek.

Logger ID	Conditions Monitored	UTM Zone	UTM Easting	UTM Northing	Elevation (m)
Mayfly	Temperature, Conductivity, Depth	12	478366	4648295	1827
T1	Temperature	12	479543	4648321	1848
T2	Temperature	12	480425	4647991	1860
T3	Temperature	12	483914	4648397	1892
T4	Temperature	12	487526	4648199	1945

Remote Sensing Analyses

We performed remote sensing analysis to characterize active channel and valley bottom conditions, as well as estimate the historical change in riparian vegetation conditions of North Eden Creek. To calculate the proportion of the valley bottom occupied by the active stream channel, we first calculated the valley bottom area within each of our study sites using the Valley

Bottom Extraction Tool (VBET; Gilbert et al. 2016) within QGIS. This tool classifies the valley bottom extent using a digital elevation model and stream channel network to identify the maximum potential area that could be used by a stream channel and riparian vegetation. We then created a polygon covering the active channel from aerial imagery in QGIS. We reprojected both polygons to NAD83 UTM Zone 12N to ensure accuracy, and divided the active channel area by the valley bottom area within each reach. To assess the change in riparian woody vegetation cover, we used the Riparian Vegetation Departure tool developed by Macfarlane et al. (2017) to estimate the valley bottom covered by native woody riparian vegetation under historical and current conditions. Using available 30 meter Digital Elevation Model (DEM) imagery, current riparian vegetation cover is modeled using the LANDFIRE Existing Vegetation Type (EVT) layer (30 m resolution) and the historical (pre-European settlement) vegetation is modeled using the LANDFIRE Bio-physical Setting (BpS) layer. While this tool is primarily intended for use in larger watershed contexts (Macfarlane et al. 2017a), it may still provide a coarse estimate of the historical change in riparian vegetation at the scale of the North Eden Creek watershed.

Results

Historical Conditions

Early accounts of the native fish and wildlife in Bear Lake Valley suggest populations were abundant in the late 1800's and attracted Native American tribes, fur trappers and mountain men, where such groups gathered to trade or sell resources (McConnell et al. 1957; Crampton and Madsen 1975). Since settlement of Bear Lake Valley in the 1860s, diverse land uses have been practiced including but not limited to, irrigated agriculture, timber harvest, cattle grazing, mining and other resource extraction. Early commercial fishing in Bear Lake and its tributaries reportedly harvested 500 to 2,000 pounds of fish per day, leading to the creation of laws to protect Cutthroat Trout of Bear Lake in 1874, which remained in place until commercial netting was banned in Utah in 1897 (Stettler 2014). However, the state of Idaho did not adopt the same regulations at the time. Idaho first closed the harvest of Cutthroat Trout during their spawning season during the 1890s, then briefly prohibited commercial fishing from 1900 to 1905. However, those restrictions were lifted in 1906 when the state decided to only close commercial fishing for the months of March, April and May (Clark 1956). Legislative action by Utah and Idaho in the ear1y 1920's ultimately closed the commercial fishery at Bear Lake (McConnell et al. 1957).

North Eden Creek is a perennial stream which begins approximately 18 km from Bear Lake flowing through the canyon as it is joined by multiple perennial, intermittent and ephemeral tributary streams and spring sources (Figure 2). Historically, North Eden Creek had low turbidity in the upper sections of stream and formed a delta flowing through wetland areas upon approaching Bear Lake (McConnell et al., 1957; North Eden on Bear Lake Land Purchase proposal, 1991). The land in North Eden Canyon was purchased in 1888 by the Nebeker family who eventually controlled or owned the entire eastern shore of Bear Lake and all of the area extending north and east from North and South Eden Canyons (Parson, 1996). The historical vegetation in North Eden Canyon consisted primarily of sagebrush (*Artimesia tridentata*), with willows (*Salix spp.*) and cottonwood (*Populus angustifolia*) in the stream riparian zones and within larger canyons (McClurg, 1970).

Figure 3. Modified version of the aerial Imagery of North Eden Canyon from September 26, 1952 collected by U.S. Geological Survey and provided by usgs.gov. The Upper and Lower North Eden reservoirs are highlighted in the red boxes.

Historical land use of the North Eden Creek area included mining, agricultural water use and cattle grazing. In 1945, two reservoirs were constructed along North Eden Creek for agricultural water storage, with the lowest elevation dam being located 2.5 km east of Bear Lake (Figure 3). The reservoirs were also maintained as a private fishery stocked with Rainbow Trout (*Oncorhynchus mykiss*) and Brook Trout (McConnell et al., 1957; Figure 4). A culvert was installed at the North Cisco Road crossing for equipment access to the canyon during this time (Michael Nebeker, *personal communication*). In 1975 the lower section of the stream was channelized from the road to the lake as an irrigation ditch (~800 m of stream; Utah Division of Parks and Recreation, 1991). Large runoff volumes from an unusually large rain-on-snow event caused the two reservoirs to fail in 1979, resulting in severe damage to stream and riparian areas downstream and leaving large amounts of boulders and cobble in the delta area (Utah Division of Parks and Recreation, 1991).

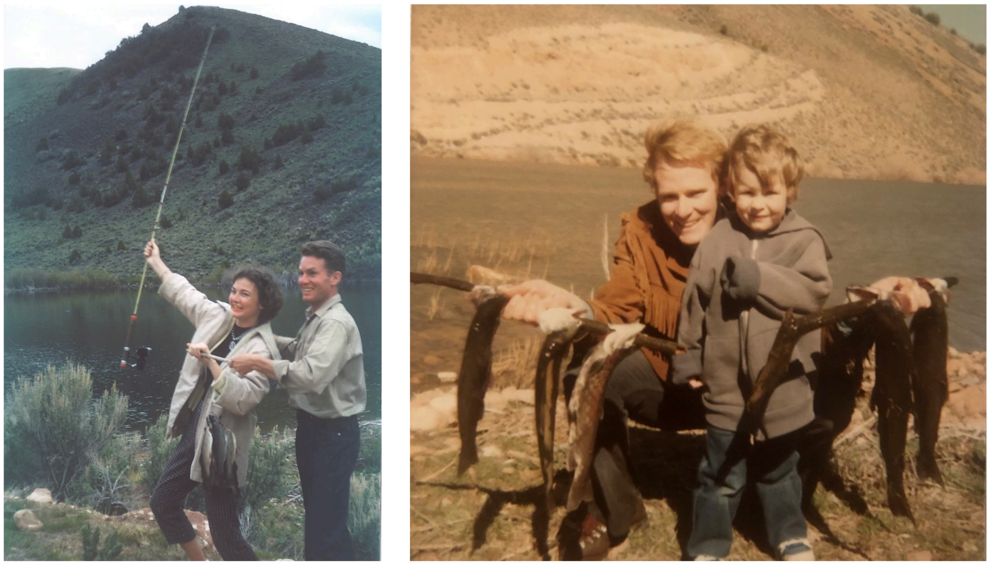

Figure 4. (Left) Carolyn and Conrad Nebeker at Upper North Eden Reservoir in 1957. (Right) Richard Nebeker and his nephew Patrick Robinson with their catch on the shores of the Upper North Eden Creek Reservoir in 1976. Photos courtesy of Michael Nebeker.

Historical surveys of North Eden Creek above the culvert documented native Cutthroat Trout from Bear Lake and nonnative Brook Trout as the only trout species present in the creek although their relative abundance sampled has varied over time (UDWR Water Management Plan 1992; Figure 5). Although stocked into the reservoirs associated with North Eden Creek, Rainbow Trout have not been documented in the stream since the reservoir failure. While an exact date on when eastern Brook Trout were first introduced to North Eden Creek is unclear, it is likely they were stocked with Rainbow Trout following completion of the reservoirs in North Eden Canyon. The last recorded stocking of Brook Trout occurred in 1962, when 1000 fish were placed into the stream. By the start of the 21st century, the Cutthroat Trout of North Eden Creek were considered the only known strong population of stream resident Bear Lake Cutthroat Trout in the Bear Lake Unit (U.S. Fish and Wildlife Service, 2001).

