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Prospects and Constraints for a Recreational Fishery on East Canyon Creek at the 910 Ranch

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910 Cattle Ranch, an 8,576-acre property north of Jeremy Ranch, Credit: Summit County.

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Introduction

Summit County Lands and Natural Resources has retained students from Utah State University's Management and Restoration of Aquatic Ecosystems program to evaluate current conditions of East Canyon Creek (ECC) in the 910 Ranch and propose prospects, constraints, and potential actions to establish a recreational trout fishery.

910 Ranch

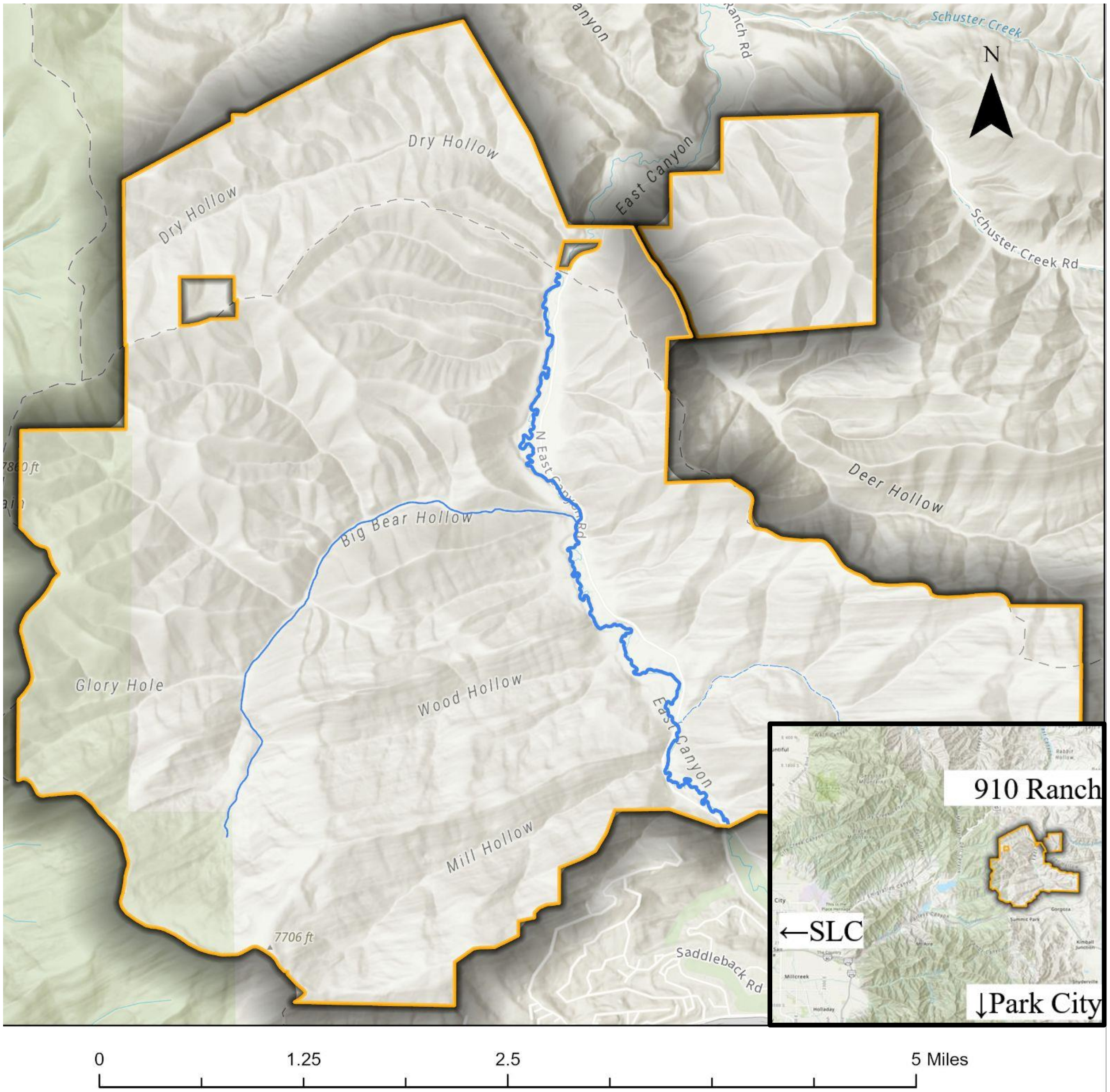

Figure 1. Map of the 910 Ranch

The ECC watershed drains approximately 375 km^2, including multiple large ski areas, as well as Park City, Utah. The ECC watershed has a long history of land use and development, leading to a number of water quality issues (SWCA, 2010). Non-point source pollution comes from urban runoff, bank erosion, and agricultural runoff. Flow in the creek is reduced through numerous diversions for municipal water use and agricultural irrigation. Significant increases in population within the watershed have occurred in recent decades, and are projected to increase to 86,000 by the year 2050 (a 358% increase from 2001) (SWCA, 2010). This population increase is likely to increase challenges for both water quantity and quality. Beneficial uses (as designated by the State of Utah) for ECC are primary contact recreation (2A), secondary contact recreation (2B), cold water fishery (3A), domestic drinking (1C) and agriculture (4). Water quality standards for these uses have largely not been met. Factors contributing to poor water quality include lack of shade and high sediment loads, leading to impairments in dissolved oxygen (3A) (SWCA, 2020).

The 910 Ranch lies on a portion of the ECC watershed that is now under contract to be sold to and managed by Summit County for public use as a recreation area. It spans 8,567 acres and has been managed for cattle since the 1860s. Historic private ownership has limited public fishing access to ECC. This property's acquisition presents an opportunity for Summit County to restore a public-access cold water fishery. ECC formerly supported a native Bonneville Cutthroat Trout (*Oncorhynchus clarkii utah*, hereafter BCT) population (SWCA, 2010). However, their presence in the system has significantly declined (SWCA, 2010) At present, a small population of Brown Trout (*Salmo trutta*, hereby BNT) exists in ECC (SWCA, 2010). The objective of this report is to characterize the feasibility of establishing a sustainable recreational trout fishery on ECC within the 910 Ranch.

This report presents an assessment of the current status of the ECC fishery and site conditions, culminating in an assessment of factors limiting the trout population. We evaluate the outcome of previous restoration actions, followed by an evaluation of potential restoration actions that could be taken to improve and maintain a sustainable trout fishery on ECC within the 910 Ranch.

Assessment of Current Fishery

Performing an assessment of current fish populations in ECC is essential to guide an investigation of limiting factors of a recreational fishery. Here we characterize the status of fish populations at the 910 Ranch through empirical population metrics. Additionally, we present a comparison of ECC with nearby fisheries and blue ribbon fishery standards to provide context for ECC's fishery status relative to other Utah fisheries.

Methods

Our assessment of the current fish population within ECC is based on three sampling campaigns, using double pass electrofishing (herein e-fishing). As part of a larger graduate research project, Wolf (2023) sampled natural beaver complexes (NBC), beaver dam analogues (BDA), and control sites (CON) on ECC within the Swaner Preserve from 2019-2021. E-fishing was also conducted on ECC at the Jeremy Ranch Golf Course (JRGC) in October of 2022 in a collaborative effort between the Utah Division of Wildlife Resources (UDWR) and Snyderville Basin Water Reclamation District (SBWRD). Finally, Clint Brunson of UDWR, together with USU students and other volunteers, conducted e-fishing on ECC on the 910 Ranch in October 2023. Population estimates, densities, percent representations, and length frequencies were determined for the three data sources. Population estimates and densities were provided by UDWR, SBWRD, and Wolf (2023). Percent representation from UDWR and SBWRD's raw data was found by dividing the total capture of a specific species (i.e BNT) by the overall capture of all fish in each survey, multiplied by 100. Age estimations were made by creating length frequency graphs, which compare the number of times different lengths were documented within data sets, and a baseline range of correlating ages and lengths found in Wolf (2023).

Additionally, we assessed the current status of the ECC fishery using the Hepworth-Walker Scale (developed by the Blue Ribbon Fishery Advisory Council). We then compared the current densities of BNT to other notable BNT fisheries in Utah. The following sites and sources were used in these calculations: Strawberry River from Birchell and Hedrick (2019); Wolf Creek and the Duchesne River form Birchell and Hedrick (2021); Rock Creek from Birchell and Hedrick (2017); Currant Creek from Hedrick and Birchell (2017); Diamond Fork from Smith (2006); Blacksmith Fork from UDWR (2021), Spring Creek from Tyler Coleman and Matthew Mckell (Personal Communication, Oct 18th, 2022); and Temple Fork from e-fishing data collected in 2020 and 2021. Lastly, we computed the proportional stock density (PSD) of the sampled BNT at both JRGC and the 910 Ranch. All PSD calculations were performed in R (version 4.3.2) using the "FSA" package developed by Ogle (2022). Length categories for BNT PSD were derived from Gabelhouse (1984).

Photos of Bonneville Cutthroat Trout [Native] (Above) and Brown Trout [Non-Native] (Below), Credit: Tyler Coleman.

Results

In the October 2023 sample from ECC on 910 Ranch, 3,181 total fish were captured, five of which were BNT, or 0.16% of the total number of fish sampled. Other species collected in this survey were Mottled Sculpin (MSC, 6.29%), Redside Shiner (RSS, 69.60%), Speckled Dace (SPD, 4.43%), Mountain Sucker (MTS, 9.43%), Fathead Minnow (FHM, 0.06%), and Long Nosed Dace (LND, 0.03%). In the Jeremy Ranch sample, a total of 150 fish were captured, of which 25 were BNT (16.67%). Other species present were: BCT (0.67%), MSC (22.67%), MTS (21.33%), RSS (12.00%), Utah Sucker (UTS 6.67%), and SPD (20.00%).

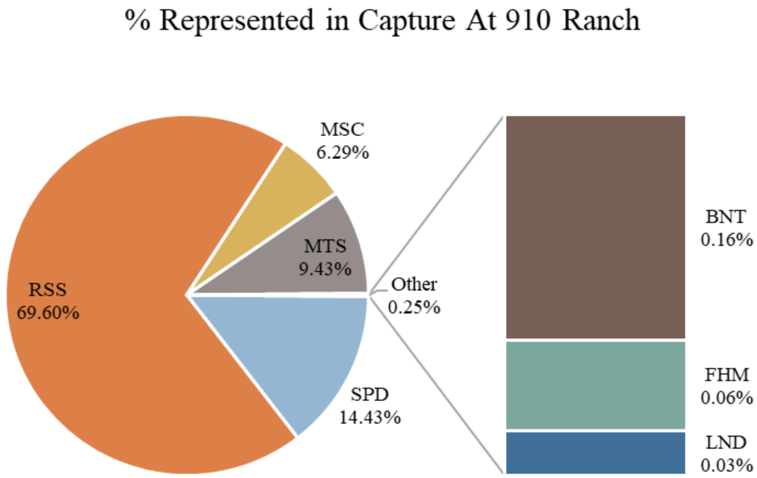

Figure 2. The percent representation of species in e-fishing capture from ECC on the 910 Ranch (3,181 fish).

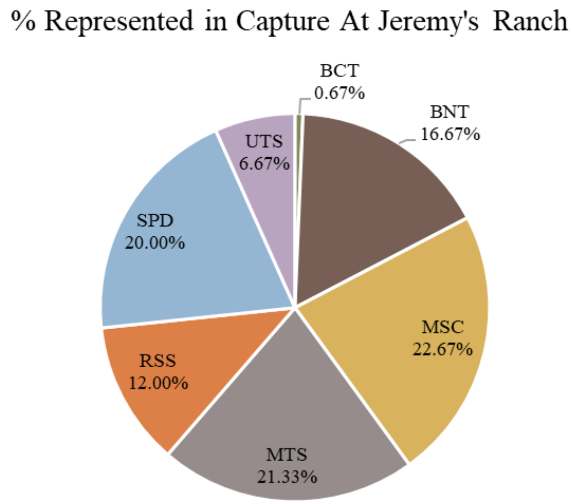

Figure 3, The percent representation of species e-fishing capture from ECC on JRGC (150 fish).

As with **Figures 2 & 3**, **Table 1** shows the mean capture of BNT at each sampled location in ECC. Higher BNT abundances were observed at the upstream sites and progressively decreased downstream. Wolf's sites, NBC, BDA, and CON had a combined population estimate of 65 fish (2023). The JRGC data shows lower BNT abundance estimates of 26 fish, and 910 Ranch as 5 fish. Similarly, **Table 2** shows densities of BNT in the ECC data from the 910 Ranch and JRGC. Data needed to calculate densities were not available from Wolf (2023). 910 Ranch had 44 BNT/km, and JRGC had 226 BNT/km.

Table 1. Mean capture counts from three separate e-fishing data sets.

Site	Mean	SD
NBC	35.50	5.90
BDA	16.80	9.69
CON.	13.00	7.00
JRGC	25.94	2.85
910 R.	5.00	0.00

Table 2. BNT densities from the JRGC and 910 Ranch surveys.

Site	Fish/mi	Fish/km	Fish/100m²
JRGC	363.03	225.58	3.32
910 R.	71.00	44.00	0.69

Comparatively, JRGC had a higher BNT density than 910 Ranch. The sampling effort at the 910 Ranch only detected five BNT and no BCT. Of the BNT, the observed length frequency distribution included age-3 (200-300 mm), age-4 (300-400 mm), and age-5+ (lengths ≥ 400 mm) fish (**Figure 4**). The fish sampled at JRGC display more age variation in the BNT populations (**Figure 5)**. Age estimates for BNT were young of year (YOY) fish measuring 0 – 50 mm, age-1 fish (juvenile) ranging from 50-150 mm, age-2 (spawning adult) spanning 150-200 mm, age-3 measuring 200-300 mm, age-4 fish ranging from 300-400 mm, and age-5+ fish measuring greater or equal to 400 mm. The singular BCT captured at JRGC age estimate was age-3 at 285 mm.

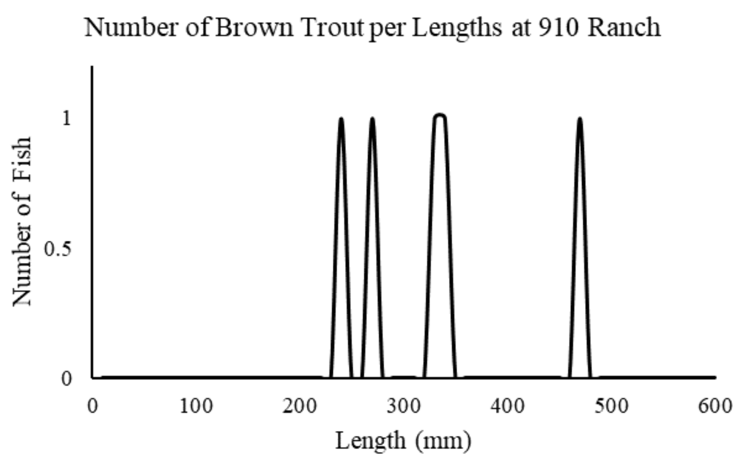

Figure 4. Frequency of BNT lengths from the 910 Ranch. There are potentially three age ranges represented: age-3 (200-300 mm), age-4 (300-400 mm), and age-5+ (lengths ≥ 400 mm). The third curve is doubled the width of the other curves and represents two fish of similar length.

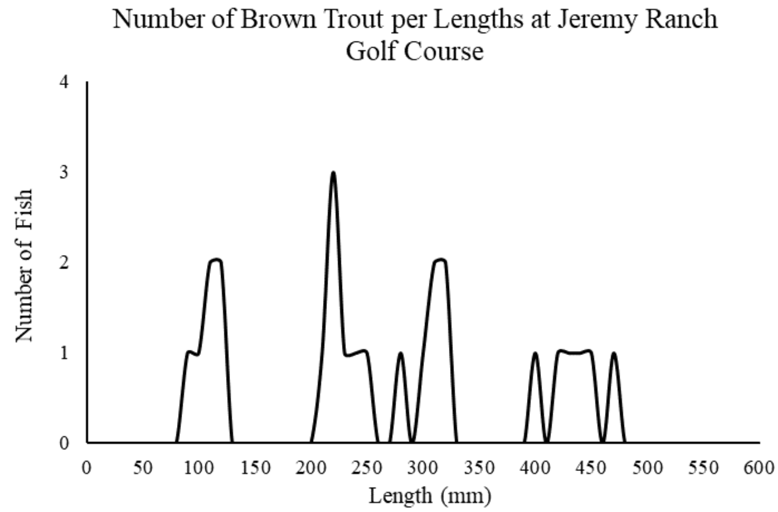

Figure 5. Frequency of BNT found in the JRGC. Age-0 – 5+ are all represented in the lengths collected [YOY (0-50 mm), age-1 (50-150 mm), age-2 (150 – 200 mm), age-3 (200-300mm), age 4(300-400mm), and ages 5+ (lengths ≥ 400 mm)].

