EFFECTS OF ROAD CONSTRUCTION ON WATER QUALITY PARAMETERS AND BULL TROUT (*SALVELINUS CONFLUENTUS)* POPULATIONS IN THREE MONTANA WATER BODIES

by

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Land Resources and Environmental Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

March 2019

DEDICATION, ACKNOWLEDGEMENTS, VITA

This work is dedicated to my sister and my friend Samantha Jon Thatcher. Thank you for all your support and encouragement. I could not have done any of this without you. Poughkeepsie.

I would like to acknowledge Dr. Scott Powell for his patience and guidance in the completion of this project as well as the United States Geology Survey Water Resources Mission Area and Montana Fish, Wildlife, and Parks for their extensive resources, databases, and available information.

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ABSTRACT

Road construction adjacent to rivers and ensuing clearing of timber and shrubs can lead to alterations in the dynamics and morphology of channel features and water chemistry that provide habitats for aquatic biota. We examined associations between bull trout (*Salvelinus confluentus*) populations and water quality parameters related to road construction in three western Montana rivers over a 15-year study period. Bull trout have specific habitat requirements that can influence their overall abundance and distribution within a watershed, making them an important indicator species of general ecosystem health. We used average annual bull trout population data from Montana Fish, Wildlife, and Parks and daily water quality observations from the United States Geological Survey between 2000 and 2014 to analyze the correlation between the data sets. We used a nonparametric statistical test to determine whether any significant change was observed between the medians of pre- and post-construction water quality parameters and bull trout population numbers. The association between the water quality parameters and bull trout numbers was visually examined with scatter plots created in R where the Y-axis was population numbers and the X was the water quality parameter. The plots were then fit with a linear regression line and from this a visual interpretation of the association and strength of said associated was determined. The analysis yielded unexpected results with only some of the water quality parameters exhibiting a negative relationship with road construction disturbance. Two water bodies (Flathead River and Warm Springs Creek) showed no significant changes in bull trout population numbers, and the control water body with no road construction (the Blackfoot River) displayed significant differences between the pre- and post-construction water quality parameter medians. The parameters that did display expected outcomes (cadmium concentration in the Flathead River; water temperature, pH, and instantaneous discharge in Warm Springs Creek; and instantaneous discharge, pH, and cadmium concentration in the Blackfoot River) were not all strongly correlated with decreased bull trout population numbers. The water quality parameters common to all the study rivers that presented a negative association with bull trout numbers was pH. High levels of recreation and management activities on the Blackfoot River (the control) could explain these unexpected findings. The results do, however, partially corroborate previous studies on the negative association between bull trout population numbers and road construction-related disturbance. A longer study period combined with finer-grained data would be beneficial for future studies.

INTRODUCTION

Species Description

Salvelinus confluentus (bull trout) are members of the Salmonidae family native to cool, high elevation watersheds in Montana, Oregon, Washington, Idaho, and Western Canada. Compared to other members of the Salmonidae family, bull trout have more specific habitat requirements that can influence their overall abundance and distribution (ECOS, 2019). The species is often confused with *Salvelinus fontinalis* (brook trout) and *Salvelinus namaycush* (lake trout) but differ in several of their physical characteristics. Bull trout are a long slender species with a large head and jaws that do not form spots on the dorsal or back fin (ECOS, 2019) (Figure 1).