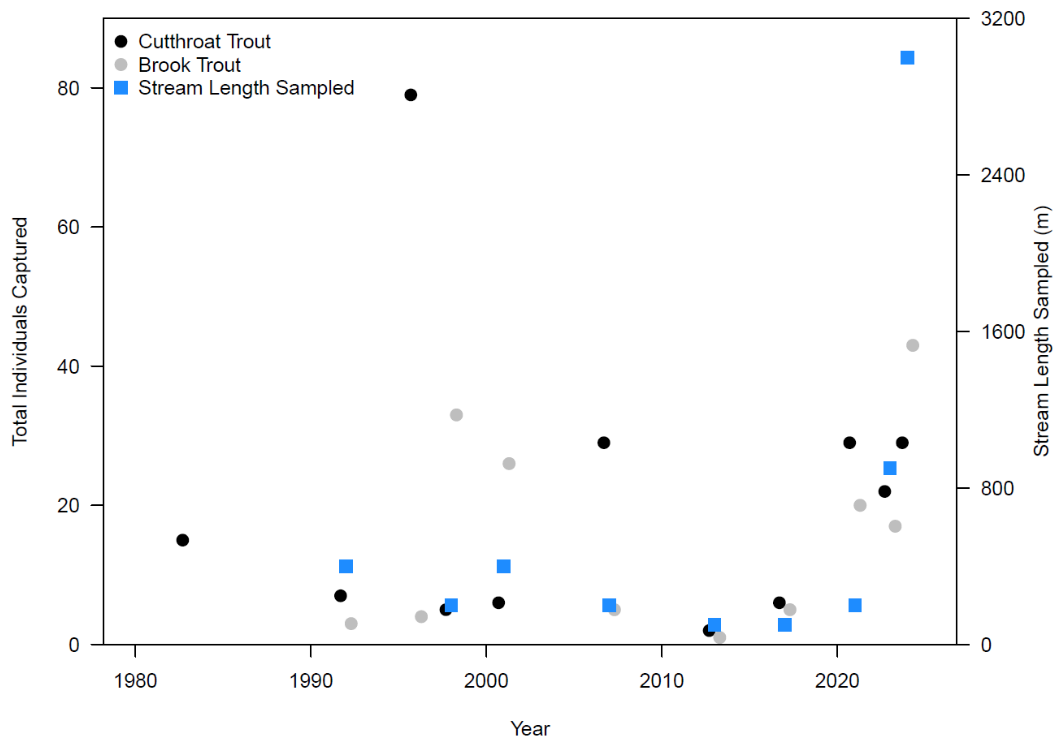

Figure 5. Total trout captured and stream length sampled during historical and contemporary electrofishing surveys in North Eden Creek. Black points represent Cutthroat Trout, gray points represent Brook Trout, and blue squares represent the total stream length sampled during each year. Note that no data regarding the length of stream sampled during 1983 and 1996 could be found in the historical files. Additionally, data points within each year are slightly offset horizontally to increase visibility of overlapping points.

Cutthroat Trout from the headwaters of North Eden Creek have historically been translocated to Laketown Creek on the south end of Bear Lake by the Utah Division of Wildlife Resources (UDWR). On June 7, 1996, the UDWR used a backpack electrofisher to collect 48 Cutthroat Trout ranging from age-1 (50-75mm) to adult (350mm) from the headwaters of North Eden Creek. These fish were placed in about 1 km of the headwaters of Laketown Creek. North Eden Creek was noted to be in poor condition with significant siltation but that the riparian zone was improving with normal precipitation. Additionally, it was noted that only four Brook Trout were captured, and all appeared to be adults with no juvenile recruitment. On November 6, 1996, 31 Cutthroat Trout were translocated (all but two fish were adults). Brook Trout were observed in North Eden Creek, but the number was not documented. On July 7, 1998, twenty-four Brook Trout but no Cutthroat Trout were captured in a lower site where stream conditions were noted as very murky. In the upper site, a total of five Cutthroat Trout (ranging from 3 to 8 inches) and nine Brook Trout (two of which were 12”) were captured. There was no mention of the Cutthroat Trout being relocated to Laketown Creek. In total, 79 Cutthroat Trout were documented being translocated from North Eden Creek.

Genetic analysis of Cutthroat Trout collected from the headwaters of North Eden Creek in 2023 determined they are 100% genetically pure Bear River strain of Cutthroat Trout, indicating they are a relict population of Bear Lake Cutthroat Trout, and remain genetically uninfluenced by non-native fish stocking in Bear Lake or the North Eden Creek Reservoirs (Evans, 2024).

Remote Sensing Analyses

The valley bottom area, representing the maximum potential extent of stream channel and riparian habitats, narrows from the lower to middle elevation sites, with site 6 being the narrowest valley bottom (Figure 6a). Valley bottom area generally increased upstream of site 6, with site 7 having the greatest valley bottom area. Site 3 had the most active channel area, matching the results of our channel wetted width surveys (*see below*). Site 8 had the smallest active channel area. Generally, between 10-15% of the valley bottom area was in active channel, though greater percentages were present in sites 3 (18%), 4 (22.8%), and 6 (25.5%; Figure 6b).

Current riparian vegetation was reduced as compared to historical cover across all of our sites (Figure 7). The Riparian Vegetation Departure Tool estimates this effect to be particularly strong in sites 2 and 7, where a complete loss of riparian vegetation is modeled. However, we urge caution when interpreting these results, as the 30m resolution used by the Riparian Vegetation Departure Tool is likely too coarse to capture small-scale changes occurring in smaller watersheds (Macfarlane et al. 2017b). Two of our sampling sites demonstrate this limitation. Site 1, located downstream of the culvert, is predicted to have lost the vast majority of its riparian vegetation (Figure 7), but in ground surveys we observed thick riparian vegetation present along the margins of the river for much of the length of the reach. This contemporary riparian vegetation habitat is relatively narrow (~10m) compared to the resolution of the remote sensing tool. Conversely, site 4 is estimated to still maintain rather extensive riparian vegetation (Figure 7), though our ground surveys found it heavily grazed, with no woody riparian vegetation. The ability to detect the impact of heavy grazing pressure is a known limitation of the Riparian Vegetation Departure Tool (Macfarlane et al. 2017b). The model uses nationwide 30m Landsat satellite imagery based land cover classification, which is likely too coarse for narrow canyons. We recommend future monitoring efforts use higher resolution (~1m) aerial imagery captured. These data will be particularly valuable if any additional in-stream or riparian habitat restoration actions are undertaken on North Eden Creek.

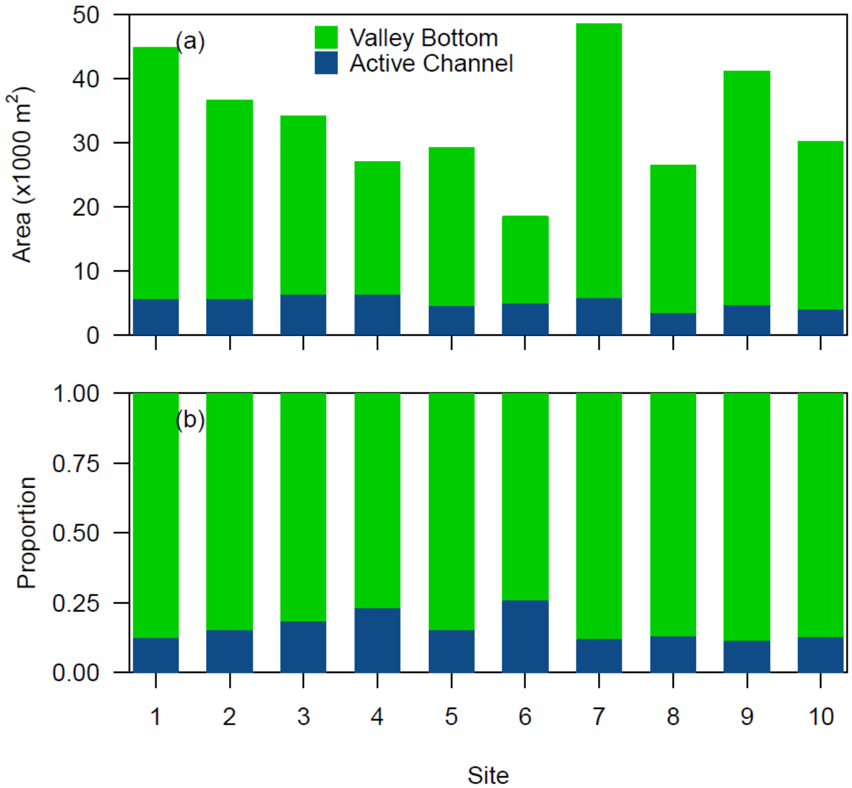

Figure 6. (a) Valley bottom and active channel area across sites in North Eden Creek. (b) Proportion of valley bottom width occupied by active stream channel. Site 1 is at the lowest elevation and nearest to Bear Lake.