Discussion

Greater capture means, representation ratios, and population densities of BNT in upstream reaches indicate a higher fitness relative to downstream stretches; in other words, there are larger populations of BNT upstream than on the 910 Ranch. If habitat utilization is considered a proxy for habitat quality, these findings suggest that upstream habitat in ECC is more suitable for BNT survival and growth.

Beyond densities, age structure provides valuable information about the resident fish populations. All five BNT documented in the 910 Ranch were longer than 200 mm, indicating all fish were aged 3+ (**Figure 4**). There are only four peaks in the distribution, as the lengths between two fish were similar, so the width of the curve is doubled. No YOY, Age-1, or Age-2 BNT were detected in the 910 Ranch, suggesting that a recruitment bottleneck is present, meaning there is little to no young fish replacing older fish. The presence of older trout in the 910 Ranch sample suggests the possibility that the sampled fish did not spawn in 910 Ranch but instead originated from upstream habitat, where higher BNT populations and recruitment are documented. There are more age classes observed at JRGC (**Figure 5**). With fish smaller than 100 mm and greater than 400 mm present, there are at least five age classes of BNT in the upstream stretch (**Figure 5**). However, the low abundance of BNT adults and YOY suggests that a recruitment bottleneck may be present system wide. This observed bottleneck suggests the conditions for either spawning or egg incubation are unsuitable for recruitment. Therefore, our limiting factor analysis will evaluate conditions across life stages to detect whether habitat impairment could be producing the observed recruitment bottleneck.

Our evaluation of Blue Ribbon Fishery status indicates that the BNT fishery at 910 Ranch is in poor condition. Out of 83 possible points, a creek must score a minimum of 55 points (for creeks with an average width less than 15 feet) to be considered for blue ribbon fishery status. ECC scored 43 points. To be considered a Blue Ribbon Fishery, defined standards, including size and density of game fish, access, habitat quality and water quantity must be met. ECC scored relatively high for access (9 out of 13 possible points), but significantly lower for fishery status and environmental quality (18 out of 36 possible points and 16 out of 28 possible points, respectively). For an in-depth explanation of metrics used to rank fisheries, see the Utah Blue Ribbon Waters Rating System (2020). While no specific criteria of fish density or size are outlined by this scoring system, Wyoming Game and Fish designates fisheries as Blue Ribbon if they support in excess of 600 lbs of fish per mile (373 lbs/km). ECC currently supports 64.52 lbs of BNT/mile (40 lbs/km), suggesting a nearly 10 fold increase in sport fish biomass is needed to achieve a high quality recreational fishery. Moreover, BNT densities in other rivers nearby tend to be significantly higher than ECC at 910 Ranch, with the 910 Ranch section of ECC falling well below any of the other fisheries by an order of magnitude (**Figure 6**).

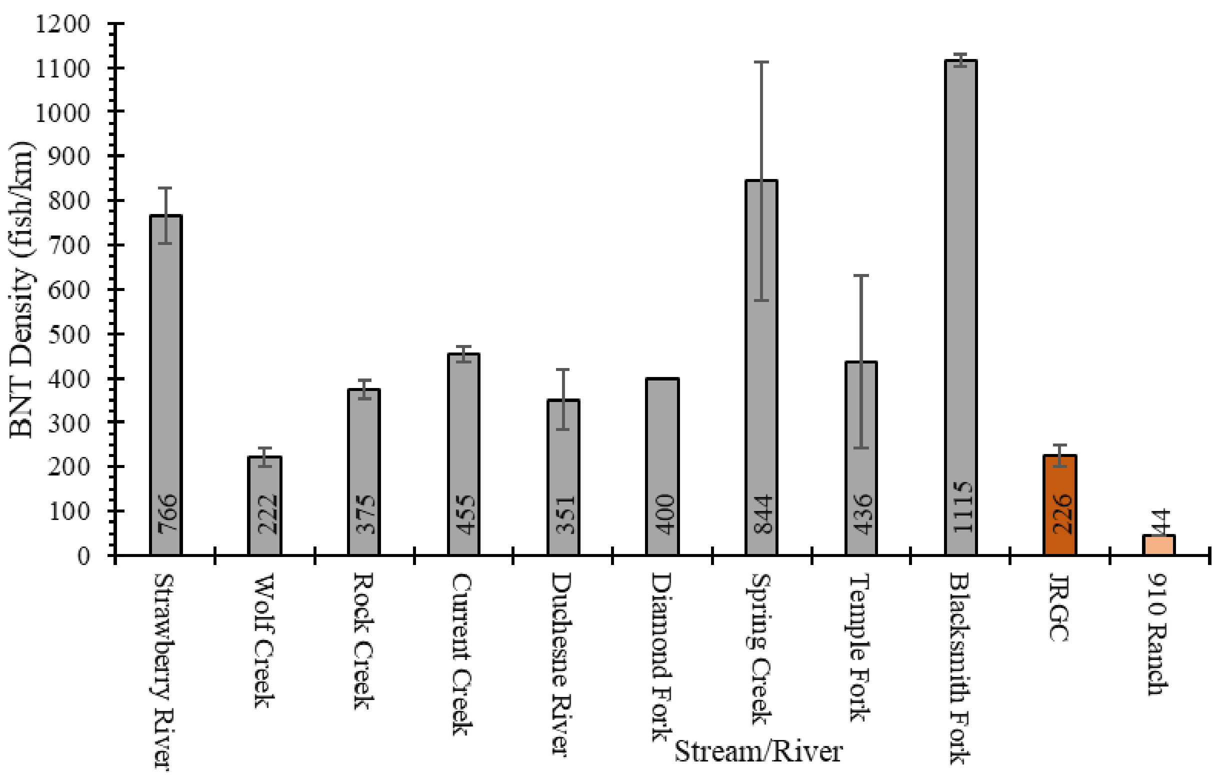

Figure 6. Comparison of estimated BNT density to other Utah BNT Fisheries with available BNT density point estimates. Height of the columns represent the estimated density and the error bars represent the 95% CI. See methods for data sources.

We calculated proportional stock densities at various sites in ECC (**Figure 7**) to assess quality of fish size. We found that, while densities at 910 Ranch are low, the proportional stock density of "preferred" and "memorable" fish is high according to the fish size classification by Gablehouse (1984). This suggests that if fish are caught by anglers, the quality (i.e. size) of the fish is likely to be high. Jeremy Ranch has lower proportions of stock, quality, and preferred fish.

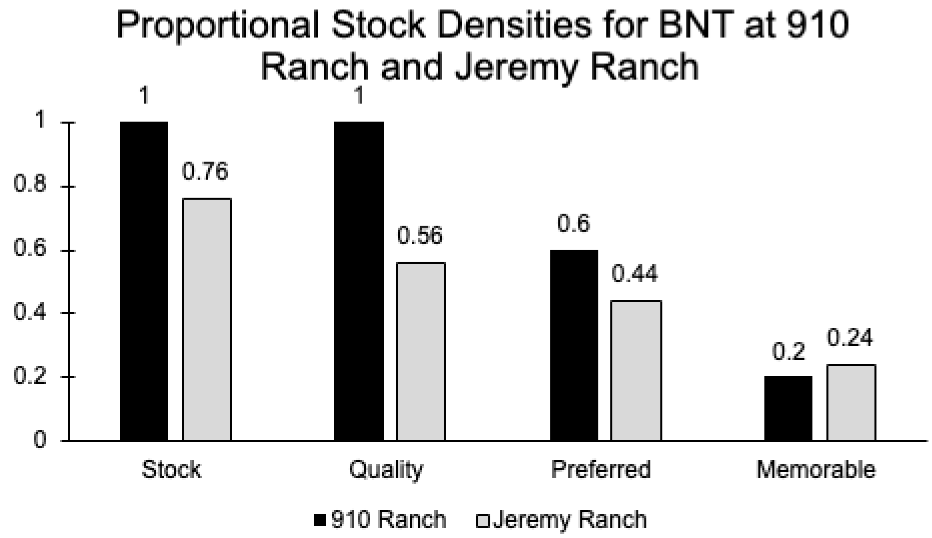

Figure 7. Proportional Stock Densities of sampled BNT at two sites: 910 Ranch and the upstream JRGC. Length categories, in inches, (from Gabelhouse 1984) for stock, quality, preferred and memorable fish are: 7.8-10.1 (198-256 mm), 14.0-15.9 (355-406 mm), 17.5-21.4 (446-544 mm), and 23.0-24.9 (584-632 mm), respectively.

Limiting Factor Analysis

The principles of limiting factor analysis arise from two foundational studies. Hutchinson (1957) classified the concept of the fundamental niche as the envelope of all environmental parameters that an organism can theoretically persist in. A fundamental niche is composed of a number of factors that combined together compose the range of areas and habitats a species can persist in. The second critical piece is Liebig's (1840) theory, "Law of the Minimum". Liebig discovered that the growth of plants, even with an excess of other nutrients, was limited to the productivity level of whichever nutrient was deficient (Smith, 2009). Therefore, Liebig theorized that the productivity of an organism [and by extension, its population] is NOT based on the sum of the available resources, but by whichever resource is the most scarce (Smith, 2009). This ecological law has withstood intense scientific scrutiny, especially in aquatic ecosystems (Smith, 2009).

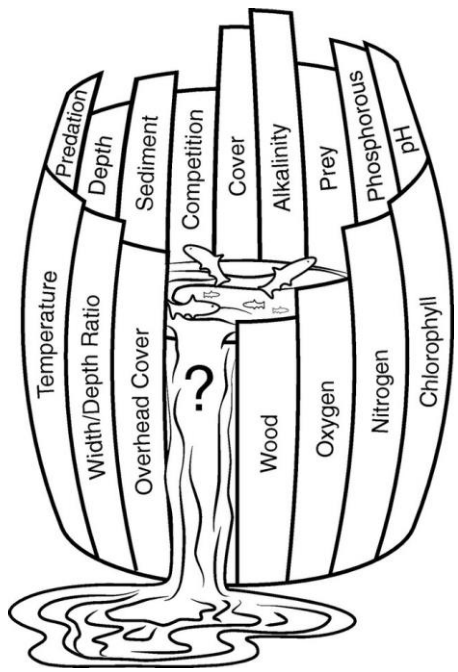

Figure 8. Liebig-Sprengel's Barrel illustrates various factors that affect fish populations, from Wurtsbaugh et al., (2015). The lowest plank would represent the limiting factor for the given population.

Summit County's goal for ECC in the 910-ranch is to improve the local salmonid population. Implementing restoration that improves some subset of factors but does not address THE limiting factor will fail to achieve an increase in the population. If the limiting factor is not addressed, the time and effort spent on implementing restoration practices will result in project failure. As found earlier within our study, ECC has a current bottleneck to recruitment for the present BNT population. Therefore, we assessed the three most likely limiting factors that have been identified in prior research as contributing to a recruitment bottleneck: low Dissolved Oxygen [DO], high summertime stream temperatures, and fine sediments (Baker et al., 2008: SWCA, 2010).

Methods

To determine which factor(s) may be limiting the BNT and BCT populations, we first compared the current regimes of water temperature and DO concentration (data from two USGS gauge stations; **Figure 9**) to the tolerances at each salmonid life stage. Dissolved oxygen and temperature (7-day rolling mean) were compared to the 7-day LC_{50} (Median Lethal Concentration) and the 7-day LT_{50} (Median Lethal Temperature) of each life stage for both species (Chapman, 1988: Johnstone and Rahel, 2003: Rombough, 1997: Siamlek et al., 2021). The LC_{50} and LT_{50} represent thresholds at which 50% of the population will die over a 7-day period. LC_{50} and LT_{50} values were not available for early BCT life stages. Therefore, we used early life stage values from a closely related species, Rainbow Trout (*Oncorhynchus mykiss*, herein RBT). For adult BCT LT_{50} we used the value (24.7℃) (Johnstone and Rahel, 2003). For adult BNT LT_{50} we used (24.7℃) found by Elliott (1981) for BNT. Adult BCT LC_{50} is 2.34 mg/L (Wanger et al. 2001), and Adult BNT LC_{50} is 2.0 mg/L (Hicks, 2002). For egg-to-emergence LT_{50} for BCT, we used 17℃ found in Rombough (1997), and we used (12℃) for BNT (Siamlek et al., 2021). Additionally, for BCT egg-to-emergence LC_{50} we used 6 mg/L found in Chapman (1988), and 5.5 mg/L for BNT (Siamlek et al., 2021).

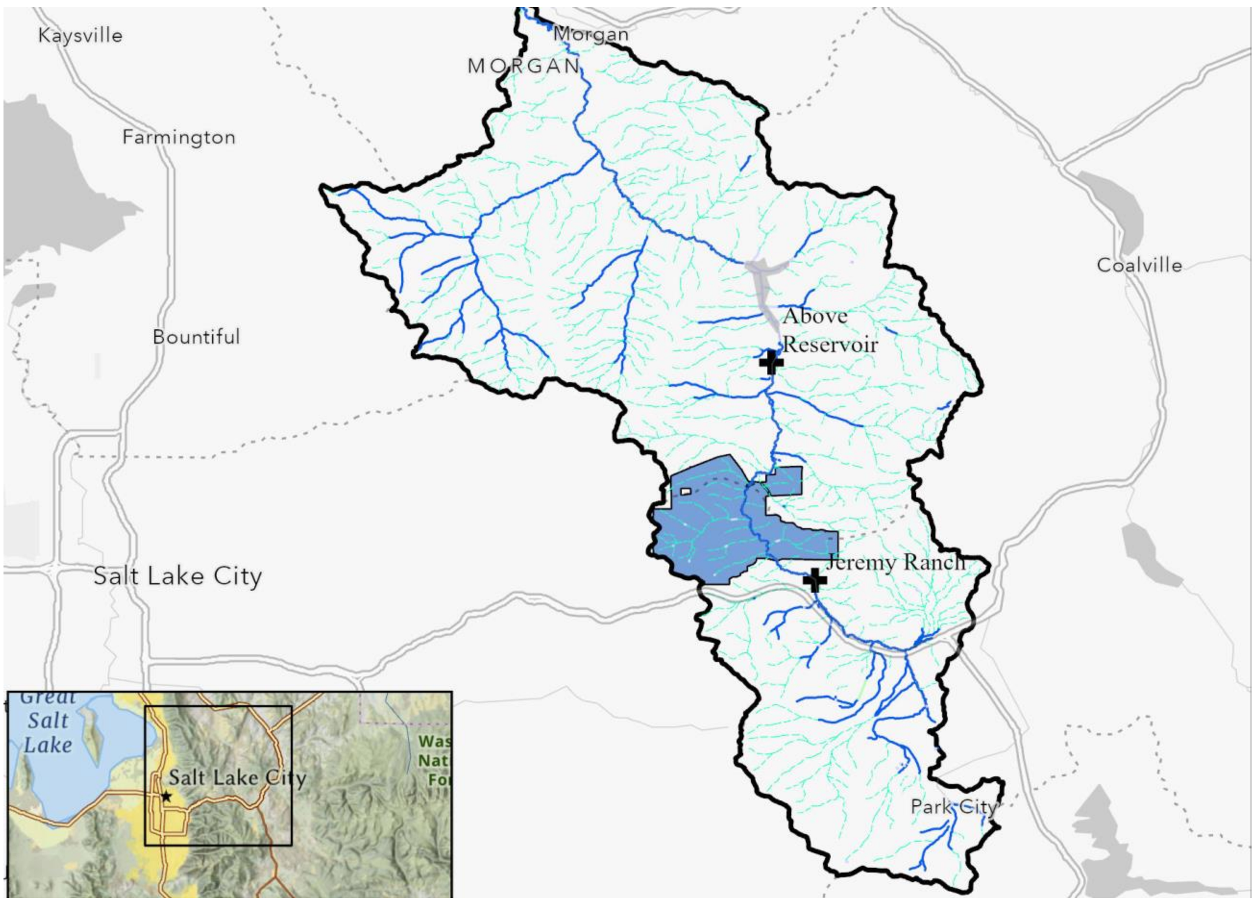

Figure 9. Map of USGS Gaging Stations used for Daily DO and Stream Temperatures relative to the 910 Ranch.