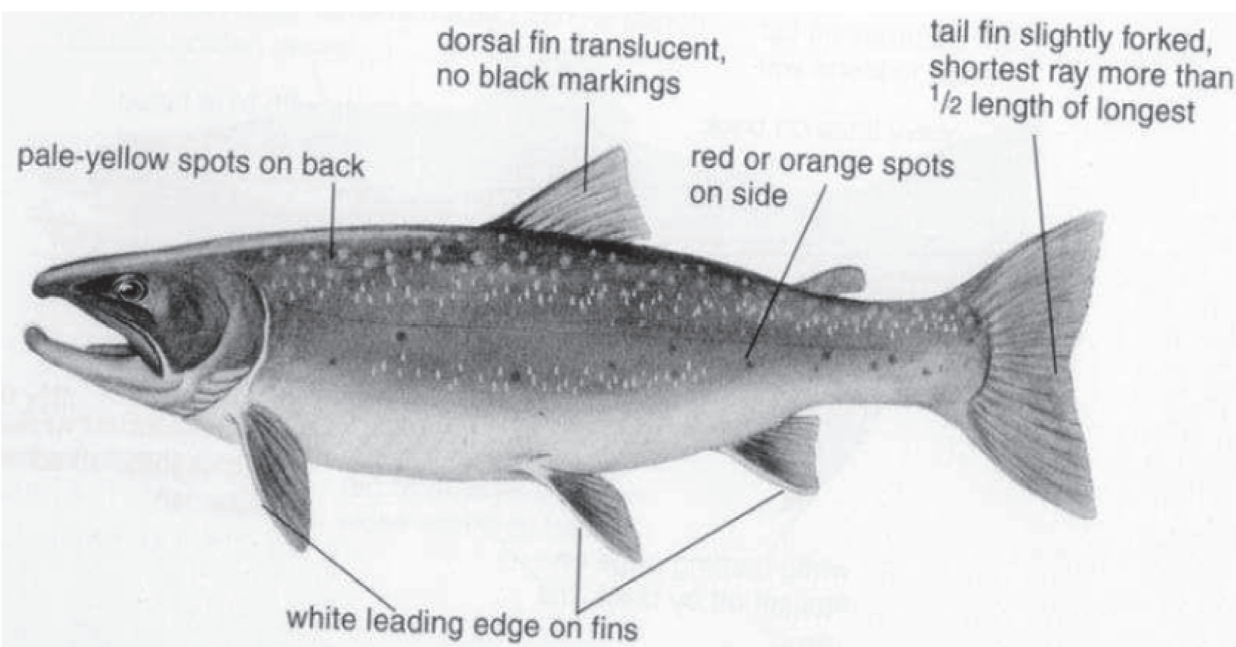

Figure 1: Adult bull trout with identifying characteristics (image obtained from http://fieldguide.mt.gov/speciesDetail.aspx?elcode=AFCHA05020).

Fluvial bull trout are an important ecological and recreational component of river systems (Swanberg, 1997). Due to their historical decline, bull trout are classified as a threatened species under the U.S. Endangered Species Act as of 1999. The cold-water species decline has been shown to be linked to several factors including habitat degradation and fragmentation, blockage of migratory corridors, water quality, watershed management practices, and the introduction of non-native species (USFWS, 2018). Bull trout are rarely found in water temperatures warmer than 5 to 18 ºC. and they require stable channels, clean gravel to spawn, complex cover, and unblocked migration routes (USFWS, 2018). Due to their sensitivity and specific habitat requirements, bull trout are an indicator species of general ecosystem health (Post and Johnston, 2002).

I focused this analysis on a group of water quality parameters that are known to be affected by road construction and have been hypothesized to be important to bull trout population numbers. This study looked at three water bodies in Montana (The Flathead River, Warm Springs Creek, and The Blackfoot River) for a 15-year study period between 2000 and 2014. I first analyzed several water quality parameters for pre- versus post-construction differences. Then, I examined the association between water quality parameters and bull trout population numbers by scatter plots, to better understand the relationships between bull trout populations and road construction. This study is intended to inform future studies, bull trout management schemes, and road construction environmental best management practices.

Water Quality Parameters:

Temperature:

Water temperature is a key element in the distribution and richness of aquatic biota. Primarily, it is regulated at two spatial scales, riparian and watershed (Wheeler et al., 2005). At the riparian scale, vegetation shields water from warming by absorbing or reflecting sunlight, so the removal of such vegetation during road construction activities can lead to an increase in stream or river water temperatures. At the watershed scale, asphalt pavements or other impervious surfaces collect and heat runoff before it reaches streams or rivers (Wheeler et al., 2005). The ideal thermal zone for bull trout is 5 to 18 ºC. Bull trout are a cold-water species that requires water temperatures of 2–4 °C for egg incubation (Hammond, 2004). Salow and Hostettler (2004) concluded that temperature can drive bull trout movement and exacerbate the effects of other water quality parameters on physiology. Increases in water temperatures can lead to population fragmentation and may lead to an increased risk of invasion by other species that can displace bull trout and lead to further population decreases (Hammond, 2004).

Discharge

Significant changes in peak flows, storm volumes, and response time to storm events are known to be associated with increased development, such as road construction, within a watershed. As the area of a clear-cut is increased, a corresponding increase in storm volume generally occurs and, in this respect, road development can lead to earlier, higher peak flows (Hammond, 2004). Decreases in discharge rates leave streams or rivers more susceptible to thermal warming, therefore, lower discharge rates during road construction season (summer months) usually result in lower thermal capacity (Jones et al., 2014). Bull trout distributions and abundance are strongly influenced by streamflow gradients and discharge rates, requiring a minimum flow rate of 0.028 m^3/s (Jones et al., 2014).