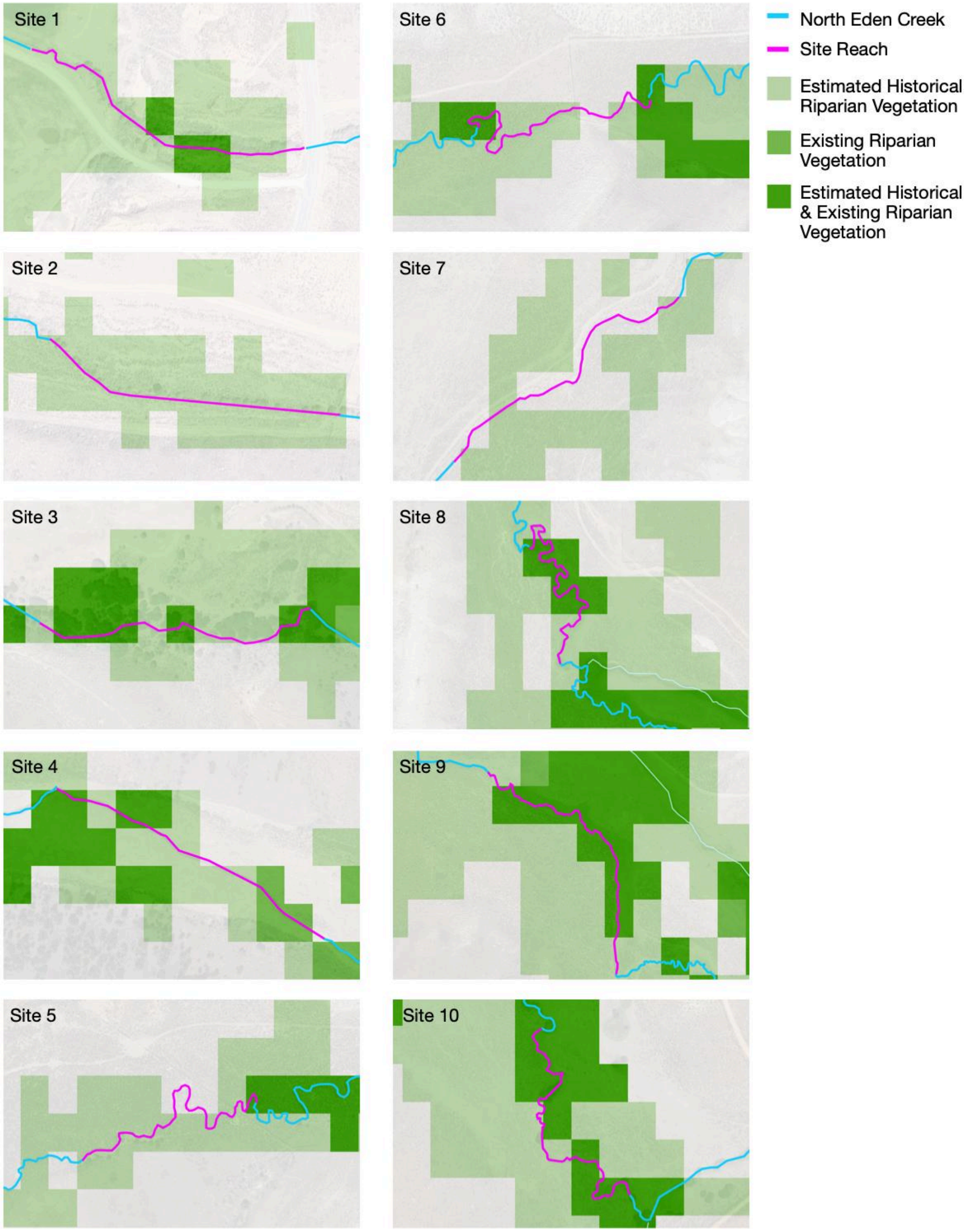

Figure 7. Sites one through ten on North Eden Creek displaying the estimated historical riparian vegetation (modeled using the LANDFIRE Biophysical setting (BpS) layer) and current riparian vegetation cover (modeled using the LANDFIRE Existing Vegetation Type (EVT) layer) from Riverscapes Consortium in Qgis.

Current Conditions: Physical Habitat Surveys

The composition of the substrate within our sampling sites changed along an elevational gradient (Figure 8a). Lower elevation sites had more cobbles than higher elevation sites. The proportion of the bed composed of silt increased in the middle elevation reaches. Silty substrate comprised at least 70% of the substrate in all sites upstream of site 3, with the exception of site 9. Gravels never comprised a large proportion of the substrate within any site, but were scattered among sites across the elevational gradient. Boulders were most abundant in site 9, being available in the three highest elevation sites, but also present in sites 3 and 5.

Overhanging vegetative cover was greatest in downstream sites (Figure 8b). More than 50% of the banks in sites 1, 2, and 3 contained overhanging vegetative cover. Conversely, very little vegetative cover was available in the middle elevation reaches, with less than 15% vegetative cover being present in sites 4 through 9. Site ten had slightly increased vegetative cover compared to the middle elevation reaches, with 25% cover. Undercut banks were limited to the highest elevation sites (Figure 8c). Site 10 had the most undercut banks (45% of the bank length), followed by sites 9 (40%) and 8 (20%). All other sites had less than 5% undercut banks. In-stream wood was present, but not abundant, in all sites (Figure 8d). Site 10 had the highest frequency of wood, with 14 pieces or about one piece of wood every 21.4m of stream.

Thalweg depth did not significantly vary among sites (Figure 8e). Site 5 had the greatest median thalweg depth (0.30m), while site 9 had the shallowest median thalweg depth (0.17m). Wetted width increased from high elevation sites to low elevation sites (Figure 8f). Site 10 had the narrowest median wetted channel width (1.04m). Site 3 had the greatest median wetted width (1.93m), and a significantly wider wetted channel than sites 5, 8, 9, and 10 (Tukey's HSD $p < 0.05$). No other sites had significantly different wetted widths. Bankfull widths increased with decreasing elevation (Figure 8f). Site 2 had the greatest wetted width among all sites (5.39m) and was significantly wider than all sites except 3 and 7 (all other Tukey's HSD p-values < 0.01). Site 3 was the second widest site by bankfull width (median = 4.96m), and was significantly wider than all sites except sites 2 and 7 (all other Tukey's HSD p-values < 0.01). Site 7 was the third widest site(median bankfull width = 3.87m), and was significantly wider than sites 4, 6, 8, 9, and 10 (all Tukey's HSD p-values < 0.05). Site 5 (median bankfull width =2.56m) was significantly wider than site 10, the narrowest site by bankfull width (median = 1.39m). No significant differences in bankfull width were found at all other sites..

Temperature, salinity, conductivity, and total dissolved solids had longitudinal spatial patterns based on our spot sampling (Table 3). Temperatures were highest in the middle elevation site (3 to 7), though site 5 was substantially cooler than sites 4 or 6. Salinity, conductivity, and total dissolved solids were all greatest at the highest elevation sites.