To characterize the exposure risk of eggs and alevins to incompatible DO and/or temperature, we estimated the expected time from oviposition (egg placement) to emergence using literature-derived values for spawning initiation and degree-day calculations. Incubation times for BNT and BCT were calculated using daily average temperatures from each gauge. Emergence dates assume oviposition for BNT begins on November 1st of each year and requires 410 - 456 degrees days of growth to emerge (Siamlek et al., 2021). Calculations used 0℃ as the lower threshold of a growing degree day, based on the absolute minimum value presented in the literature (Siamlek et al., 2021). Oviposition dates for BCT were determined by selecting the first day of the year with a mean daily temperature greater than or equal to 7℃. This number was determined by taking the average range of spawning temperatures presented in the literature (4℃ - 10℃) (Kershner, 1995). Emergence for BCT was assumed to take 310 - 345 degree days of growth-to-emergence based on the widest range of possible values found in the literature (Kershner, 1995).

Additionally, to characterize whether surface sediment could be limiting recruitment, we compared the ranges of suitable substrate grain-size for BCT and BNT spawning relative to the surface sediment distribution at the property. We performed Wolman Pebble Counts at random intervals along the length of the stream (n=12) within the 910 Ranch property (**Figure 10**). At each transect we randomly collected at least 100 substrate samples and used a gravelometer to classify sediment by grain size. We then compared the distribution of grain size for each site relative to suitable ranges derived from the literature for BCT and BNT.

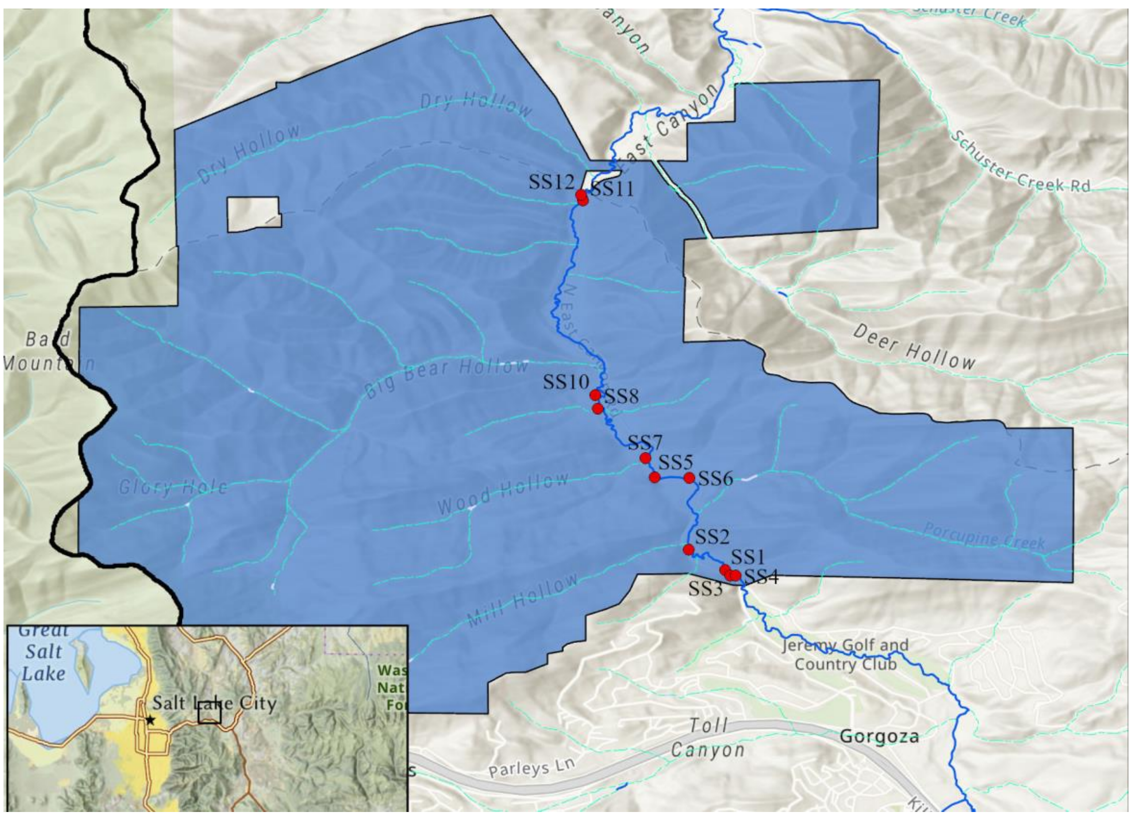

Figure 10. Map of surface sediment transects relative to the 910 Ranch property.

Lastly, we investigated the grain size of the river bed subsurface for potential impacts of egg incubation. To do so, we collected 2 random sediment samples from observed BNT Redds and 2 control samples from the bed adjacent to the redds using a 30 cm bed core apparatus. The redd samples were collected from the redd tail-spill, where eggs are deposited for incubation (**Figure 11:** Siamlek et al., 2021). The sediment cores did not extend deeper than 22 cm, which is reported to be the maximum depth of oviposition for BNT (Siamlek et al., 2021). We calculated the proportion volume of each substrate grain size via sieve separation and volume displacement in water for each core sample. We then assessed potential impacts of fine sediment accumulation on the egg-to-emergence survival within the redds via a review of the available literature. We compared fine sediment accumulation values to the observed effects of fine sediment on BNT and BCT egg-to-emergence survival in the available literature.

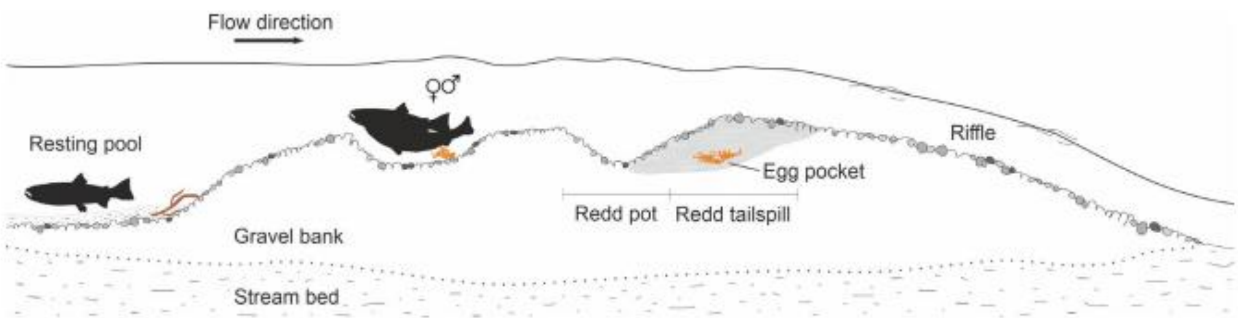

Figure 11. Longitudinal diagram of BNT redd, from Siamlek et al., (2021). The redd tail spill is the location where the sampling of redd sediment distributions where collected.

Results and Discussion

Our incubation-duration model predicted that BNT mean annual emergence dates ranged from March 16th until March 26th near the Jeremy Ranch gauge, and from April 18th until April 23rd near the Above Reservoir gauge. All predicted oviposition dates were assumed to be November 1st. Additionally, our model for BCT predicted the mean annual oviposition day as April 3rd and predicted emergence to occur on average between May 10th and May 13th near both gauge sites. Spawning behaviors of BCT are more temporally variable than BNT. The dates presented for BCT represent the earliest expected spawning and emergence. However, our findings of the rapid growth and emergence for BCT are supported by Merriman's (1939) study which found that BCT egg-to-emergence timing can vary by 28 to 57 days depending on temperatures, with warmer conditions shortening time to emergence.

Neither DO nor temperature exceeded the tolerance of adult BCT or BNT at both sites (**Figure 12, 13, 14, 15**). Likewise, during the estimated periods of incubation, neither DO nor temperatures exceeded the LT_{50} or LC_{50} of either BCT or BNT (**Figure 12, 13, 14, 15)**, suggesting that neither DO nor Temperatures are dominant limiting factors at either life stage for both species. However, it is important to note that both UILT and LC_{50} can vary between populations and are based on acclimation regimes. So, the true value for ECC may differ from the critical thresholds used here. Therefore, further research into developing these ECC-specific critical threshold values will reduce uncertainties between our estimates and the population parameter. However, given this study's time limitations, we used the most applicable values for the site with the available current literature. Although our findings suggest that neither DO or temperature is a dominant limiting factor, improvement in either factor could improve/// the fishery.

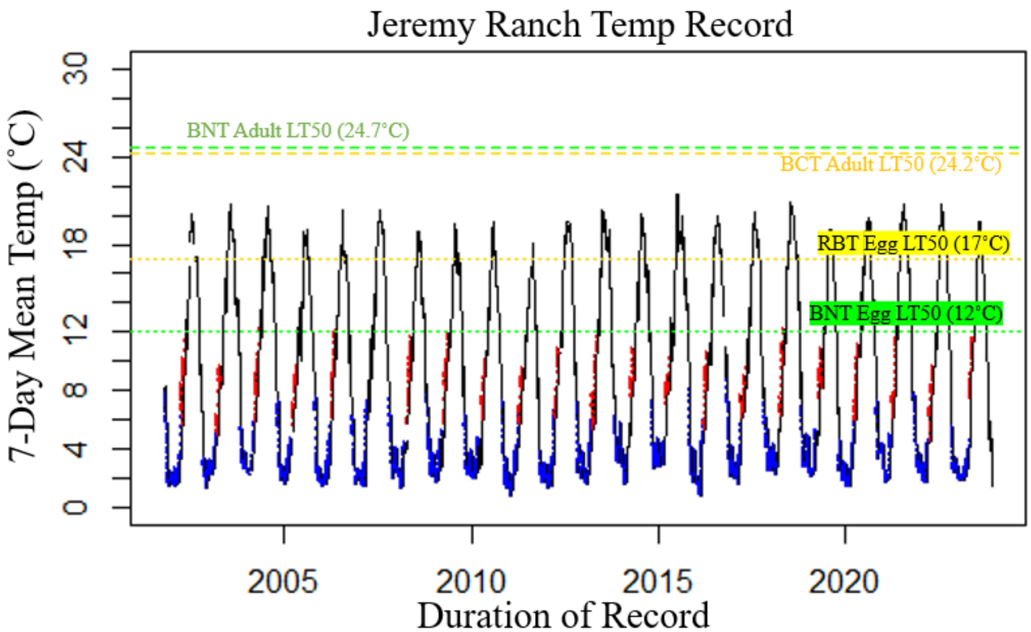

Figure 12. The 7-day mean temperature of the Jeremy Ranch gage cross plotted with 7-day LT_{50} of BNT adults (green-dashed line) and egg-to-emergence (green-dotted) and BCT adult and egg-to-emergence (gold-dashed and gold-dotted, Respectively). Note: LT_{50} of BCT embryos has not been established, instead the gold dotted line represents the Rainbow Trout LT_{50} as a surrogate. The blue and red points represent the calculated incubation time for BNT and BCT, respectively.

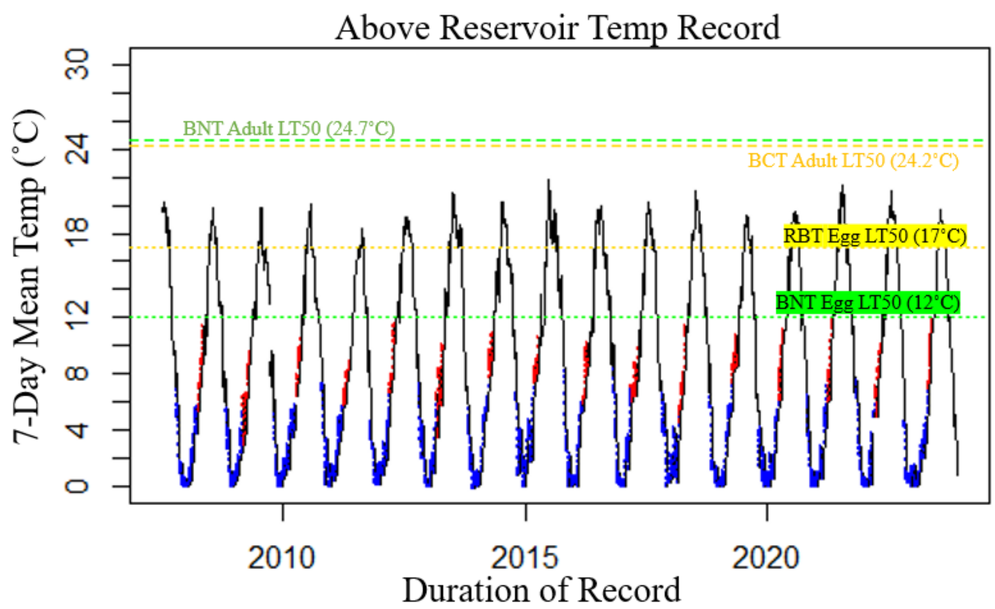

Figure 13. The 7-day mean temperature of the Above Reservoir gage cross plotted with 7-day LT_{50} of BNT adults (green-dashed line) and egg-to-emergence (green-dotted) and BCT adult and egg-to-emergence (gold-dashed and gold-dotted, respectively). Note: LT_{50} of BCT embryos has not been established and the gold dotted line uses Rainbow Trout LT_{50} as a surrogate. The blue and red points represent the calculated incubation time for BNT and BCT, respectively.

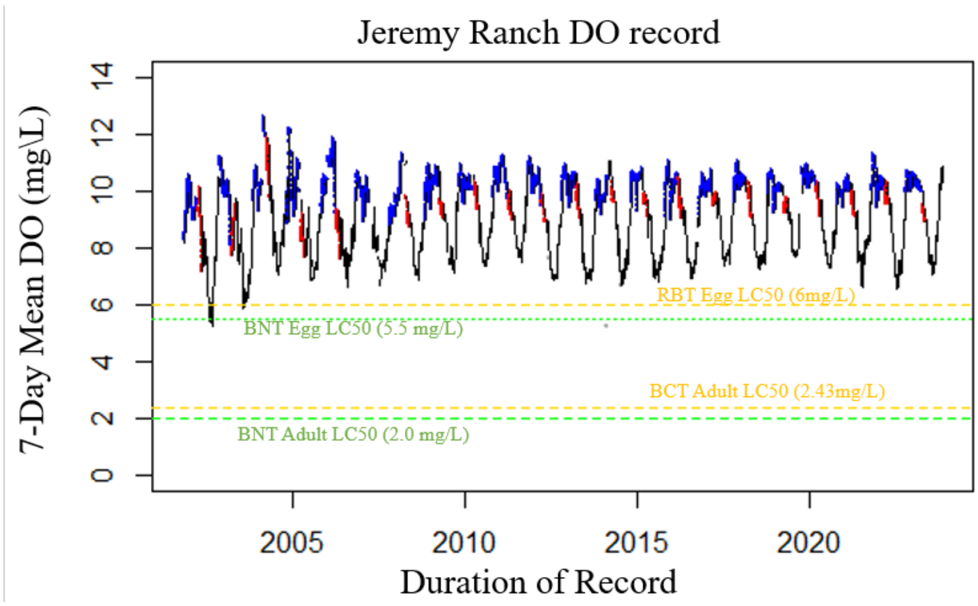

Figure 14. The 7-day mean DO of the Jeremy Ranch gage cross plotted with 7-day LC_{50} of BNT adults (green-dashed line) and egg-to-emergence (green-dotted) and BCT adult and egg-to-emergence (gold-dashed and gold-dotted, Respectively). Note: the LC_{50} of BCT embryos has not been established, instead the gold dotted line represents the Rainbow Trout LC_{50} as a surrogate. The blue and red points represent the calculated incubation time for BNT and BCT, respectively.

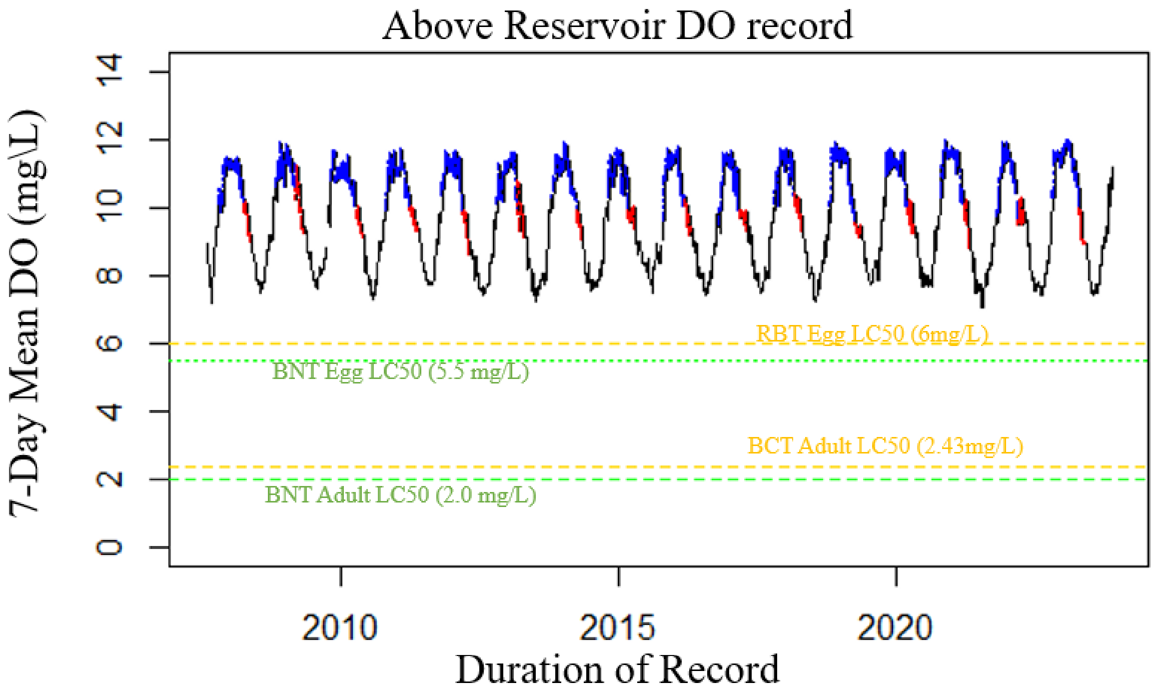

Figure 15. The 7-day mean DO of the Above Reservoir gage cross plotted with 7-day LC_{50} of BNT adults (green-dashed line) and egg-to-emergence (green-dotted) and BCT adult and egg-to-emergence (gold-dashed and gold-dotted, Respectively). Note: the LC_{50} of BCT embryos has not been established, instead the gold dotted line represents the Rainbow Trout LC_{50} as a surrogate. The blue and red points represent the calculated incubation time for BNT and BCT, respectively.

The suitable range in grain size for BCT is reported to be 3 mm – 80 mm (Hickman and Raleigh, 1982). The proportion of surface sediment in that size range 0.72∓0.15, suggesting that sufficient gravel of suitable size for BCT spawning is found on ECC in the 910 Ranch (**Table 3**; **Figure 16**). Suitable grain size for BNT spawning is reported to be 16 mm – 64 mm (Siamlek et al., 2021), which composes 0.57∓0.13 of sampled surface grain sizes on ECC (**Table 3**; **Figure 16**). These results suggest that sufficient gravel of appropriate grain size surface exists for both BNT and BCT spawning. These findings are supported by the observation of abundant BNT redds o ECC at 910 Ranch in late October and early November 2023, indicating that BNT are making spawning attempts within the property. Furthermore, given BCT's complete overlap of the BNT substrate size niche, we may assume that BCT, if present, would attempt to spawn within the 910 Ranch property.

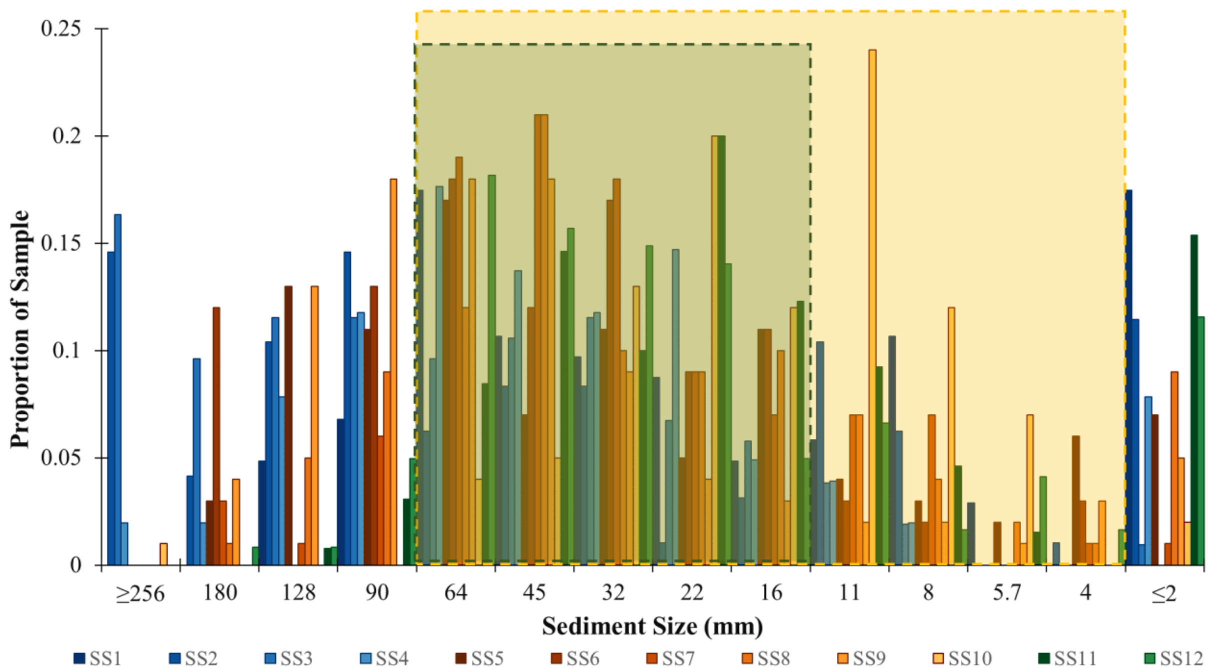

Figure 16. Observed proportion of sediment sizes (mm) at transects. The green shaded area represents the suitable ranges (16-64mm) for BNT. The gold-shaded area represents the suitable substrate for BCT (3-80mm). Individual sites are colored from blue to green and sorted in descending order downstream.

Table 3. 910 Ranch Fish Spawning Gravels Suitability

	BCT		BNT	
	Suitable	Unsuitable	Suitable	Unsuitable
Mean	0.72	0.28	0.57	0.43
SD	0.15	0.15	0.13	0.13

Excessive fine sediment (< 2 mm) in the subsurface of the river bed can inhibit successful spawning (**Figure 11**). Fine sediment concentration was 11% at the upstream redd sampled and 10% at the downstream redd (**Figure 17**). The upstream and downstream bed samples adjacent to redds contained 15% and 12% finer than 2 mm (**Figure 17**). In a study of a similar system (Rock Creek, ID) (Maret et al., 1993), estimated survivorship to emergence of BNT declined significantly for a proportion of fine sediment greater than 15%. Moreover, Conallin (2004) found that BNT emergence survival is significantly impacted by ≥ 8% fines in a European stream. Budy et al., (2012) found that BCT survival during egg-to-emergence had an inverse relationship with the proportion of fines, but did not give an explicit recommendation for fine sediment proportions. However, Hickmen and Raleigh (1982) suggested that beds composed of ≥ 30% fines would significantly impair egg-to-emergence survival. This is a higher value than computed by Marret et al., (1993) or Conallin (2004). Additionally, Kreshner (1995) noted the Bear Lake strain of Bonneville cutthroat trout successfully recruited in St. Charles Creek, Idaho, where fine sediment composes the majority of the bed. This suggests the BCT may have evolved better tolerance for fine sediment than BNT. Regardless, we conclude that fine sediments may be a significant limitation of BNT in ECC under Conallin's (2004) Criteria.

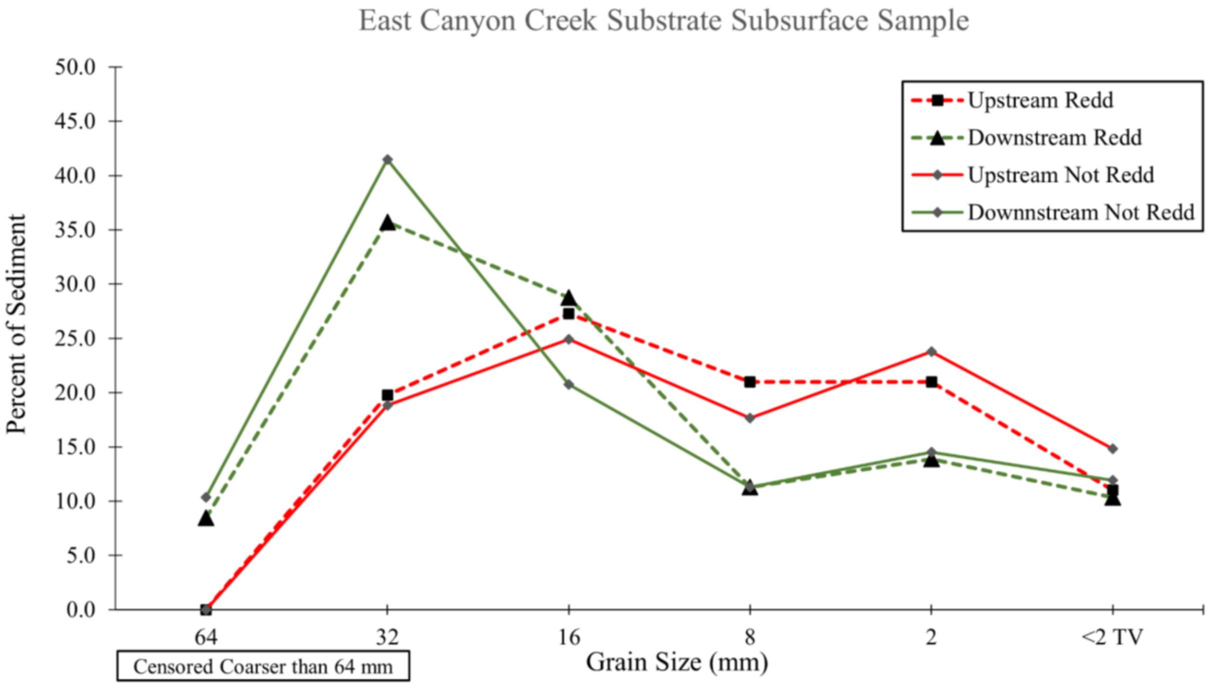

Figure 17. Percentage of Below Surface Substrate Compositions of Each of the Sediment Cores.

The impact of fine sediment concentration on emergence survivorship may be largely site and context dependent, as suggested by the variability in estimates. This may be due to the fact the proportion of fines can indirectly affect egg mortality via the Interstitial Dissolved Oxygen Concentration (IDOC) (Maret et al., 1993). IDOC depends on the DO of the water column, the oxygen demand of the substrate, and flow velocity through the substrate (Marret et al., 1993). We hypothesize that **sediment-macrophyte interactions may be limiting salmonid recruitment.** Oxygen consumption from decomposition of aquatic vegetation and other chemical processes within the substrate can lower IDOC relative to the DO I the overlying water column (Maret et al., 1993). Fine sediments will lower the hydraulic conductivity of the substrate, which reduces the rate of oxygen delivered and increase the water residence time in the substrate (**Table 4**; Maret at al., 1993). Thus, IDOC can reach inhospitable levels in the subsurface eve if suitable levels of DO are observed in the stream flow (**Figure 18, 19**). Baker et al., (2008) hypothesized that the high composition of organic matter and primary producer respiration produces significant Biological Oxygen Demand (BOD) in the river bed. We observed abundant epiphytes and macrophytes that could contribute to significant BOD through decomposition. This would reduce IDOC relative to the overlying water column DO. Lower DO paired with low flow rates through sediment could produce IDOC concentrations near or at the LC_{50} for both BT and BCT and contribute to the observed recruitment bottleneck. **Both BNT and BCT eggs may struggle from the indirect effects of fine sediments despite the apparent suitability of the overlying sediments**. We concur with previous recommendations to reduce fine sediment loads in order to increase the success of a self-sustaining recreational fishery at 910 Ranch. We also recommend that direct sampling of BNT redds and measurement of DO within the occupied redds would provide a relatively simple test of these recruitment challenges.

Decreasing fine sediment could also be complemented by increasing the DO and/or reducing stream temperatures. Higher DO could provide enough oxygen to satisfy both BOD and egg survival requirements. Reducing stream temperatures will also increase initial DO (Krueger, n.d.). Moreover, decomposition is impeded under cooler temperatures, and thus, the BOD may be reduced under cooler temperatures relative to warmer temps (Chapra et al., 2021). Likewise, shading of the stream bed will limit periphyton and macrophyte growth, which reduces the amount of organic detritus produced (SBWRD, 2008). This would attenuate BOD losses through the sediments. Lastly, alteration of the velocities through the phreatic zone would increase the rates of DO delivered through the redd (**Table 4**).

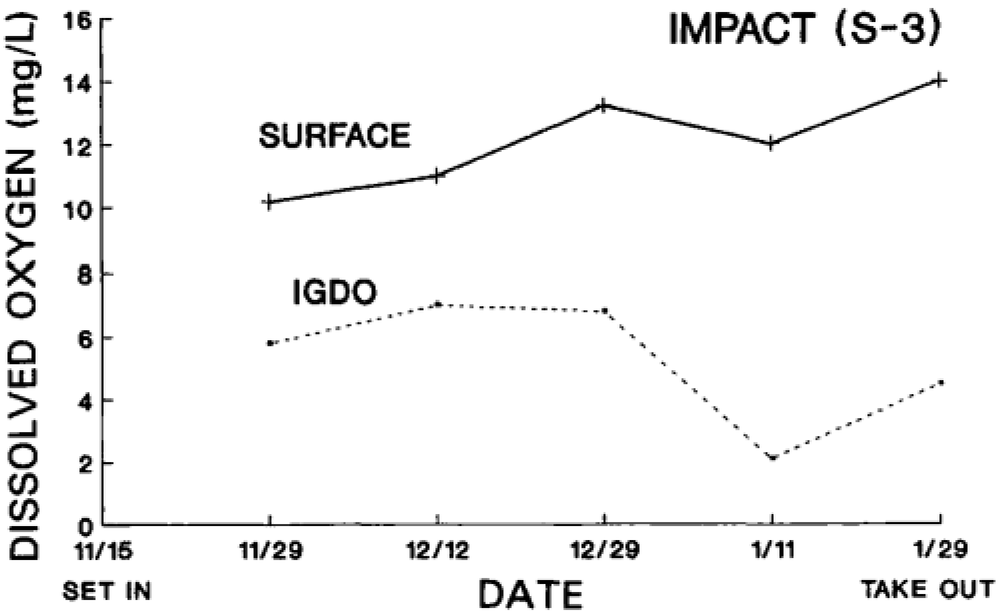

Figure 18. The difference between surface DO and subsurface dissolved oxygen (IGDO is Intragravel Dissolved Oxygen) for a study site of Marret et al., (1993). Apparently optimal DO in the overlying water column is reduced to lethal levels in the steambed subsurface.

Table 4. Typical flow rate (hydraulic conductivity) for various grain sizes (Shackelford, 2013).