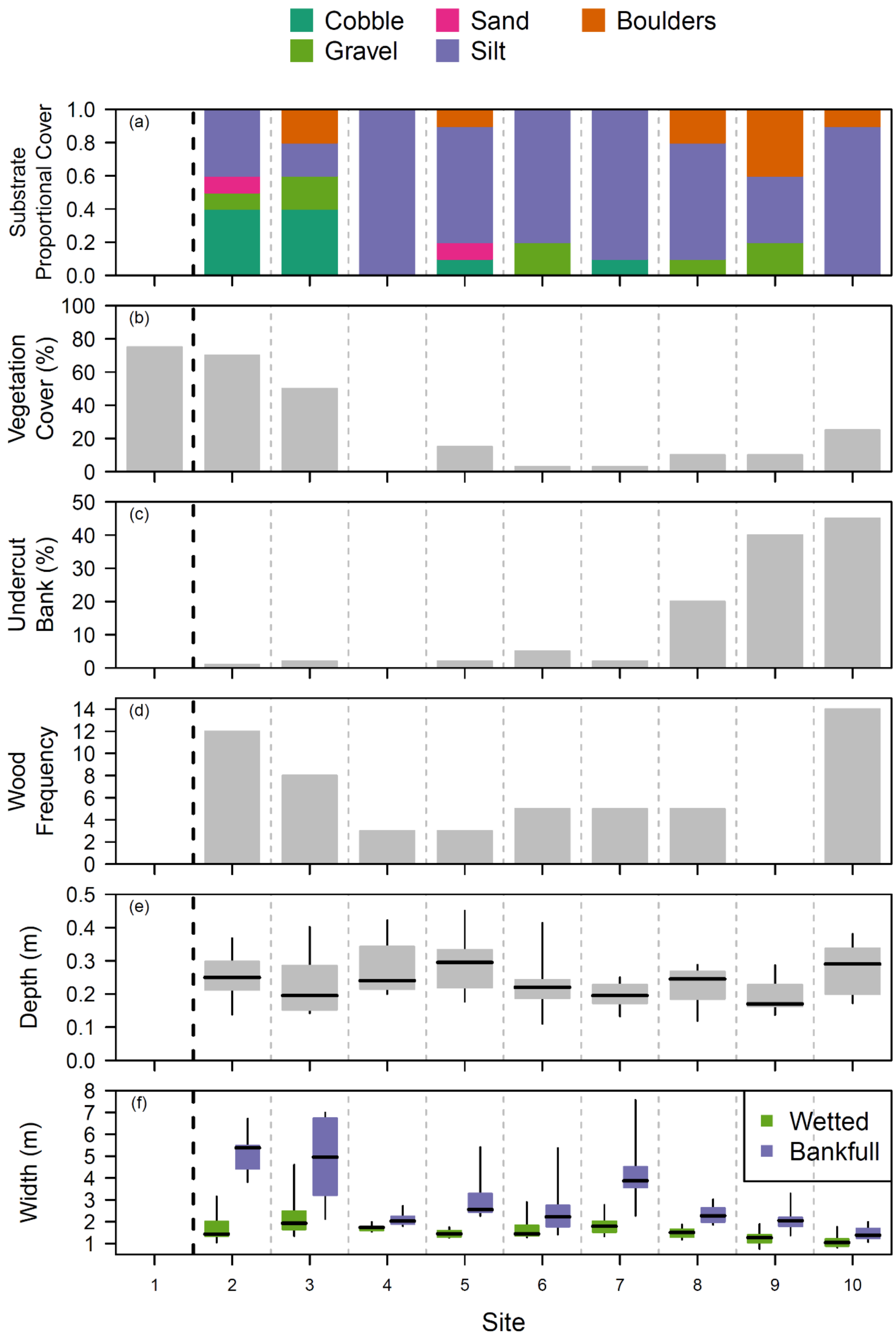

Figure 8. Summary statistics of the physical habitat conditions at each sampling site in the summer of 2024. (a) Proportional contribution of dominant substrate types across ten transects within each site (b) Percent of banks with vegetated cover. (c) Percentage of undercut banks. (d) Total frequency of wood. (e) Distribution of thalweg depths measured at each of ten transects. (f) Distribution of wetted (green boxplots) and bankfull (purple boxplots) widths at each of ten transects. Vertical dashed black line represents the location of the impassable culvert.

Table 3. Spot samples of water temperature, conductivity, salinity, and total dissolved solids (TDS) at each of our ten sampling locations from August 22, 2024.

Date	Time	Site	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (ppm)
8/22/2024	15:00	1	16.1	667	270	450
8/22/2024	15:25	2	17.8	642	290	450
8/22/2024	15:50	3	20.0	640	300	450
8/22/2024	16:15	4	24.0	579	260	400
8/22/2024	16:38	5	20.0	637	290	430
8/22/2024	16:58	6	29.4	542	240	380
8/26/2024	15:06	7	20.0	600	280	430
8/26/2024	16:04	8	16.7	615	280	430
8/26/2024	16:34	9	15.6	747	340	520
8/26/2024	16:53	10	13.3	802	340	530

Current Conditions: Continuous Stream Temperature, Depth, and Conductivity

Water temperatures in North Eden Creek were relatively homogeneous along the longitudinal gradient from January through March, with the exception of the highest elevation site (T4 in Figure 1), which was consistently ~1°C warmer than all other sites due to its proximity to headwater springs (Figure 9). Temperatures began to warm throughout the creek in mid-March, passing Cutthroat Trout spawning temperature threshold (5°C; Budy et al. 2007) in early April. From mid-April through late August when temperature logger data were downloaded, the highest elevation site had the coldest temperatures due to the moderating influence of springs. Interestingly, the lowest elevation (site name "Mayfly") and the middle elevation site (T2) had temperatures more similar to the high elevation T4 than to the more proximal sites T1 and T3. As such, there was not a linear elevational gradient in summer temperatures due to the effects of springs at different locations throughout the basin. This pattern is reflected in the cumulative amount of time each site demonstrated temperatures greater than the 7-day incipient lethal temperature for Bonneville Cutthroat Trout (24.2°C; Johnstone and Rahel 2003; Figure 9b).

Water depths at the low elevation Mayfly logger site in 2024 were steady at approximately 0.22 m prior to the onset of spring snowmelt runoff in March, with the exception of a couple relatively large, short-lived runoff events (Figure 9c). Water depths peaked during late March and early April, before slowly declining throughout the remainder of the runoff period. Depths declined rapidly beginning in June due to the beginning of water withdrawals at the beginning of irrigation season. Depths varied between approximately 0.18m and 0.22 m throughout the summer.

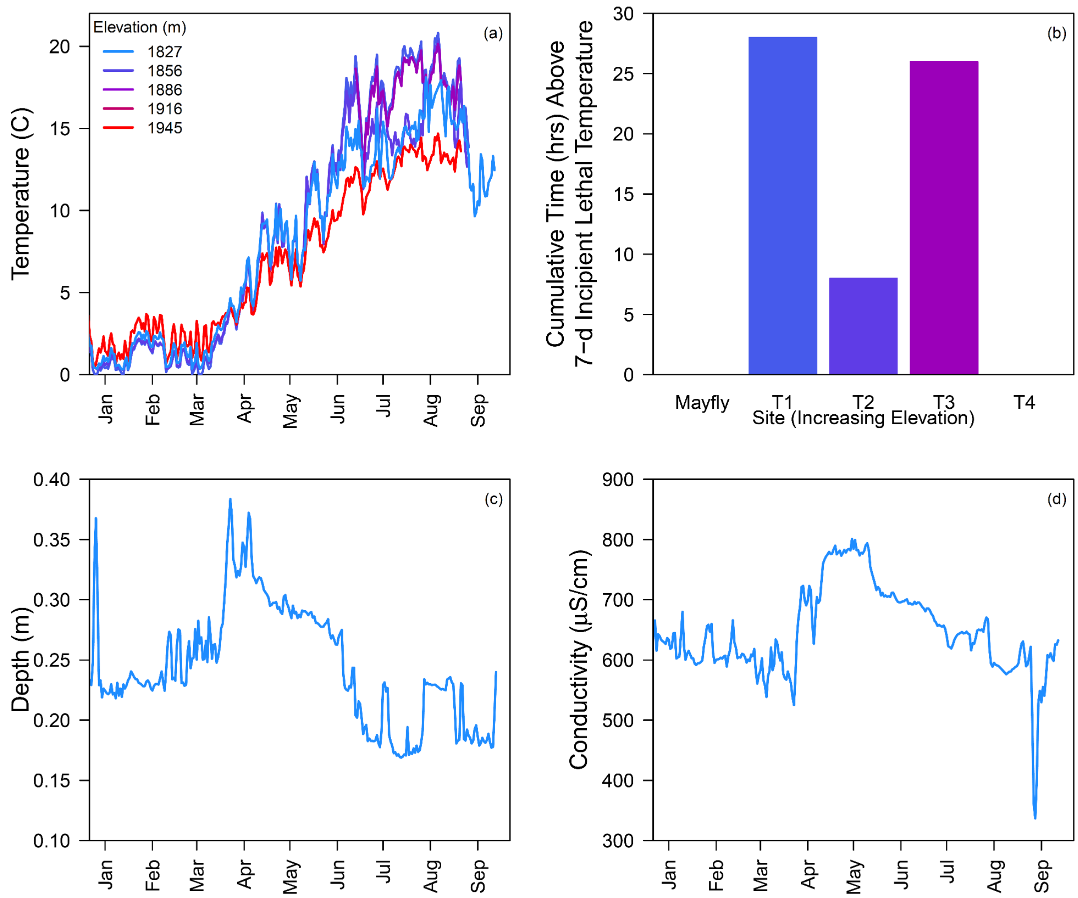

Figure 9. Time-series data from loggers along North Eden Creek from December 21, 2023 to September 13, 2024. Colors indicate the elevation of each logger and are maintained throughout all panels. (a) Temperature at different elevations. (b) Cumulative number of hours spent above the 7-day incipient lethal temperature for Cutthroat Trout of 24.2°C at each temperature logger site. (c) Mean daily water depths recorded at the Mayfly logger. (d) Mean daily conductivity measured at the Mayfly logger. We recommend caution when interpreting short-duration, large magnitude spikes in these data (e.g., conductivity dip in September), as they may represent instrument error rather than true changes.

Conductivity at the Mayfly site in 2024 (Figure 9d) increased during spring runoff to a maximum daily mean value of 1037 μS/cm before slowly decreasing to the levels typical of baseflow periods in North Eden Creek, with means that varied between ~570 - 700 μS/cm.