Grain Type	Hydraulic Conductivity (cm/s)
Gravel	1-0.1
Sand	0.1-0.001
Silt	$0.001\text{-}10^{-6}$
Clay	$10^{-6}\text{-}10^{-10}$

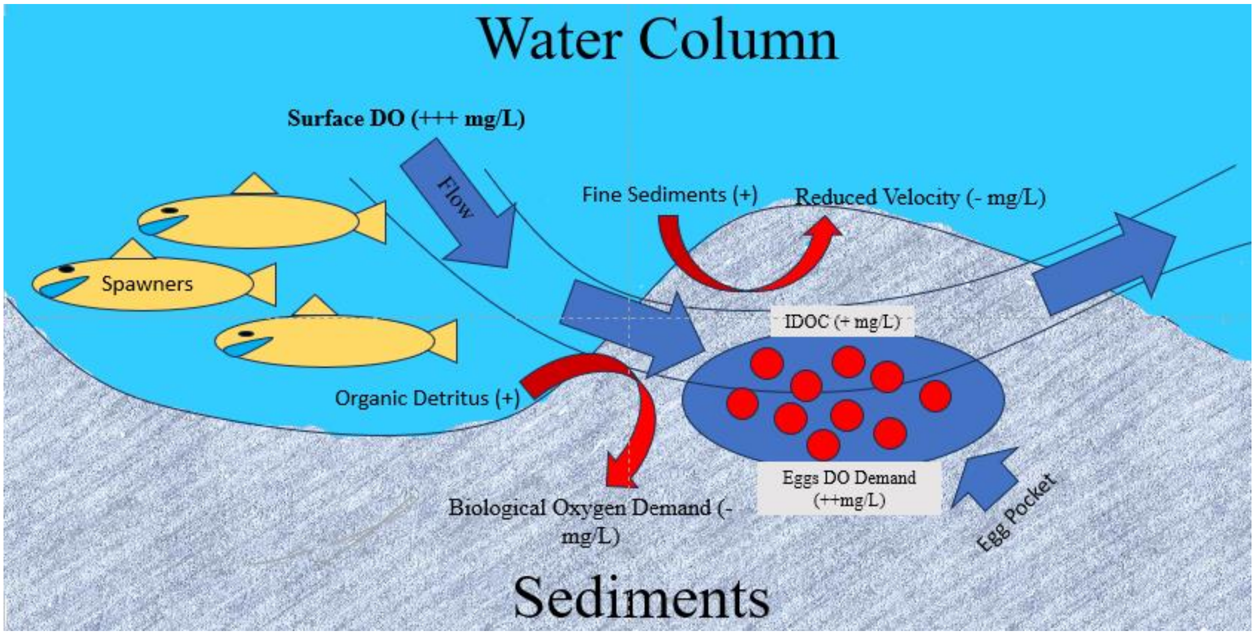

Figure 19. Diagram of Sediment-Macrophyte Hypothesis for IDOC dynamics.

Although we cannot identify a single limiting factor as dominant, our work suggests that fine sediment may be a leading factor driving the observed poor recruitment of BNT and BCT. Improvements in the temperature and DO of stream flow delivered to ECC on 910 Ranch could assist in alleviating and reducing IDOC. The observed bottleneck of BNT recruitment suggests that the population is struggling with recruitment (Eggs to Fry life stages). Therefore, restoration should proceed with improving early life stage habitat by increasing DO concentration, reducing temperatures, and reducing fine sediment loading.

Problems with Current Fishery

Our assessment of the current salmonid fishery indicates:

1) The current BNT and BCT fishery on ECC at 910 Ranch is deficient in terms of relative abundance and lack observed young of year.
2) The fishery does not meet the standards of a blue ribbon, or a marginal recreational fishery.
3) The BNT population upstream of 910 Ranch displays evidence of recruitment but low density.
4) Our limiting factor analysis suggests that IDOC is limiting trout recruitment in ECC.

Modeling Possible Drivers of the Sediment Macrophyte Problem

Change in Floodplain Vegetation Coverage Over Time

Vegetation on the floodplain affects the aquatic ecosystem in myriad ways and vegetation coverage is important for ecosystem function and aesthetics. Vegetation was also studied as a possible driver of sediment inputs from bank instability and as a way to shade out macrophytes.

Methods

The 2020 vegetation height was found by subtracting bare-earth-DEM elevation values from first-return-DEM elevation values from UGRC. The 1977 vegetation coverage was estimated by classification of colors from the 1977 black and white imagery based on sections of identifiable and known large vegetation.

Results and Discussion

Upstream → Downstream

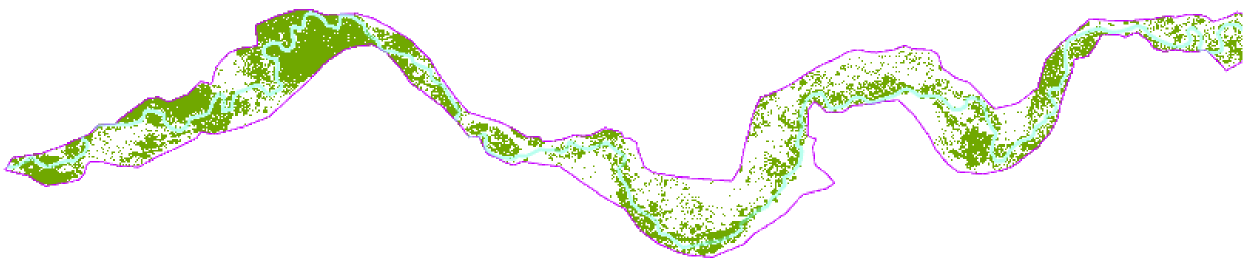

Figure 20. 1977 910 Ranch vegetation coverage

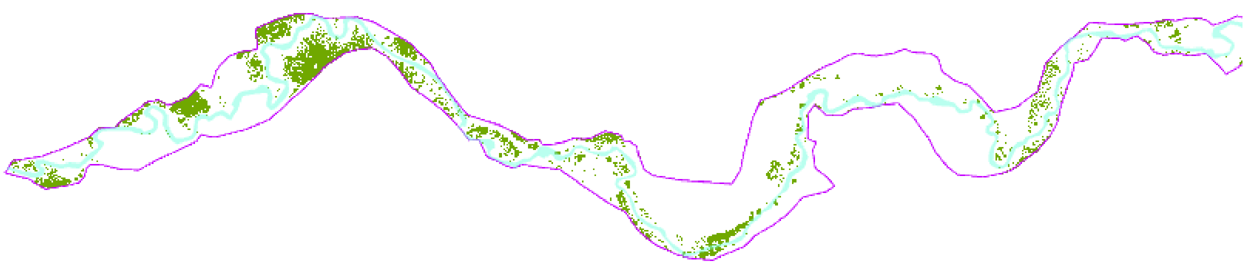

Figure 21. 2020 910 Ranch vegetation coverage

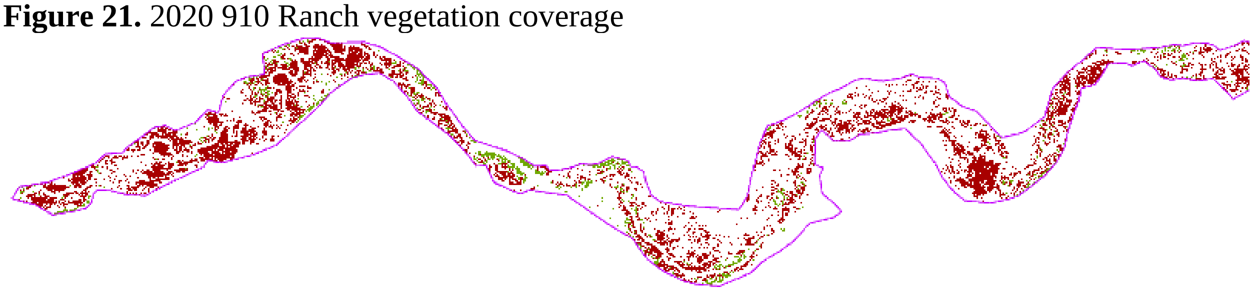

Figure 22. 910 Ranch Vegetation **Loss** and **Gain** from 1977 to 2020

Upstream → Downstream

Figure 23. 2020 Mormon Flats State Park vegetation coverage

In 1977, 39% of the 910 Ranch floodplain was covered by vegetation estimated to be larger than 0.5 m. In 2020, 19% of the floodplain was covered by vegetation taller than 0.5 m. At Mormon Flats in 2020, 38% of the floodplain was covered by vegetation taller than 0.5 m.

Modeled Stream Shading

Planting vegetation to increase shade has been proposed by multiple studies to address high stream temperatures and low dissolved oxygen in the past (SWCA, 2010: SBWRD, 2008). Moreover, vegetation shading can reduce submerged vegetation growth via photo-inhibition. We assessed the outcomes of prior restoration projects on ECC to characterize its application to the 910 Ranch, modeling shade extent on three sites on ECC with different development histories.

Methods

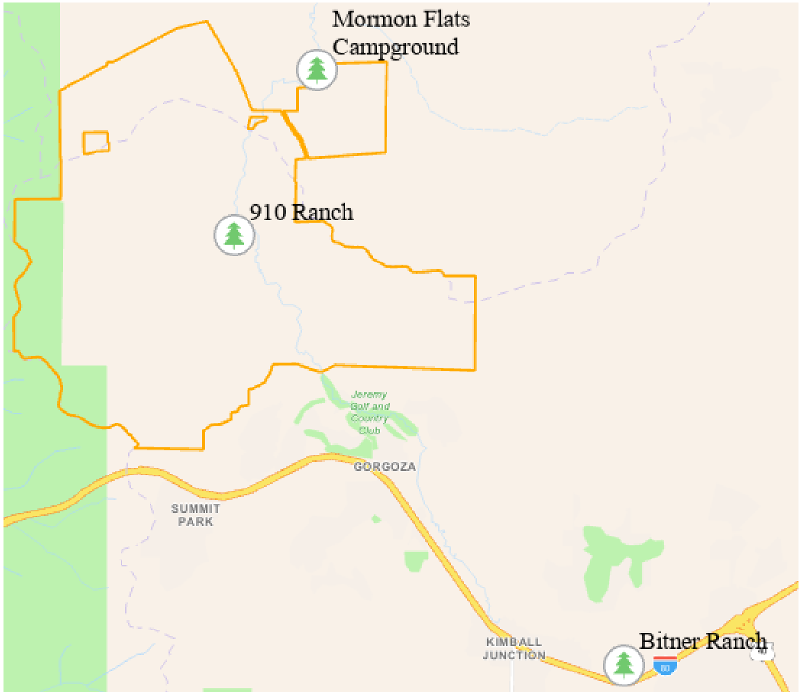

Figure 24. Map of study sites.

We used an ArcGIS Python script that computes the percentage of shaded stream bed created by vegetation along ECC. Using the 2020 0.5m Utah digital elevation model (DEM) from Utah Geospatial Resource Center, vegetation height was extracted by subtracting the Bare Earth DEM from the First Return DEM. Using the hourly azimuth and elevation of the sun at Jeremy Ranch on July 15 (this date is associated with maximum stream temperatures and high macrophyte growth), the model computed how much sunlight is blocked by vegetation along the streambed. The model was run for three different reaches: Mormon Flats, Bitner Ranch, and the 910 Ranch. Cattle grazing has been excluded from Mormon Flats since at least the early 2000s; potentially since the 1960's. (Eric Bradshaw, Personal Communication, Nov 8th, 2023). The riparian area at Bitner Ranch was revegetated in 2011 but is still grazed by sheep (**Figure 25**; SBWRD, 2011).

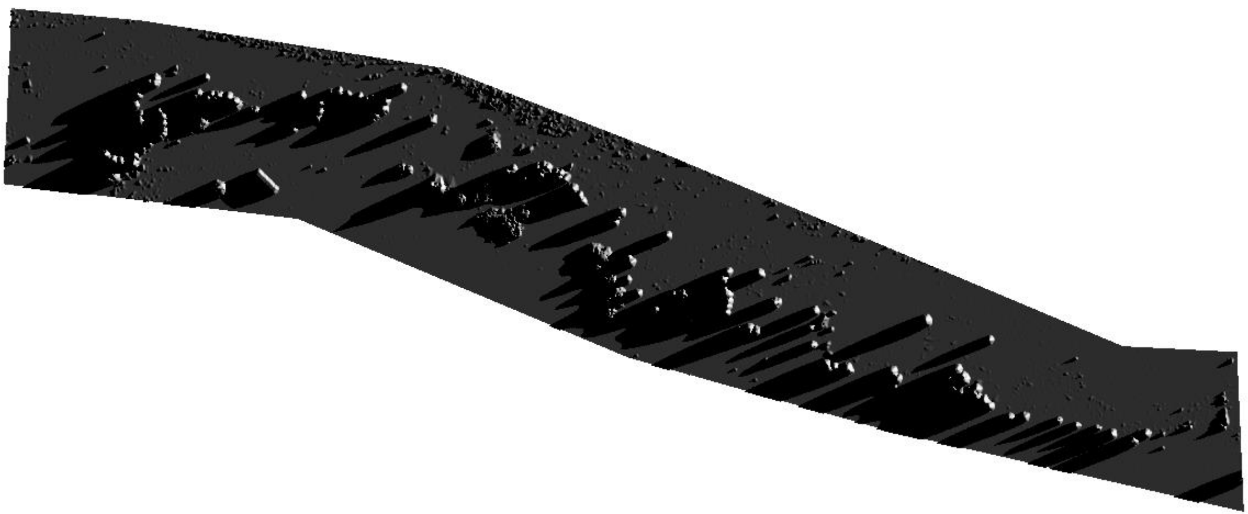

Figure 25. Bitner Ranch Valley Bottom Hourly Shade Coverage

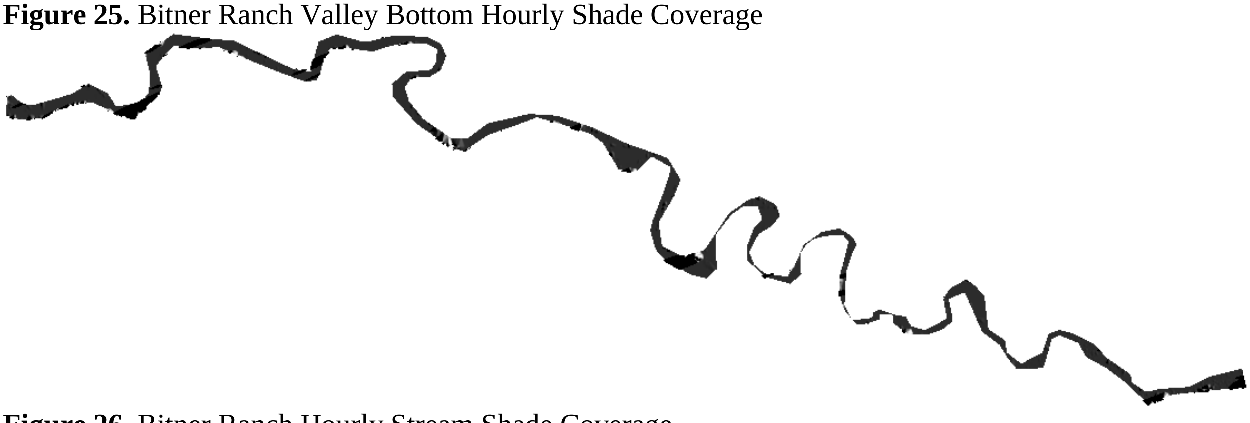

Figure 26. Bitner Ranch Hourly Stream Shade Coverage

Results:

Table 5. Site Comparison incoming solar radiation blocked by vegetation.

Mormon Flats	**20%** (most vegetated site)
Bitner Ranch	**10%** (replanted site)
910 Ranch	**4%** (heavily impacted vegetation)

Table 6. 910 Ranch at Bear Hollow Minimum Daily Dissolved Oxygen Scenarios (mg/L) (w/ data from SBWRD 2008)

	Baseline	**Revegetation Scenario (10-20% sunlight reduction)**	25% Sunlight Reduction	50% sunlight Reduction
July	3.67	**3.67-4.59**	4.59	5.52
August	3.72	**3.72-4.5**	4.50	5.27

A calibrated stream metabolism model was developed for ECC by Hydroqual in 2008 (SBWRD, 2008). The model was used to test scenarios of increased shading of the stream bed in order to reduce aquatic macrophyte and periphyton growth via photoinhibition. Baseline conditions for ECC at 910 Ranch had essentially zero shading for the existing (2007) conditions, and Hydroqual modeled conditions with a 25% and a 50% reduction in solar radiation. For a study site o n910 Ranch (Big Bear Hollow), Hydroqual computed stream flow dissolved oxygen DO of 3.7 mg/L for July and August. These minimum summertime (DO) levels improved marginally to 4.5 mg/L for a 25% sunlight reduction and 5.3 mg/L for a 50% sunlight reduction (SBWRD 2008).

Based on the results of the shade model, none of the study sites exhibited a 25% reduction in sunlight from vegetation, let alone a 50% reduction. At Mormon Flats, the most vegetated reference site we found on ECC, vegetation was not tall enough or overhanging the stream sufficiently to reduce insolation by more than 20%. The Hydroqual modelign results suggest that this degree of shading might increase minimum summer DO by at most 1 mg/L. On ECC upstream of Jeremey Ranch, the extensive replanting undertaken 10-12 years ago has produced negligible increasing in streambed shading. If riparian revegetation is undertaken to improve stream shading, an approach different from that implemented previously will be needed to have a worthwhile effect on shading.

Model of Sediment Loading from Stream Banks

Fine sediment has been identified as problematic for fish spawning on ECC. We observed fine sediment on the streambed throughout the ECC on 910 Ranch. In addition to the surface and subsurface samples discussed previously, we consistently observed clouds of suspension when walking on the bed. We modeled the proportion of fine sediment produced by streambank erosion to inform potential restoration actions. This will help inform how 910 Ranch contributes to the overall sediment budget and how much sediment is delivered by the meandering channel.

Methods

In October 2023, our team measured bank height and water depth at 24 transects throughout the 910 Ranch reach. Using georeferenced imagery for 2020 and 1977, the stream channel banks were digitized and a stream centerline computed (**Figure 27**). Stream lateral erosion was computed by creating a difference-polygon between the two stream centerlines. Erosion volume was estimated by multiplying the area between the centerlines by an estimated erosion height defined by subtracting the water depth from the observed bank height at the transect sample locations. As the channel migrates, it erodes the entire height of the eroding bank and the portion of the bank below water level was subtracted to accout for redeposition of sediment on the trailing, or depositing bank.

Results

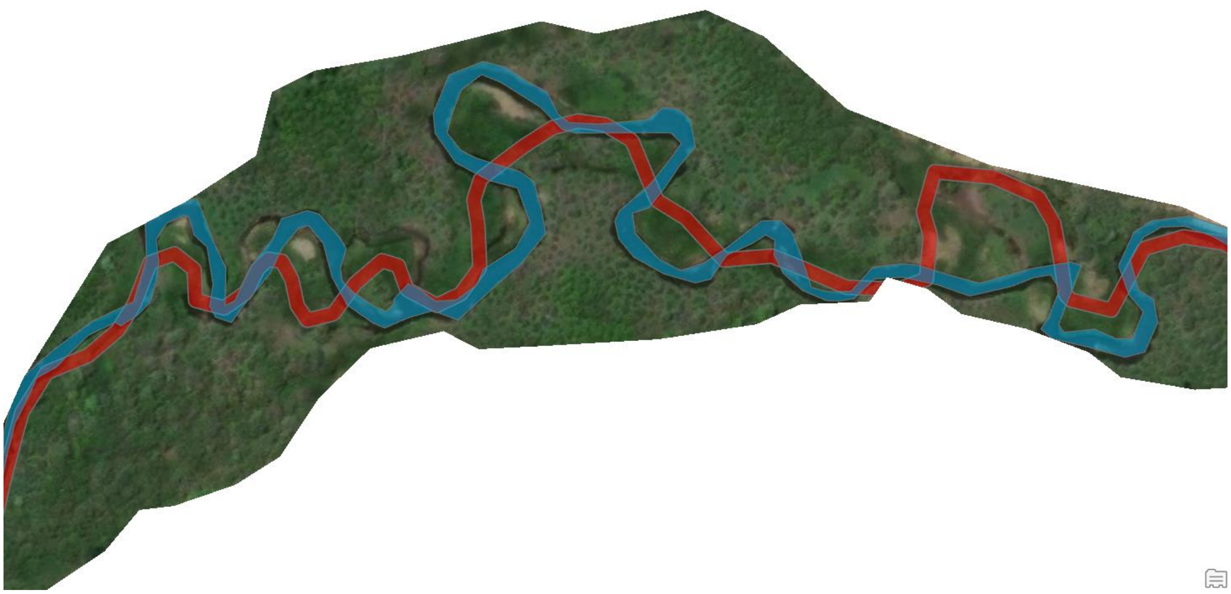

Figure 27. 1977 Channel vs 2020 Channel. 910 Ranch channel change through meander migration

The ECC channel on 910 Ranch had a mean lateral channel migration of 0.15m/yr between 1977 and 2020, producing an estimated 30,000 m³ of sediment through channel shift, for an annual load of 744 m³ of sediment sourced from eroding banks (**Figure 28**).

At an average stream width of 8 m over the ranch, this means that the banks are producing **enough fine sediment to cover the entire stream bed in 1.25 cm of sediment per year.** A portion of this fine sediment produced by the banks spends time deposited on the streambed throughout the 910 Ranch reach as it eventually makes its way to East Canyon Reservoir.

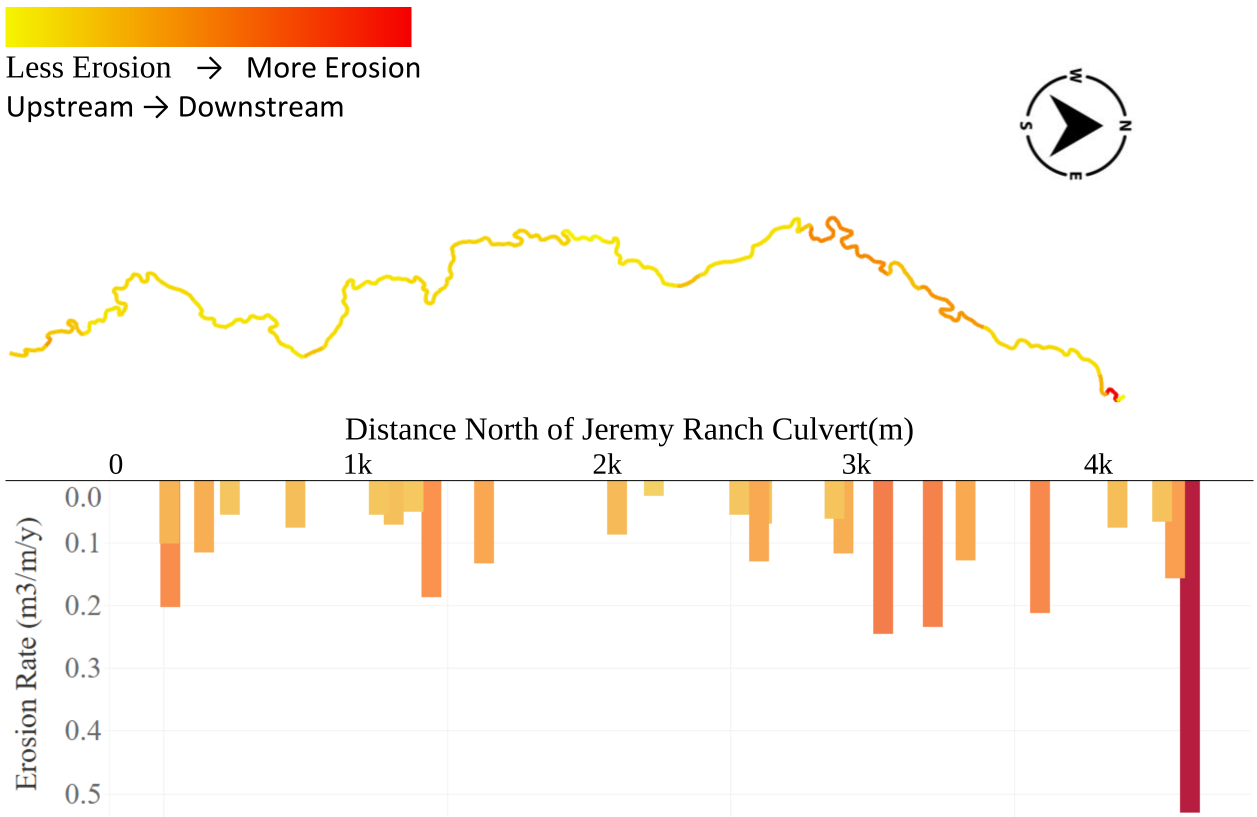

Figure 28. East Canyon Creek Bank Average Erosion Rates at 910 Ranch. Displays the estimated erosion rate at transects using 2023 bank height measurements and historical channel migration measurements from 1977-2020.

Discussion:

Our estimated sediment load of 744 m^3/year matches previous findings that identify 910 Ranch as a major source of sediment in East Canyon Creek. This compares closely to an estimate of 449 m^3/y for the 910 Ranch Reach from Olsen and Stamp (2000). Olsen and Stamp estimated 83% of the sediment is delivered during spring runoff, while 17% is delivered during baseflow, although year round activities produce conditions that eventually lead to erosion and sediment delivery. Olsen and Stamp also estimated that the 910 Ranch Reach produces 50% of the total sediment in East Canyon Creek, while upstream sources produce the other 50%.

As mentioned in the TMDL (Baker, 2008; SWCA, 2010), the bank sediment is high in phosphorus, can become anoxic when deposited in the streambed, and supports the growth of macrophytes. Based on the study of beaver dams by Wolf (2023), the 910 Ranch produces enough sediment to fully fill 115-200 beaver dams per year, assuming each dam holds 4 cubic meters of sediment. Bank erosion is a significant source of fine sediment within the 910 Ranch site. Since bank erosion occurs on the 910 Ranch site, this source of fine sediment could be targeted through on-site management actions. Grazing related impacts on channel stability have been identified as the primary source of sediment production at the ranch. Actions targeting grazing provide a good first option to reduce 50% of fine sediment delivery to the stream. Targeting upstream sediment sources would require significant sediment input reduction efforts basinwide. Alternatively, a large settling reservoir on ECC could be built to sequester a portion of the upstream sediment deliveries at peak streamflows.

Restoration Alternatives

A variety of restoration alternatives can be considered for improving the ECC fishery on 910 Ranch.

Cattle Exclusion

Cattle grazing is known to deleteriously affect aquatic ecosystems by trampling biota, consuming riparian vegetation, and increasing fine sediment loading and mobilization, which increases mortality of eggs in redds via IDOC reduction (Platts, 1979). Kreshner (1995) found that Cutthroat Trout abundance is negatively related to presence of grazing. Furthermore, Bayley and Li (2008) found that juvenile salmonid populations in areas where cattle were excluded were 2.5 times more abundant compared to grazed streams. Removing cattle from the riparian area will assist in reducing the loading of fine sediments in the bed, an important impact given that fine sediment is proposed to be a key limiting factor for a successful trout fishery. Moreover, the presence of cattle grazing has been known to decrease dissolved oxygen and reduce water quality in grazed streams by increasing nutrient loading (manure) and reducing shading, thereby increasing temperatures and decreasing DO (Grudzinski et al., 2020). Therefore, excluding cattle may help alleviate all three factors (temp, DO, fine sediment), and would help promote the success of any riparian planting actions by reducing herbivory risks to the plantings.

We observe that the density of riparian vegetation on 910 Ranch has declined from 1977 to 2020, a period in which cattle were free to graze the valley bottom. In contrast, cattle grazing has been excluded from the Mormon Flats reach and the density and height of willow in that reach is the largest observed on ECC. This suggests that cattle exclusion can produce important improvements in the riparian vegetation on 910 Ranch, although the full effect may take many years to achieve.

Revegetation and Planting

Riparian vegetation in the 910 Ranch has declined significantly (50%) from the 1970s, and only 4% of incoming solar insolation is currently blocked by riparian vegetation. Past management, including grazing and herbicide application have affected riparian vegetation on the ranch. Increasing riparian vegetation at the 910 Ranch would improve the resilience of a salmonid fishery in ECC.

Riparian planting can decrease instream fine sediment loading by collecting and storing fine sediments on the floodplain (Gurnell et al., 2004). Moreover, riparian plants have been shown to decrease water temperatures by intercepting solar insolation to the creek (Espland and Kettering, 2018). In fact, Wondzel et al., (2019) found that among the three dominant factors driving stream temperatures (air temperature, discharge, and riparian vegetation), riparian vegetation was the largest driver influencing stream temperatures. Riparian vegetation also influences DO as the solubility of oxygen decreases with warmer waters. And therefore, cooler waters are able to maintain higher dissolved oxygen content. As noted in Baker et al., (2008) and the 2010 TMDL implementation report (SWCA, 2010), ECC supports a large abundance of macrophytes and periphyton which respire at night and deplete the available dissolved oxygen. Additionally, Baker et al., (2008) noted that the fine sediments are composed of a large amount of organic detritus which likely has significant BOD and would reduce IDOC. Therefore, increasing the stream bed shading will photo-inhibit this community, reducing their impact on IDOC.

Given that increasing riparian vegetation may mitigate concerns for fine sediment, stream temperature and dissolved oxygen, riparian plantings make an attractive restoration alternative for the 910 Ranch. The Bitner Ranch and Mormon Flat reaches as looked at by our vegetation and shade models provide valuable insight into vegetation management. Neither site provides shading sufficient to resolve DO or fine sediment issues on their own. Any revegetation efforts pursued on 910 Ranch should closely examine planting plans from Bitner Ranch and management plans from Mormon Flats for positives and negatives, and then seek to build upon those previous efforts to optimize the potential outcome of revegetation on 910.

In order to achieve necessary shading levels, revegetation efforts should seek to establish a multi-level canopy including high densities of large shade trees such as cottonwoods and/or box elder trees. Revegetation should also be supported by grazing exclusion, at least during the period of establishment, in order to maximize survival of plantings.

Fish Stocking

Stocking fish into the 910 Reach of ECC can be used to address short-term or long-term goals. Prior to 1991, ECC was stocked with RBT and other game species, although that practice was discontinued due to limited public access to the stream (UDWR, 1998). Resuming stocking at 910 Ranch could accomplish two goals. One is to establish an immediate functional fishery, and the other is to aid in the recovery of populations following restoration. Supplementing BNT or BCT stocks may aid in overcoming the recruitment bottleneck. Currently, if recruitment is limited due to a high proportion of eggs dying, a higher density of adult spawners would be necessary to increase recruitment post restoration. If issues causing high egg mortality rates are addressed, it may also be helpful to supplement BNT or BCT stocks to re-establish a diverse age class structure. Moreover, introducing sterile hybrid fish species, such as the Tiger Trout (*Salmo trutta* × *Salvelinus fontinalis;* herein TGT) may serve as a recreational angling resource while restoration is ongoing. Below are four stocking options that may accomplish both long-term and short-term goals:

Option 1: Brown Trout (BNT): Already present in ECC, BNT stocking efforts could be focused on supplementing current populations until the instream habitat is restored sufficiently to recruit new generations of fish. The addition of BNT would increase angling quality and bolster public approval. Monitoring the relative abundance of stocked BNT (if tagged for identification) and naturally recruited offspring may be a helpful indicator of restoration success.

Option 2: Bonneville Cutthroat Trout (BCT): Once creek restoration is near completion, there is a possibility to move into native species stocking with BCT (*Oncorhynchus clarkii utah*). If the water temperatures, dissolved oxygen, and sediment distribution are improved, introducing BCT at 910 Ranch may increase the possibility of establishing a BCT population. However, this would also require interspecific competition considerations, as BCT are often competitively excluded by BNT.

Option 3: Tiger Trout (TGT): TGT is an alternative trout species that could be stocked while restoration actions are underway. TGT is a hybrid between BNT and Brook Trout and requires conditions similar to BNT. A large benefit of stocking TGT into ECC is that they are sterile. The sterility of TGT means that the species can be introduced into a system without risk of colonization, allowing for more management control. TGT are favored by anglers, as their unique pattern, aggression, and novelty as a species make the fish fun to catch. Introducing TGT would provide Summit County anglers with an immediate opportunity to fish while restoration is ongoing.

UM Creek in Sevier County, Utah, is an example of stocking TGT to support recreational angling during restoration. According to Clint Brunson (Personal Communication, Oct 10th 2023), the UDWR planted TGT to serve as an immediate fishery while restoration actions were taking place, with the ultimate goal of re-establishing Colorado River Cutthroat Trout (*Oncorhynchus clarkii pleuriticus*). According to report by Hepworth et al. (2009), TGT were stocked annually into UM Creek from 1996-2000, with a four fish harvesting limit. Over the study's time frame, TGT densities fluctuated between 305 fish/mile and 65 fish/mile from 2000 - 2009 in all observed reaches of UM Creek (Hepworth et al., 2009). TGT have not been stocked since 2000, but populations have been observed since, as angler intentions shifted from harvesting TGT to catch and release (2009). Despite the shift in angler intention, the overall decrease of TGT populations offered unique niches for Colorado River Cutthroat Trout populations (2009). A recommendation from Hepworth et al. (2009) that would be beneficial to keep in mind with stocking TGT into ECC is to only stock until another fishery (BNT or BCT) can be sustained naturally, to prevent high competition from occurring. If a sustainable fishery based on natural spawning cannot occur, the county may choose to continue TGT stocking or alternate species.