Current Conditions: Fish Assemblage

We collected a total of four unique fish species in North Eden Creek during our 2024 surveys: Cutthroat Trout, Brook Trout, Speckled Dace (*Rhinichthys osculus*), and Utah chub (*Gila atraria*). Of these species, only Cutthroat Trout and Brook Trout were captured upstream of the culvert at Cisco Road. All four species were captured at site 1 downstream of the culvert, only Brook Trout were captured at site 6, and both Cutthroat Trout and Brook Trout were captured at each of sites 8, 9, and 10 (Figure 10a). Additionally, while not captured in our 2024 surveys, Utah Sucker (*Catostomus ardens*) were observed downstream of the culvert in 2023.

Brook Trout were the most abundant species across all of our site surveys, and were the most abundant species captured at sites 6 (n=1), 8 (n=19), and 10 (n=18; Figure 10b). Cutthroat Trout were the most abundant species captured at site 9 (n=5), and the same number of Cutthroat Trout and Brook Trout were captured at site 1 (n=4). Three speckled dace and one Utah chub were captured at site 1. Abundance estimates from our two-pass removal survey at site 10 indicate a total abundance of 20 Cutthroat Trout (95% CI = 17 - 29.6) and 18 Brook Trout (95% CI = 18-19.6).

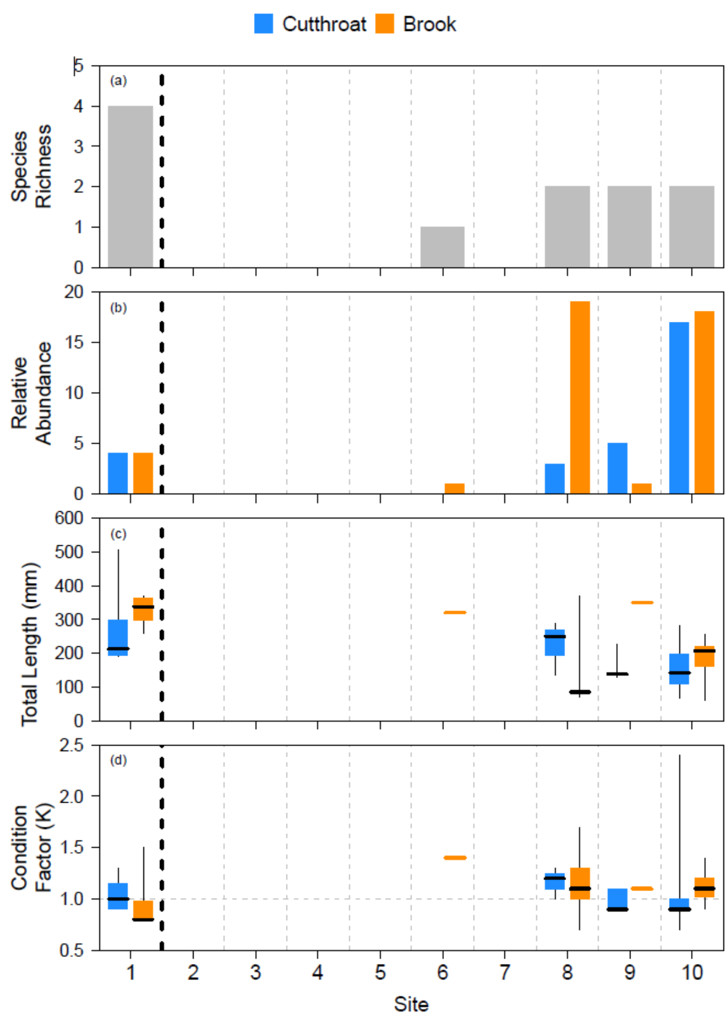

Figure 10. Fish assemblage data by site from surveys conducted in summer 2024. No fish were captured at sites 2 through 5, or 7. (a) Species richness. (b) Relative abundance of Cutthroat Trout and Brook Trout. (C) Distribution of observed total lengths of Cutthroat Trout and Brook Trout. (d) Distribution of body condition indices (Fulton's K) for individual Cutthroat Trout and Brook Trout. Vertical dashed black line represents the location of the impassable culvert.

Cutthroat Trout and Brook Trout differed in TL within species among sites, but did not significantly differ between species either across all sites or within individual sites (Figure 10c). Cutthroat Trout were significantly larger at site 1 (below the culvert) than in site 10. Additionally, the difference in total length between Cutthroat Trout in site 9 and site 1 was marginally significant ($p = 0.078$), with Cutthroat Trout in site 1 being larger than those in site 9. These results suggest the Cutthroat Trout attempting to ascend the creek in spring are larger than those residing year round in the headwaters. Brook Trout were also significantly larger below the culvert than in two of the three headwater sites (site 8 $p < 0.001$ and site 10 $p = 0.013$). Brook Trout in site 9 were significantly larger than those in site 8, though this result should be interpreted with caution, as only 1 Brook Trout was captured in site 9 during our survey. We detected no significant differences in body condition between Brook Trout and Cutthroat Trout, or between individuals captured at different sites within each species, by either the Fulton's K or length-weight regression residual methods (Figure 10d, Figure 11).

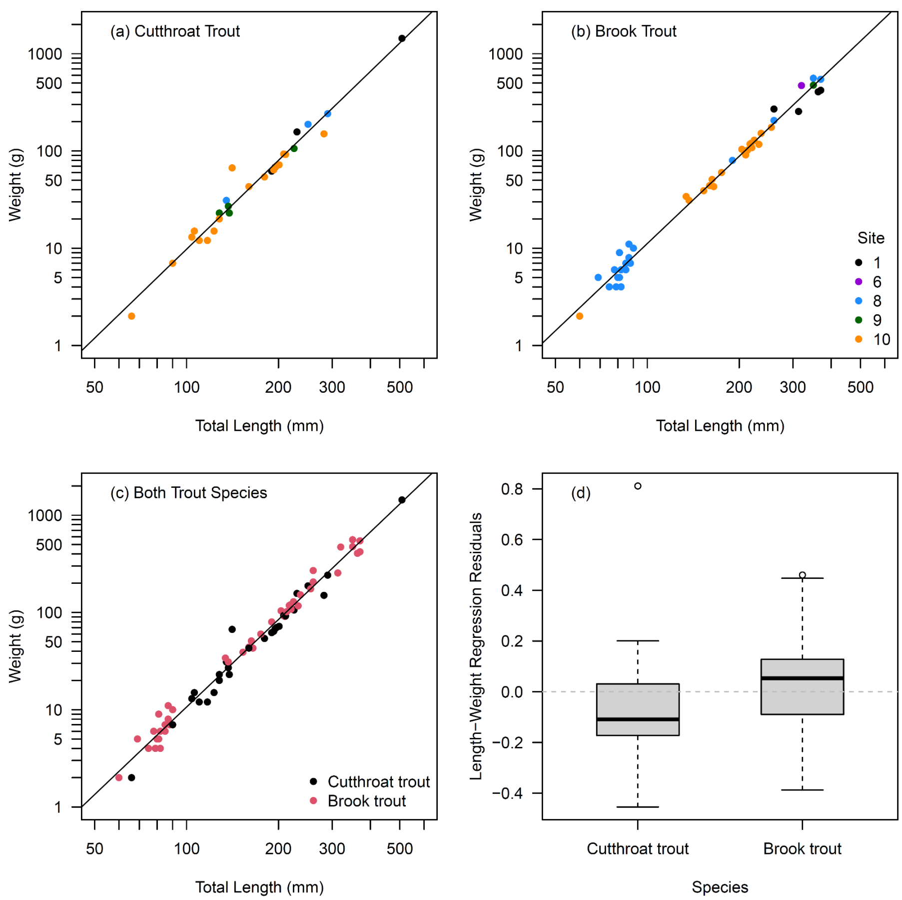

Figure 11. Length-weight relationships for (a) Cutthroat Trout, (b) Brook Trout, and (c) all trout captured in North Eden Creek in 2024. Point color in (a) and (b) indicates the site at which individuals were collected, while point color in (c) indicates the species. (d) Boxplot comparing residuals from the length-weight regression for all trout between Cutthroat Trout and Brook Trout.

Current Conditions: Aquatic Invertebrate Assemblage

There were substantial differences in the abundance, diversity, and composition of the aquatic invertebrate community among our sample sites (Figures 12, 13). Relative abundance of aquatic invertebrates was generally greater in higher elevation sites than middle or low elevation sites, though site 1 had the second highest total invertebrate abundance (Figure 12a). Site 7 had the highest invertebrate abundance among all sites, having more than twice the total number of aquatic invertebrates as the second most abundant site (site 10). Sites 2–6 had the lowest invertebrate abundances. Middle elevation sites also demonstrated a substantially lower percentage of EPT taxa within their aquatic invertebrate communities than did high and low elevation sites (Figure 12b). Sites 1-3 and sites 9-10 each had EPT taxa proportional contributions greater than 70%, while EPT taxa made up less than 30% of the aquatic invertebrate community in sites 4-6. While total abundance and contribution of EPT taxa were generally reduced in the middle elevation sites, Shannon Diversity indices were generally greater in the middle elevation sites than in the high and low elevation sites (Figure 12c). This is due to a greater diversity of invertebrate orders being present, and the communities being less dominated by Ephemeroptera.