Photo of TGT (Credit: USGS)

Option 4: BCT after TGT: Stocking BCT could be a secondary action, with TGT stocked first. This two-step stocking may reduce the potential competition with BCT, both by TGT and BNT. TGT populations will phase out over time, and TGT may initially competitively exclude BNT if stocked in relatively high densities. This is in opposition to the approach of stocking BNT. TGT would be introduced during restoration and BCT would be stocked after restoration, with the intention of reintroducing a native fish species in the creek.

Increased Baseflow

Baseflow, the minimum flow that is maintained through the driest months, directly impacts water temperature, dissolved oxygen content, sediment movement, and deposition. Thus, base flow directly impacts salmonid fishery health and sustainability (Constantz, 1998; GU et al., 1998).

Using the Jeremy Ranch gauge to quantify flows of East Canyon Creek enntering the 910 property, the creek has an average annual low flow of 7.1 cfs over the period of record (2001-2023). The hydraulic model developed by HydroQual (SBWRD, 2008) recommended a minimum summer base flow of at least 7.7 cfs in order to stabilize stream water temperature, decrease the channel width to depth ratio, and increase reaeration rates. The 2010 TMDL implementation report (SWCA, 2010) also recommend an augmented baseflow in order to improve low summer DO values. Flows smaller than 7.7 cfs occurred in 13 of the 23 years of record at the Jeremy ranch USGS gage, indicating that the recommended minimum flow levels are not met in more than half the years. We re-iterate and support these recommendations for increasing summer low flows. Multiple actions can and should be taken in order to effectively increase base flows in ECC. First, as recommended in the TMDL, by reducing upstream water usage by stricter enforcement of water rights and agreements. Second, also per the TMDL, by direct augmentation through acquisition of in-stream, senior water rights of at least 500 acre-ft (SWCA, 2010). We recognize that feasibility of these two actions may be limited by the logistics of enforcing water rights and the price for water rights. As lower cost alternatives to indirectly augment base flow, we suggest upland runoff detention structures and vegetation management focused on increasing soil infiltration and subsurface moisture replenishment. Vegetation management can be an effective strategy to reduce runoff during storm events by routing water into and through the soil profile. This pathway increases soil moisture and releases water into the stream during low flow months to augment the base flow. (Jigour, 2011). We point to the case studies presented in Ponce & Lindquist (2016) as examples of vegetation management for base flow augmentation.

Baseflow augmentation could increase fish survival rates by reducing summertime stress on fish by increasing dissolved oxygen, but it would not have any impact on fish spawning and recruitment. In addition, water rights would be expensive and difficult to obtain and base flow augmentation through alternative methods such as vegetation management for increased infiltration and subsurface moisture replenishment has uncertain impacts.

Table 7. Projected Minimum Dissolved Oxygen (DO) for different Baseflow Augmentation Scenarios
Projected values were calculated from the DIURNAL model in the 2008 Hydroqual Report.

	Baseline DO (mg/L)	5 CFS Increase	10 CFS Increase	15 CFS Increase	20 CFS Increase
July	3.67	4.24	4.61	5.11	5.58
August	3.72	4.29	4.63	5.12	5.58

Beaver Augmentation

Restoration actions utilizing North American Beavers (*Castor canadensis*) could be implemented on 910 Ranch. These recommendations are based on a growing body of evidence indicating the positive impact of beavers on habitat complexity and salmonid populations. Historically, and under the most recent ownership, beavers have been trapped out of the 910 Ranch (Jessica Kirby, Personal Communication, Nov 17th 2023). Despite this, beaver activity is still present at the 910 Ranch, indicating some resilience and that basic habitat requirements for beaver are met at the site. Beaver activity is currently minimal and is not providing significant habitat diversity in ECC (**Figure 29)**.

The Beaver Restoration Assessment Tool (BRAT) suggests a significantly higher potential for beaver dam density at the 910 Ranch compared to current levels (currently there are ~5 dams, and BRAT predicts a capacity of 36-98 for the full length of ECC on 910 Ranch) (**Figure 30**). Wolf and colleagues installed and monitored multiple BDAs, and monitored natural beaver complexes upstream of the 910 Ranch property (Wolf, 2023). In both the BDA and natural beaver sites, aggradation of fine sediments was significant. Moreover, water depths and wetted areas were significantly higher at the BDA and natural beaver sites. These factors likely improved habitat for salmonids as evidenced by increased growth rates and the presence of juvenile fishes at the BDA and natural beaver sites. With recruitment being a primary limiting factor at ECC, it is notable that Wolf found that BDAs and natural beaver dams had higher abundances of young of year BNT, suggesting improved spawning habitat, as well as growth and survival for juvenile fish. Habitat at ECC may be negatively impacted by BDAs through warming, however, which consistently occurred at the BDA and natural beaver dam sites. All the top 20 warming observations in Wolf's study occurred at the ECC paired sites with maximum warming being 0.76 °C. It appears that the geomorphic conditions required for BDAs and beaver dams to cool streams are not present at ECC, likely due to minimal hyporheic flow. It is also notable that, for all metrics indicating increased fish utilization, natural beaver complexes outperformed BDAs, highlighting the importance of maintaining beaver populations, rather than simply installing BDAs. Another mechanism by which BDAs and beaver may indirectly improve habitat for trout at the 910 Ranch is increasing riparian productivity, which in turn may provide shade and decrease water temperatures. Wolf (2023) found that riparian productivity was significantly higher at BDAs and natural beaver sites compared to control sites. Specific actions to enhance benefits to the fishery by beaver at the 910 Ranch include:

Support Present Beaver Population: Achieving a self-sustaining population of beaver that supports a high density of dams is a priority, and requires less maintenance than BDAs. First, specific restrictions on beaver trapping and harvesting should be implemented at the site. Habitat enhancement, specifically by promoting woody vegetation growth (currently limited due to grazing and historical removal), is recommended.

Install BDAs: Given the current relative floodplain disconnection at 910 Ranch, BDAs can address riparian productivity issues limiting beaver populations. BDAs have a lifespan, and are likely to be breached. BDA augmentation would require maintenance and would serve as an intermediary approach designed to enhance habitat for beavers currently at 910 Ranch, and is not a permanent solution.

Figure 29. Recent Beaver activity at the 910 Ranch (left over larger woody debris) showing green vegetation being recruited to the channel. Photo taken Oct 28, 2023.

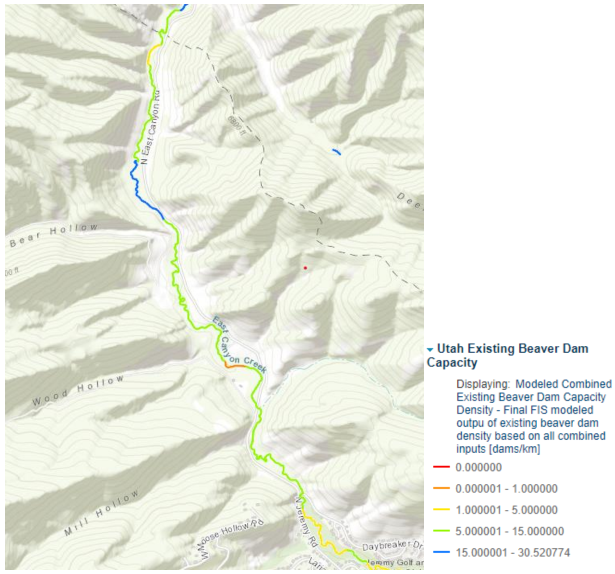

Figure 30. Beaver Dam Capacity at the 910 Ranch as estimated by BRAT (version PyBRAT 3.0.17)

Bank protection

Our results in the Limiting Factor analysis suggest that fine sediments are contributing to the recruitment bottleneck in ECC by supporting macrophyte growth and reducing IDOC. Therefore, implementing action to reduce fine sediment can alleviate these dynamics. Moreover, our sediment model analysis has shown that 50% of ECC fine sediment is sourced from the banks of the 910 Ranch. Therefore, bank protection actions could be taken to target this large source of fine sediment to ECC.

In a study conducted on the geomorphologically similar Rock Creek in Idaho, BNT incubation survival rates decreased when the amount of fine sediment in the streambed reached 15% (Maret et al., 1993). From our estimate of fine sediment loading, sufficient sediment finer than 2 mm is delivered each year to cover the bed of ECC by 1.25 cm. Furthermore, streambank erosion along ECC releases about 2.3-7.2 tons/year of organic matter and nutrients into the creek itself; both of which will increase the BOD within the ECC streambed (Baker et al., 2008). The cumulative threat posed by excessive fine-grain sedimentation, organic matter, and nutrient loading into the creek illustrates the necessity of reducing streambank erosion to ensure DO concentrations remain sufficient.

One possible source of sediment to ECC on 910 Ranch is East Canyon road. Research has shown that roads can increase sediment supply to streams by through erosion of the road surface and/or increasing hillslope erosion (Croke and Mockler 2001). The East Canyon Road is a dirt road throughout 910 Ranch and the amount of erosive sediment it contributes to the creek may increase as the 910 Ranch becomes open to the general public and more vehicles use the road. Therefore, paving should be considered as an action item, along with control of drainage off the road. Further analysis is needed to establish how much fine sediment is contributed by the road. Visual observations suggest that more fine sediment is sourced from streambanks, such that streambank reinforcement is recommended before paving operations.

Streambank reinforcement can be accomplished in several ways, including willow wattle/fascine installation, conifer revetments, riprap, or vegetated soil lifts (NRCS, 1998). Erosion mitigation through willow wattle/fascine installation increases over time, with immediately reduction in surface erosion of streambanks, followed by colonization of native vegetation along stream banks (NRCS, 1996). Conifer revetments have been shown to stabilize stream banks in a case study conducted at Chalk Creek, a creek located about 30 miles east of ECC; though they were also slightly more expensive per linear foot than willow fascines (Green, 2007). Riprap would be the most expensive on a per linear foot basis, but has the greatest potential to provide long term stability to stream banks (Green, 2007; NRCS, 1996). As a final word of caution, riprap has been shown to have a wide variety of success rates (Green, 2007) and further maintenance costs should be included in its final cost assessment if chosen as an action alternative.

Herbicide

Aquatic herbicide is a potential solution to kill aquatic macrophytes and periphyton whose respiration and breakdown leads to DO impairments. A detailed study of herbicide types for killing macrophytes in ECC was not performed in our analysis. Herbicide application in creeks in Utah is uncommon in the literature as a management practice for reducing macrophyte coverage. Herbicide application would likely need to be annual, as herbicide would not last in the water column over a long timescale. Application should be performed in the spring and summertime after the stream bed sediments are mobilized from spring runoff, and when water clarity allows for adequate sunlight infiltration. Herbicide would also affect all downstream portions of ECC, including East Canyon Reservoir. Herbicide would likely kill beneficial riparian plants whose roots draw from the water table directly connected to the stream (Sheley et al., 1995). Herbicide treatments can have several negative effects throughout a creek system, including increasing the amount of plant breakdown and respiration; thereby negatively impacting the creek’s BOD (Brooker and Edwards, 1975).

Tributary Improvement

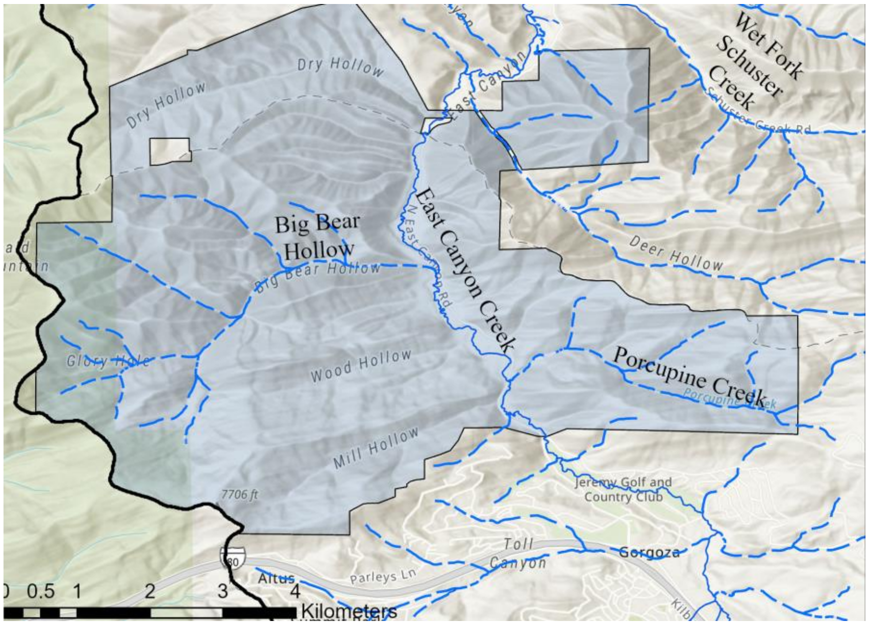

Figure 31. Map of ECC tributaries in the 910 Ranch Property.

Intermittent tributary streams may provide a significant proportion of BCT spawning habitat (Rousseau, 2022). As we identified a salmonid recruitment bottleneck, restoration of tributaries could support a BCT fishery on ECC. Potential for greater BCT spawning habitat exists in Porcupine Creek and Big Bear Hollow (**Figure 31**), two tributaries to ECC within the 910 Ranch Property. Options include removal of the culvert on Porcupine Creek (**Figure 32**) to improve fish passage to spawning habitat above, removal of cattle ponds on Porcupine Creek (which may also prevent fish passage), extension of cattle exclusion to tributary streams, and supporting beaver activity on both tributary streams.

Figure 32. Photo of culvert on the Porcupine Creek.

Do Nothing

The current fishery on ECC at 910 Ranch does not achieve Blue Ribbon Status, but does provide opportunities to catch desirable fish. The overall density of BNT is low compared to upstream reaches, but proportional stock density of large, potentially trophy size, BNT is high. The majority of BNT in the 910 Ranch are older, spawning adults, with a notable absence of younger fish, indicating possible issues with spawning success and recruitment. The current conditions of the creek, if left unaddressed, could continue to hinder the recruitment of new generations of fish. Without intervention, the 910 Ranch is unlikely to see improvements in its fishery. In the absence of restoration actions, the 910 Ranch is likely to have moderate value as a recreational fishery.

Despite the challenges it faces, 910 Ranch has considerable ecological value. Although limited in terms of its BNT population, the ECC supports a variety of other native fish species. The presence and high density of native fish species (Mottled Sculpin, Redside Shiner, Speckled Dace, Mountain Sucker, and Long Nosed Dace) indicates that ECC at 910 Ranch is important habitat for these fishes, and therefore has conservation value (**Figure 33**). The presence of mature BNT indicates that the 910 Ranch provides a suitable environment for at least a portion of their life cycle. The riparian zone, despite being reduced in vegetation, still plays a vital role in the creek's ecosystem. It offers habitat for various terrestrial and aquatic species, aids in the filtration and aggradation of sediments, and contributes to the overall ecological integrity of the creek. The site, despite its historical land management practices, demonstrates ecological resilience, and has the potential to support a richer biodiversity with improvements in habitat conditions. As a component of a larger watershed scale system, the ranch's conservation value extends beyond its immediate boundaries, playing a role in regional biodiversity and wildlife habitat connectivity.

Figure 33. Photo of juvenile Mountain Sucker. Photo Credit: USFWS

If we consider alternatives to improve the fishery at the 910 Ranch without engaging in restoration, the focus shifts to the management of recreational angling. Implementing special angling policies could enhance the fishery by ensuring sustainable fishing practices that protect existing fish populations. One effective approach may be implementing a catch-and-release policy during certain times of the year (to support successful spawning) or year-round. Another less stringent but helpful policy could be setting restricted bag limits for ECC. For example, in some Utah waters, a special limit is set to two trout. Restricting fishing to artificial flies and lures limits catch-and-release mortality and is another strategy for protecting current fish populations. Many areas in Utah have regulations that allow only artificial flies and lures. These measures can be adjusted based on the evolving state of fish populations in ECC. The goal is to balance recreational fishing with conservation needs, ensuring the long-term health and viability of the fishery at the 910 Ranch.

Alternatives Evaluation

We summarize the restoration alternatives according to our assessment of whether the benefit is likely to be achieved (confidence), the magnitude of the benefit impact, and the associated effort and cost (**Table 8**). In recommending priorities, we aim to enhance and establish broader ecological processes that are known to address the limiting factors we identified. For maximum impact, we recommend prioritizing cattle exclusion, revegetation, and trout stocking to target deficiencies in the ECC fishery. These alternatives have outsized impacts because they can positively impact multiple limiting factors that are believed to impair the fishery based on our analysis. Cattle exclusion and revegetation efforts are complementary and are required in conjunction to effectively shade the stream and stabilize the streambank in order to reduce fine sediment loading and temperature and DO impairments. Fish stocking serves as an immediate and predictable benefit to the fishery while restoration progresses.

Table 8. Table of possible actions to restore the 910 property, explaining the potential benefits, effort, and costs required. Based on a high, medium, and low scale.

Priority	**Confidence**	**Benefit Impact**	**Effort and Cost**
1. Cattle Exclusion	High	High	Low/Medium
2. Revegetation	High	High	Medium/High
3. Fish Stocking	High	High	Medium
Increased Baseflow	Medium	Medium	High
Beaver Augmentation	High	Low/Medium	Low
Tributary Improvement	Unknown	Unknown	Unknown
Bank Protection	Medium	Medium	Medium/High
Herbicide	Low	Low	Low
No Action	No Benefit	No action	No Effort/Free

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Appendices

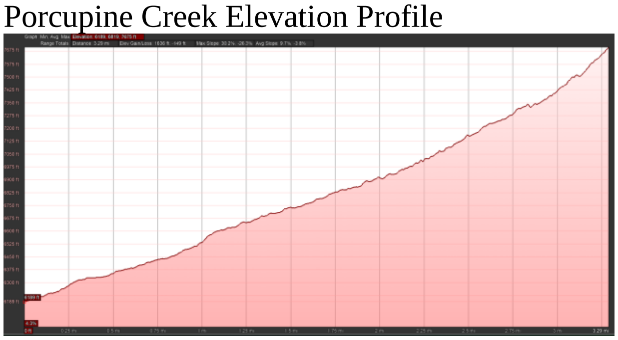
Appendix 1: Assessment of Tributary Streams

A simple visual walking inspection of Porcupine Creek and Big Bear Hollow were performed in November 2023 to look for evidence that these streams have potential to be fish habitat, particularly BCT spawning and rearing habitat.

Porcupine Creek:

In November, no streamflow was in the channel at Porcupine Creek at its confluence with ECC. Several hundred feet upstream, a trickle of water appeared and disappeared every so often. Close to the creek mouth, a culvert was identified as a likely impediment to salmonid passage. This culvert would need to be removed if restoration of Porcupine Creek for BCT spawning and rearing is to be pursued. Upstream of the culvert, an oversteepened stream slope preceded a large valley-bottom-spanning earthen dam with a dry cattle pond behind it. The dam presents an issue for fish habitat because of steep slopes at the base of the dam and stagnant, muddy water and high water temperatures in the pond. Upstream of the pond, the channel became more defined, flow increased, bank vegetation increased, and stream slope decreased. Beaver activity was noted. In addition, active beaver pond complexes were identified at the very upstream parts of the stream via satellite imagery. Our inspection gave an initial impression that Porcupine Creek could contain suitable trout spawning habitat during snowmelt season that is uniquely suited to the life cycle of native BCT.

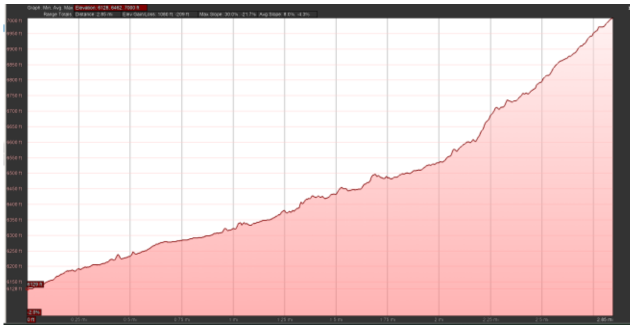
Porcupine Creek Elevation Profile



Big Bear Hollow:

Big Bear hollow was visited in November 2023 and had < 1 cfs flow. Near the mouth, the stream was affected by small cattle operation structures. Small fish were observed in the water. Upstream from the mouth, the creek valley bottom was steep and straight and confined by a road on the north side. Going upstream, streamflow stayed consistent, stream sinuosity increased, stream velocity decreased, and valley bottom width increased. There appeared to be good floodplain conductivity and multithreaded channels with pools and riffles. Impacts of cattle grazing were apparent in the channel and vegetation. The floodplain was grazed and streambank vegetation coverage was somewhat sparse. Due to suspected year round flows, Big Bear Hollow could contain spawning habitat for BNT and BCT.

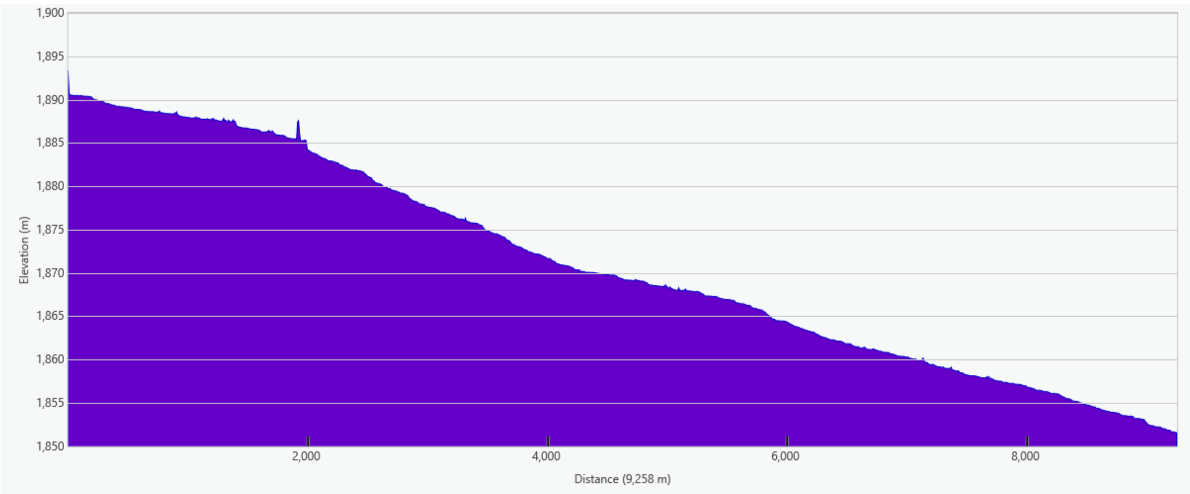
Big Bear Hollow Elevation Profile



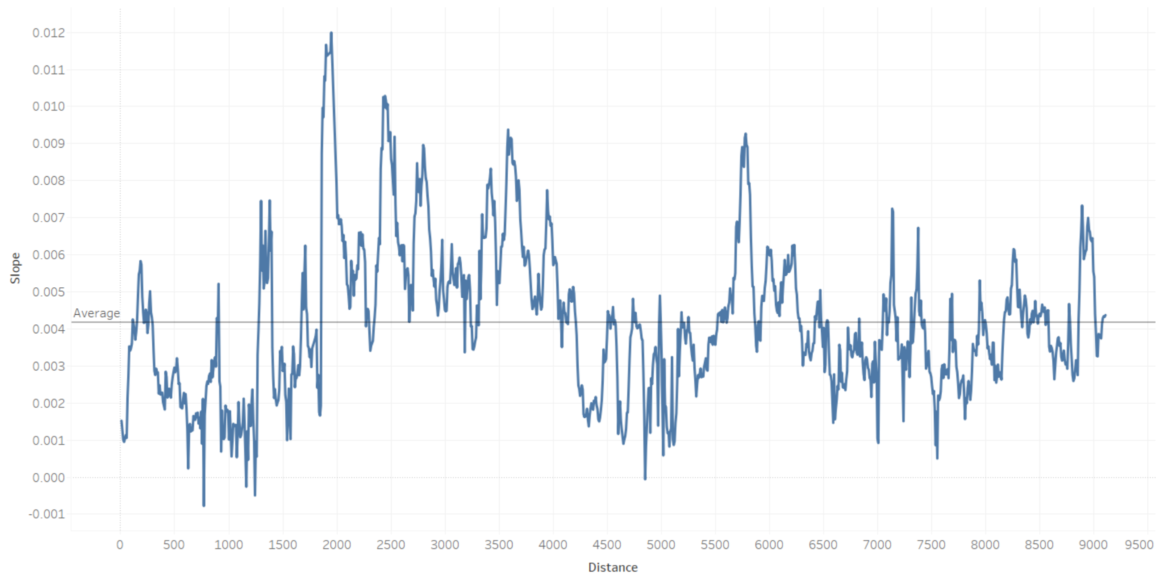
Appendix 3: 910 Ranch Site Characteristics

Elevation: 1891 m at Jeremy Ranch culvert, 1852m at end of reach at county boundary, giving 39m (128ft) total elevation change
Road mileage (valley bottom length): 6.4 km
Average valley bottom slope: 0.61%
Valley bottom acreage: 90 acres from parcel end to end
Total ranch acreage: 8576
Valley bottom percentage of acreage: 1%
Stream length 2020: 9.3 km
Stream length 1977: 8.6 km
Stream slope 2020: 0.42%
Average stream width- 8.3 m
Stream surface area = 79,500 m2, 19.6 acres

910 Ranch Stream Elevation Profile



910 Ranch Stream Slope Profile



Appendix 3: Expected Spawning and Emergence Dates for Brown Trout and Bonneville Cutthroat Trout

Calculations of expected spawning and emergence dates were developed using temperature data from USGS gauges (Jeremy Ranch - 10133800 & East Canyon Creek Above Reservoir - 10133980). Growing degree day calculations were made using average daily temperatures from each gauge (daily time steps). Oviposition date, the day that eggs are laid, for BCT was determined by selecting the first day of the year with a mean daily temperature greater than or equal to 7 °C. This was determined by taking the average of the range of spawning temperatures presented in the literature (4 °C - 10 °C) (Kershner, 1995). First and last emergence dates are 310 - 345 degree days after the day of spawning, based on the widest range of possible values found in the literature (Kershner, 1995). For BNT, oviposition date was November 1st of each year, and 410 - 457 Degree Days are required for emergece. Calculations used 0 °C as the lower threshold of a growing degree day, based on the absolute minimum value presented in the literature (Siamlek et al., 2021).

A range of expected spawning and fry emergence dates for BNT and BCT was calculated using the growing degree day values and temperature data from the Jeremy Ranch and Above Reservoir USGS gauges. Assuming **BNT lay their eggs on November 1st, they are expected to hatch from March 16th to March 26th near the Jeremy Ranch gauge, and April 18th to April 23rd near the Above Reservoir gauge.** Using temperature cues for oviposition, **BCT are expected to lay their eggs April 3rd, and fry emergence is expected to occur May 10 until May 13th, near both gauge sites.** Spawning behaviors of BCT are more temporally variable than BNT, so the dates presented for BCT represent earliest expected spawning and emergence. Merriman et al. (1939) found that BCT emergence can last anywhere from 28 to 57 days depending on temperatures, with warmer temperatures related to earlier emergence.

The below charts are calculated spawning and emergence dates for each year of temperature record for BCT (top) and BNT (bottom), based on Jeremy Ranch gauge temperatures (left) and Above Reservoir gauge temperatures (right).

Jeremy Ranch			
Cutthroat Trout Emergence			
Based on absolute min (0* C)			
Spawning Year	**Eggs Laid Estimate**	**First**	**Last**
2002	4/5/2002	5/12/2002	5/14/2002
2003	3/22/2003	5/2/2003	5/5/2003
2004	3/25/2004	5/2/2004	5/3/2004
2005	4/2/2005	5/10/2005	5/13/2005
2006	4/12/2006	5/17/2006	5/19/2006
2007	4/23/2008	5/28/2008	5/30/2008
2008	4/23/2008	5/28/2008	5/30/2008
2009	4/13/2009	5/18/2009	5/20/2009
2010	4/17/2010	5/25/2010	5/27/2010
2011	4/16/2011	5/26/2011	5/29/2011
2012	3/30/2012	5/5/2012	5/8/2012
2013	3/28/2013	5/7/2013	5/10/2013
2014	4/7/2014	5/11/2014	5/14/2014
2015	3/13/2015	4/19/2015	4/22/2015
2016	3/21/2016	4/28/2016	5/1/2016
2017	3/17/2017	4/29/2017	5/2/2017
2018	3/30/2018	5/6/2018	5/7/2018
2019	4/18/2019	5/21/2019	5/24/2019
2020	3/31/2020	5/6/2020	5/9/2020
2021	4/2/2021	5/8/2021	5/11/2021
2022	3/26/2022	5/7/2022	5/10/2022
2023	4/29/2023	5/30/2023	6/1/2023
Average	3-Apr	10-May	13-May

Above Reservoir			
Cutthroat Trout Emergence			
Based on absolute min (0* C)			
Spawning	**Eggs Laid Estimate**	**First**	**Last**
2008	4/13/2008	5/21/2008	5/24/2008
2009	3/17/2009	5/6/2009	5/8/2009
2010	4/15/2010	5/25/2010	5/28/2010
2011	4/12/2011	5/25/2011	5/28/2011
2012	3/25/2012	5/1/2012	5/3/2012
2013	3/15/2013	4/29/2013	5/2/2013
2014	4/7/2014	5/10/2014	5/13/2014
2015	3/14/2015	4/20/2015	4/22/2015
2016	3/20/2016	4/27/2016	4/30/2016
2017	3/18/2017	5/1/2017	5/3/2017
2018	3/12/2018	4/26/2018	4/28/2018
2019	4/18/2019	5/22/2019	5/25/2019
2020	3/31/2020	5/6/2020	5/9/2020
2021	4/2/2021	5/8/2021	5/10/2021
2022	3/26/2022	5/6/2022	5/9/2022
2023	4/30/2023	6/1/2023	6/4/2023
Average	3-Apr	10-May	13-May

Jeremy Ranch Daily		
Brown Trout Emergence		
Based on absolute min (0* C)		
Spawning Year	**First**	**Last**
2001-02	4/4/2002	4/10/2002
2002-03	3/23/2003	3/30/2003
2003-04	3/14/2004	3/23/2004
2004-05	3/13/2005	3/23/2005
2005-06	4/1/2006	4/10/2006
2006-07	3/26/2007	4/2/2007
2007-08	3/19/2008	4/3/2008
2008-09	3/9/2009	3/19/2009
2009-10	3/16/2010	3/26/2010
2010-11	4/8/2011	4/15/2011
2011-12	4/5/2012	4/11/2012
2012-13	3/15/2013	3/24/2013
2013-14	2/13/2014	3/2/2014
2014-15	2/16/2015	2/28/2015
2015-16	3/21/2016	3/29/2016
2016-17	3/1/2017	3/12/2017
2017-18	2/15/2018	3/4/2018
2018-19	3/12/2019	3/21/2019
2019-20	3/30/2020	4/5/2020
2020-21	3/14/2021	3/24/2021
2021-22	3/4/2022	3/17/2022
2022-23	4/9/2023	4/23/2023
Average	**16-Mar**	**26-Mar**

Above Reservoir Daily		
Brown Trout Emergence		
Based on absolute min (0* C)		
Spawining Year	**First**	**Last**
2007-08	4/24/2008	4/30/2008
2008-09	4/11/2009	4/17/2009
2009-10	4/22/2010	4/27/2010
2010-11	4/14/2011	4/21/2011
2011-12	4/11/2012	4/16/2012
2012-13	4/4/2013	4/10/2013
2013-14	4/11/2014	4/15/2014
2014-15	3/19/2015	3/24/2015
2015-16	4/5/2016	4/9/2016
2016-17	4/3/2017	4/9/2017
2017-18	3/31/2018	4/6/2018
2018-19	4/24/2019	4/29/2019
2019-20	4/14/2020	4/20/2020
2020-21	4/16/2021	4/21/2021
2021-22	4/12/2022	4/18/2022
2022-23	5/14/2023	5/18/2023
Average	**18-Apr**	**23-Apr**