The first two principal components of our PCA explained 97.1% of the variance observed in invertebrate community composition among sites, and the abundance of Ephemeroptera, Amphipoda, Annelida, and Coleoptera were the primary taxa discriminating aquatic invertebrate communities among sites on both of these axes (Figure 13). Site 7 demonstrated a unique assemblage with large contributions of Amphipoda and Coleoptera, as well as Ephemeroptera, while all other sites are discriminated from each other primarily by the relative abundance of Ephemeroptera.

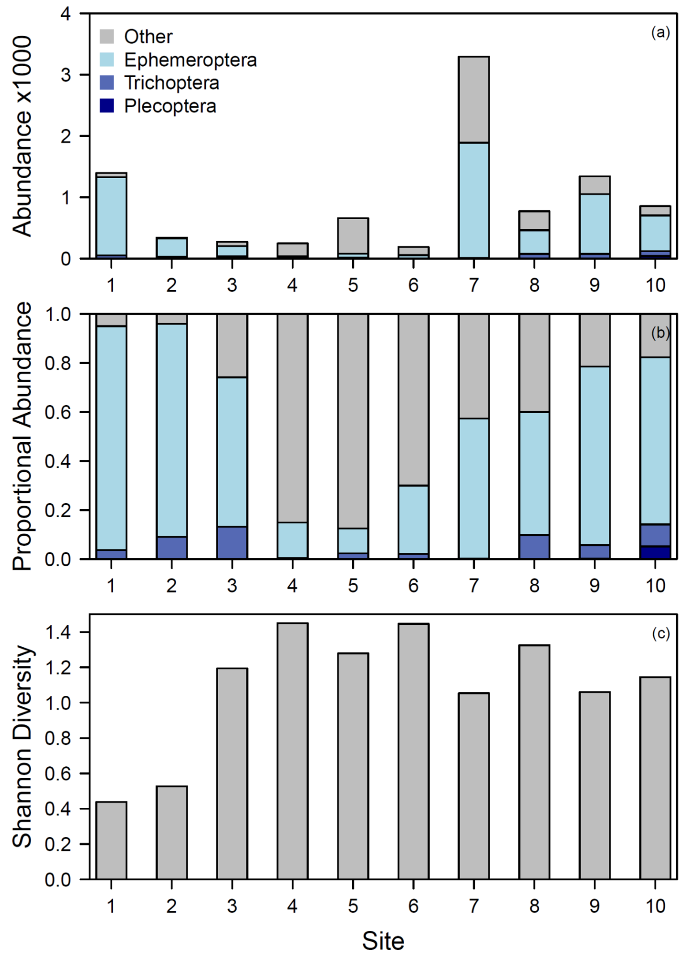

Figure 12. (a) Total abundance of aquatic invertebrate taxa collected during kick net samples at each site, with abundance of Ephemeroptera, Trichoptera, and Plecoptera (EPT taxa) represented by shades of blue. All other taxa are represented in gray. (b) Proportional contribution of EPT taxa to the total invertebrate abundance at each site. (c) Shannon diversity indices for the aquatic invertebrate community sampled at each site.

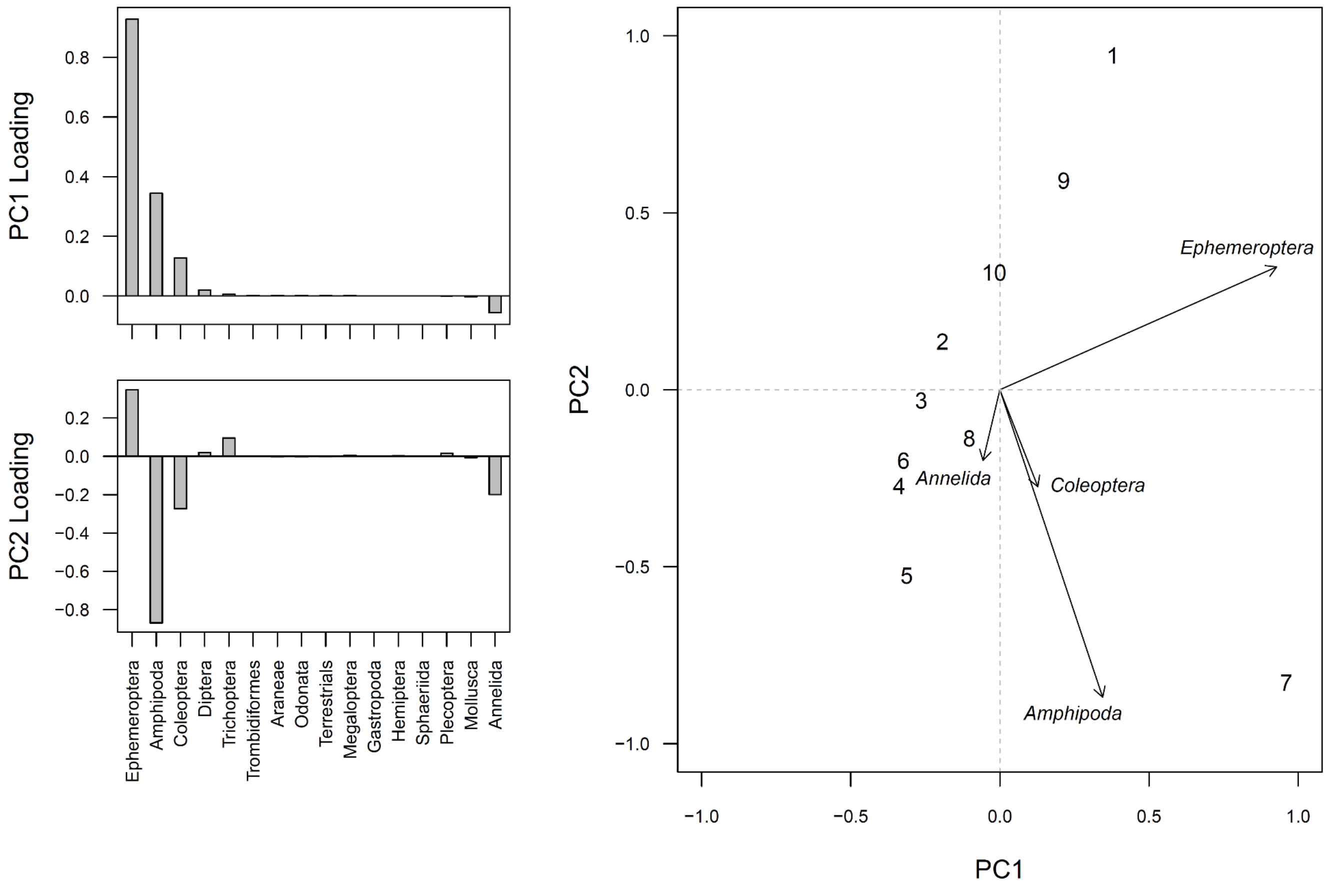

Figure 13. Principal components of aquatic invertebrate community composition among sampling sites. Left panels indicate the loading of individual taxa on each of the first two principal components. Right panel represents the first two principal components in bivariate space (only presenting vectors for the top four drivers as most taxa had little influence on the first two principal components), and the relative compositions of the different sampling sites. Sites closer together on the biplot contain aquatic invertebrate communities that are more similar than sites whose points are further apart.

Discussion

Understanding both the historical and current conditions of an ecosystem are critical for setting goals and determining success of restoration projects (Hobbs and Norton 1996; Wortley et al. 2013). North Eden Creek, like many of Bear Lake's tributaries, historically supported annual spawning migrations of Cutthroat Trout from the lake to the creek. Following the construction of roads, culverts, and upstream dams, this spawning migration was cut off, reducing the total available spawning habitat, as well as reducing the diversity of spawning habitats available to the Cutthroat Trout of Bear Lake. As this pattern was repeated in tributaries around the lake, the population of wild Cutthroat Trout dwindled until restoration activities began reconnecting historical spawning grounds to the lake (Heller et al. 2022). In preparation for the future replacement of the culvert at the crossing of North Eden Creek and North Cisco Road, we have compiled historical information and contemporary survey data of in-stream and riparian conditions of the system pre-restoration that can be used to assess the ultimate impacts of reconnection and any subsequent restoration activities in the creek.

Both the fish assemblage and the physical habitat conditions demonstrate distinct spatial patterns, with substantial sections of the creek demonstrating highly degraded and depauperate conditions. Both physical habitat and Cutthroat Trout abundance are in relatively good condition at the highest elevation sites, yet fish and complex habitats are lacking in the middle elevation reaches of the stream. Further, the culvert is blocking access to upstream habitats for large, adfluvial Cutthroat Trout from Bear Lake, and appears to be limiting the ability of other species, including other native species, from accessing the creek. By identifying these baseline conditions, we have set the stage for future research to examine whether and by how much conditions change following culvert replacement and any subsequent restoration actions.

Resident Cutthroat Trout of the relict population are currently limited to the highest elevation sites in North Eden Creek, and adfluvial trout from Bear Lake are limited to the ¼ mile of habitat downstream of the culvert at North Cisco Road. Further, no fish of any species were captured between sites 2 and 5, and only one Brook Trout was captured between sites 2 and 7, indicating extremely limited suitable habitats in this stretch of river. The lack of any fish in stream reaches immediately upstream of the culvert, despite the presence of complex, overhanging vegetation habitat and plentiful water in 2024, provides further evidence of the likely impassibility of this culvert. Removal of this barrier through culvert replacement would immediately open access to additional spawning habitat for adfluvial Cutthroat Trout. Additionally, it would provide access to tributary spawning habitat for the native Utah Sucker, which is abundant in Bear Lake and was captured downstream of the culvert in North Eden Creek in 2023. As the adfluvial Cutthroat Trout population in Bear lake responded rapidly to reestablishing connectivity to St. Charles, Fish Haven, and Swan Creeks on the western shore of the lake (Heller et al. 2022), allowing access to additional spawning habitat in North Eden Creek may produce further increases in abundance of these wild fish. Additionally, by increasing the number of distinct spawning tributaries available to adfluvial Cutthroat Trout in Bear Lake, restoring access to North Eden Creek may reduce the interannual variability in recruitment of wild Cutthroat Trout at the meta-population level through portfolio effects (e.g., Schindler et al. 2010; Brennan et al. 2019).

Notably, Cutthroat Trout were always found in the same habitat with Brook Trout. Brook Trout have repeatedly been demonstrated to negatively impact Cutthroat Trout abundance, growth, and recruitment throughout the Intermountain West (Peterson et al. 2004; McGrath and Lewis 2007). Previous research suggests Brook Trout have their greatest impact on age-0 and age-1 Cutthroat Trout, while having limited impact on age-2 and older Cutthroat Trout (Peterson et al. 2004; McGrath and Lewis 2007). Thus, the negative effects of Brook Trout on Cutthroat Trout appear to arise from competition with and predation on the youngest age classes of Cutthroat Trout. While the effects of Brook Trout on Cutthroat Trout can vary among streams (Dunham et al. 2004), managers may want to consider controlling the population of Brook Trout from North Eden Creek if they hope to maximize survival and recruitment of adfluvial Cutthroat Trout to the Bear Lake population and to increase abundance of the resident Cutthroat Trout population in North Eden Creek. Given the small size of North Eden Creek, mechanical suppression of Brook Trout by means of multiple pass electrofishing may be an effective control method, though it would likely need to be repeated periodically to maintain low densities (Peterson et al. 2008; Rytwinski et al. 2019). Additionally, suppressing Brook Trout in North Eden Creek would reduce the risk to native fishes presented by the population acting as a source for Bear Lake and other connected tributary habitats.

Resident Cutthroat Trout appear to be limited to the headwaters due to limited availability of complex habitats and elevated summer temperatures at mid-elevation sites. Most of the Cutthroat Trout we captured were found in undercut bank habitats, which were extremely limited in all but the three highest elevation sampling sites. Undercut banks can provide thermal refugia, as well as refuge from avian and terrestrial predators, which is particularly important in small shallow streams (Penaluna et al. 2021). These higher elevation sites also had boulder substrates available, which provide low-velocity habitats and can also serve as preferred refuge habitats for trout in small streams (Penaluna et al. 2021). Woody structure is very limited throughout North Eden Creek, likely reflecting the loss of riparian vegetation that has occurred over the past century of grazing and reservoir construction. As woody structure is an important component of in-stream habitat, creating hydraulic complexity that generates complex habitats (e.g., riffles, pools, bars; Gurnell et al. 2002; Johnson et al. 2005;), increasing the availability of wood for the stream may be an effective restoration strategy for managers to consider in the future.

Summer temperatures in the middle elevation reaches were substantially higher than those in high and low elevation reaches, potentially limiting the ability of Cutthroat Trout and Brook Trout to persist in these reaches. While estimates for Bear Lake Cutthroat Trout are limited, Cutthroat Trout have optimal growth temperatures between 10-16°C (Bear et al. 2007; Thomas et al. 2023; Ziegler et al. 2013), and begin to demonstrate lethal responses after chronic exposures to temperatures greater than 24.2°C (Johnstone and Rahel 2003) and acute exposures between 27°C and 29°C (Rogers et al. 2022). Our point measurement of temperature in site 6 in the afternoon of August 22, 2024, exceeded these critical thermal maximum estimates from the literature, and each of our middle elevation loggers experienced periods of temperatures exceeding the 7-d incipient lethal temperature threshold, indicating that these middle elevation reaches are likely unsuitable during the warmest periods of summer. However, while summer stream temperatures of these mid-elevation reaches may be unsuitable, the warmer but not stressful temperatures occurring in these reaches during spring and fall may provide increased growth opportunities relative to colder high and low elevation sites (Armstrong et al. 2021). As adfluvial Cutthroat Trout gain access to spawning habitat in North Eden Creek following culvert replacement, these warm mid-elevation reaches may become important for growth and survival of juvenile individuals. Additional restoration actions increasing the amount of complex habitats in these middle reaches could therefore benefit the growth potential of trout in North Eden Creek, providing predator refugia near areas of high growth potential during spring and fall, and potentially reducing the maximum temperatures experienced during the height of summer.

Overhanging riparian vegetation provides multiple benefits to stream fishes, including reducing water temperatures by shading the stream (Cross et al. 2013; Fuller et al. 2022) and increasing prey availability due to terrestrial insects falling into the stream (Kawaguchi and Nakano 2001; Baxter et al. 2005). In North Eden Creek, the vast majority of bank vegetation was found at the lowest elevation sites, being very limited in middle elevation sites. While we did not observe fish in all sites with overhanging bank vegetation, this likely reflects the inability of fish from habitats downstream of the culvert to access the sites immediately upstream of the culvert. The spatial distribution of bank vegetation likely reflects the result of grazing activities in the watershed, as cattle grazing frequently reduces riparian vegetation cover (Saunders and Fausch 2012). Restoration actions to increase overhanging bank and riparian vegetation may increase the habitat suitability of middle and higher elevation reaches for trout in North Eden Creek (e.g., Fuller et al. 2022). Riparian grazing exclosures (Saunders and Fausch 2012; Dauwalter et al. 2018), short duration rotational grazing (Saunders and Fausch 2007), and beaver dam analog construction (Pollock et al. 2014; Orr et al. 2024) represent potential approaches to increasing the distribution and abundance of riparian vegetation.

Aquatic invertebrates account for a large proportion of stream salmonid diets, and growth rates and production of stream salmonids is therefore related to the production and availability of invertebrate prey (Rosenfeld and Taylor 2009; Hannesdottir et al. 2013). As such, the relative abundance of aquatic invertebrates among sites can be used as an index of prey availability and growth potential for trout within different habitats. In North Eden Creek, aquatic invertebrate prey were more abundant at high elevation sites and below culvert than in middle to low elevation reaches. These results suggest middle and low elevation sites with reduced aquatic invertebrate densities may provide reduced growth opportunities for trout in North Eden Creek. However, we urge caution with this simple interpretation, as trout growth is impacted by more factors than prey availability alone (e.g., temperature; Leeseberg and Keeley 2014; Armstrong et al. 2021), the relationship between prey availability and predator abundance is not necessarily linear (e.g., Power 1992), and static measures of prey abundance (or biomass) are not equivalent to prey production and energy flow to predators (Jenkins 2015). As such, we recommend aquatic invertebrate monitoring data be used in conjunction with habitat and fish assemblage monitoring data to assess relative growth opportunities in different reaches. Additionally, future studies could incorporate aquatic invertebrate data into food web models to estimate production and consumption across different sites.

Aquatic invertebrate community composition is also frequently used as an index of habitat integrity in streams (e.g., Roy et al. 2003; Paulsen et al. 2008), and EPT taxa in particular are frequently used as an index of high quality coldwater habitats required by stream salmonids (Wallace et al. 1996; VanDusen et al. 2005; Stoddard et al. 2008). The relative abundance of EPT taxa among sites in North Eden Creek followed a similar pattern to total invertebrate abundance, but appeared to follow the distribution of silty habitats and temperatures more closely. Sites with greater contributions of silt substrate and in warmer sections of the river had reduced contributions of EPT taxa to their invertebrate communities than those sites with either more complex substrates, colder water temperatures, or both. Taken together, the physical habitat and invertebrate prey conditions in the middle elevation reaches of North Eden Creek suggest degraded habitat conditions that may limit these sites' capacity to support trout production even after culvert replacement allows adfluvial Cutthroat Trout to access these habitats. Therefore, in-stream and riparian habitat restoration may be required in these reaches to realize increased trout production across the full length of North Eden Creek.

Following the replacement of the culvert on North Eden Creek at North Cisco Road, we anticipate greater connectivity between the lake and tributary habitats. Adfluvial Cutthroat Trout, currently limited to habitats downstream of the culvert, would be able to migrate farther upstream to spawn. This would increase the total area of spawning gravels available to adfluvial individuals, reducing competition for spawning habitat, and increasing total potential production of age-0 Cutthroat Trout from the creek. We would also expect the abundance of small Cutthroat Trout to increase in the lower elevation reaches of the creek, as offspring of adfluvial Cutthroat Trout rear in the stream temporarily before migrating to the lake, and some may remain as resident life history variants in the stream as seen in other salmonids (e.g., Berejikian et al. 2014; Ferguson et al. 2019). Additionally, we anticipate immigration of other species which are currently blocked from accessing the creek by the culvert, including native Utah Sucker during their spring spawning season. While we anticipate substantial changes to the distribution and abundance of fishes in the lower reaches of North Eden Creek, we do not anticipate culvert replacement to have major effects on in-stream habitat conditions except in the immediate vicinity of the culvert. As such, fish populations in mid-elevation reaches will likely still be limited by the availability of complex habitats and patches of stressful thermal conditions. Improving conditions in these reaches for fish will likely require further restoration efforts, such as grazing exclosures (e.g., Bayley et al. 2008; Dauwalter et al. 2018), construction of beaver dam analogs (e.g., Bouwes et al. 2016; Weber et al. 2017), and re-introduction of beavers (e.g., Kemp et al. 2012; Needham et al. 2021). Such process-based restoration approaches may ultimately increase the recruitment of wood to the stream, increasing hydraulic complexity, and thus habitat complexity in the stream (e.g., Pollock et al. 2014; Bouwes et al. 2016), ultimately supporting the expansion and growth of fish populations.

Stream restoration projects can provide substantial conservation benefits to species experiencing declines due to habitat degradation, and restoration actions targeting the removal of migration barriers have proven particularly beneficial (Duda et al. 2021; Pess et al. 2023; Anderson et al. 2019; Heller et al. 2022; Clark et al. 2020). However, determining the effectiveness of any restoration actions requires an understanding of how the system responds, necessitating effective monitoring both prior to and following the restoration action (Palmer et al. 2005; Kroll et al. 2019). Previous projects reconnecting spawning tributaries to Bear Lake have been highly successful at increasing the abundance of wild, adfluvial Cutthroat Trout (Heller et al. 2022), suggesting further reconnection of habitats will continue to benefit this unique population. The baseline information we have gathered here sets the stage to allow assessment of the impacts of the planned culvert replacement at North Eden Creek. If the monitoring surveys described herein and in our Proposed Monitoring Plan (Appendix A) are repeated every 1-3 years, changes in distribution, abundance, or size structure of Cutthroat Trout and other fishes, in-stream habitat conditions, and/or prey abundance can be determined, and management actions can be adapted as necessary. Further, lessons learned through long-term monitoring of North Eden Creek following culvert replacement can provide insight for similar projects elsewhere.

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Appendix A: Proposed Monitoring Plan

The following monitoring plan has been designed to assess the response of the stream habitat, fish community, and aquatic invertebrate community to proposed restoration efforts in North Eden Creek, Utah, a tributary of Bear Lake. Monitoring should occur every 2-3 years for the standardized fish, habitat, and invertebrate surveys, and annually for redd counts and spawning migration counts.

Standardized Sample Sites

Standardized fish community, aquatic invertebrate, and physical habitat surveys will occur at ten standardized sites, each consisting of a 300m reach of stream arranged along an elevational gradient from downstream of the culvert at North Cisco Road near Bear Lake to the headwaters of North Eden Creek (Table A1; Fig. A1). Sites will be sampled following the peak of spring runoff during sample years.

Fish Surveys

At each standardized survey site, crews will conduct single pass electrofishing of the full 300m reach. All fish captured will be identified to species, the first 50 individuals of each species at each site will be measured (total length), and the first 30 individuals of each species at each site will be weighed (g). We recommend conducting three-pass depletion estimates via electrofishing at at least one site each sampling year to estimate catchability, thus allowing single-pass surveys to produce estimates of total abundance. If resources allow, three-pass depletion surveys should be conducted at each site each sampling year.

Additionally, we recommend annual redd counts and/or fish traps be used to assess the abundance of adfluvial spawners in the system once the culvert has been replaced to allow passage. Ideally, redd counts would occur multiple times at each site throughout the Cutthroat Trout spawning season (late April through mid-July) to assess temporal change and estimate total spawner abundance throughout the spawning season. However, if resources are limited, single redd counts conducted at a consistent time across sites and years can provide an index of relative abundance. During redd counts, crews will walk the banks of each reach to visually identify, count and note the location of all trout redd clusters. At each redd cluster crews will note the number of redds in the cluster and an index of redd age (1-3 from fresh to old). In addition to conducting redd counts at each standardized sample site, we recommend crews conduct redd counts for the entire length of stream upstream of North Cisco Road to identify the presence of redds upstream of the soon to be removed culvert barrier.

Operating a fish trap or weir to capture upstream migrating adfluvial Cutthroat Trout in conjunction with redd surveys can help develop a relationship between redd counts and number of spawners present in the system (e.g., Baldock et al. 2023). The fish trap would have the added benefit of capturing any upstream migrating Utah sucker, allowing for characterization of this native fish's spawning behaviors and abundance in North Eden Creek. The fish trap should be installed prior to the peak of spring runoff and operated throughout the descending limb of the hydrograph. Crews will check the trap at a minimum once daily, identify all captured fish to species, measure and weigh all individuals, and insert PIT tags into all Cutthroat Trout. Alternatively, counts of adfluvial fish passing weirs from a subset of days across the spawning period can be used to estimate total run size using hierarchical models (e.g., Adkison and Su 2001; Walsworth and Schindler 2015; Walsworth et al. 2024).

Physical Habitat Surveys

At each standardized sampling site, crews will survey bankfull width, wetted width, thalweg depth, and dominant substrate at each of ten evenly-spaced transects. Dominant substrate will be determined visually from the categories cobble, gravel, silt, sandy silt, silty gravel, and boulders. If in-stream habitat restoration actions are proposed, more detailed substrate monitoring may be warranted, such as Wohlman pebble counts, wherein ten individual sediment particles would be measured from each of the ten transects using a gravelometer.

Crews will visually estimate the total percentage of the entire 300m reach containing overhanging vegetation and undercut bank habitats. Additionally, crews will enumerate the number of woody structures in the river, counting all pieces of wood larger than 0.3 m in length.

Continuous temperature monitoring from multiple locations along the length of North Eden Creek will be collected via temperature loggers. At a minimum, loggers should be placed at the locations noted in Table A2 (Figure A1), though additional loggers may help identify the presence of further thermal heterogeneity in the system.

Aquatic Invertebrate Surveys

At each of the standardized sampling sites, crews will collect an aquatic invertebrate sample using the kick-net sampling methodology adapted from standard protocols for sampling macroinvertebrates in wadeable streams in New Zealand (Stark et al. 2001). Crews will position a standard 500 um mesh D-frame kick net within a representative portion of the stream, holding the net vertically upright with the base of the frame in contact with the substrate and the open portion of the net facing into the flow. The collector will then stand approximately 60 cm upstream of the net and kick for one minute using a stopwatch. The net will then be removed from the water and immediately emptied into a tray and rinsed clean to ensure all macroinvertebrates collected were captured before being placed into a jar. Samples will be preserved in ethanol and returned to the lab for sorting and identification. In the lab, all aquatic invertebrates will be sorted, identified to at least order, and counted. Samples can then be characterized for the relative abundance of different taxa across sites, and relative abundance of EPT (Ephemeroptera, Trichoptera, Plecoptera) taxa across sites.

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