Suspended Sediment

Wheeler et al. (2005) found that deposition of fine sediment from road construction can immediately alter fish populations by impairing visibility and reducing reproductive success of a species. Concentrations of metals in water body sediments have been found to be positively related to the volume of traffic and amass in proportion to the length of the road construction project being drained, suggesting that pollution will be most severe when large projects are drained by smaller streams (Wheeler et al., 2005). Rieman (1993) also linked levels of fine sediments in streams to road densities. Disturbances can also lead to an increase in sedimentation and erosion which is undesirable as has been shown to lead to degradation of bull trout spawning and rearing habitats, as well as cause direct injury to the (Hammond, 2004). Most fish have an upper tolerance level for suspended sediment of between 80 and 100 mg/L (EPA, 2003).

Zinc Concentration

Zinc originates from the corrosion of galvanized metals, roofing materials, and painted wood. Common materials utilized in road construction activities containing zinc are bolts, guard rail, corrugated metal pipe, slope pin plates, sign posts, fencing, testing equipment, tires, and recycled asphalt shingles or RAS products. Newly constructed roadway surfaces collect a variety of pollutants during and after construction from automobile traffic and are disproportionate contributors to an ecosystem's overall pollutant loads (Wheeler et al., 2005). Such pollutants are mobilized by runoff and transported to streams where they accumulate in sediments and biota and spread downstream, resulting in chronic and widespread effects (Wheeler et al., 2005). Hansen et al. (2002) found that the 120-hour LC_{50} concentration for bull trout exposed to zinc can range from 36 to 80 g/L, such acute zinc exposure causes mortality in bull trout through a net loss of calcium. Temperatures greater than 12 °C are common in bull trout habitat during summer months and can increase the toxicity of zinc (Hansen et. al., 2002).

Cadmium Concentration

Cadmium and its associated compounds are highly toxic. Oil and vehicle tires contain zinc and cadmium. Pollution of this metal in road construction can also originate from fly ash, road striping paints; cadmium electroplated steel nuts, bolts, and rivets; anti-corrosives; alkaline batteries; and welding (MIOSHA, 2019). Bull trout are susceptible to cadmium exposure in that, like zinc, the metal inhibits the uptake of calcium (Hansen et al., 2002). Hansen et al. (2002) found the cadmium concentration that reduced growth and survival of bull trout was 0.786 µg Cd/L. Exposure levels of 0.786 µg Cd/L can reduced both survival and growth in bull trout in a 55-day exposure and concentrations as low as 0.052 µg Cd /L cause elevated cadmium tissue concentrations (Hansen, J. A., 2002).

<u>Lead Concentration</u>

Lead exposure can result from such road construction activities as abrasive blasting, sanding, cutting, burning, or welding of bridges and other steel structures coated with lead-containing paints; digging, drilling, chipping, or the expansion or resurfacing of old road surfaces or adjacent shoulders (particularly around old or repainted bridge structures) (NYDH, 2015); and from brick surfaces (Wheeler et al., 2005). Due to the accepted toxicity of lead in the United States during the early 1970s, very few current road construction activities lead to exposure. Holcombe et al (1976) reported that lead exposure can cause severe spinal deformities as well as large accumulations of lead in the gills, liver, and kidneys of the study species. Davies et al. (1976) found that lead was highly toxic to members of the Salmonidae family, particularly when they were exposed as eggs.

pH

The United States Environmental Protection Agency has concluded that a pH range of 6.5 to 9.0 provides adequate protection for the life of freshwater fish and bottom-dwelling macroinvertebrates. Outside this range, bull trout suffer adverse physiological effects that increase in severity as the degree of deviation increases until lethal levels are reached (Hansen et al., 2002). Anthropogenic causes of pH fluctuations are usually related to pollution and may be related to road construction, which has become one of the major nonpoint pollution sources, leading to both short- and long-term effects on stream biotic and abiotic conditions (Chen et al., 2009). pH is temperature dependent and is a controlling factor in the solubility of elements and compounds such as cadmium and zinc (Tuncan et al., 2000). This makes toxic chemicals more mobile and increases the risk of absorption by fish and other organisms. pH of water is vital to aquatic life in that it directly affects aquatic organisms’ ability to regulate their basic life processes, mainly exchanges of salts and respiratory gasses with the water in which such organisms reside.

METHODS

The objectives of my study are to ascertain if any of the selected water quality parameters are affected by road construction activities and if these parameters are associated (either negatively or positively) with bull trout population numbers for the given study period (2000-2014). The first objective will be assessed by testing the water quality parameters and population data for normal distributions, then conducting an appropriate statistical test in R version 3.4.1. on the data to establish if pre-construction disturbance medians differ significantly from post-construction disturbance medians. Objective two will be assessed by creating scatter plots in R where bull trout population numbers are plotted on the Y-axis and the water quality parameter on the X. These plots will then be fit with a linear regression line and the association and strength of said association with be determined. Scatter plots with down-sloping regression lines will display the hypothesized negative association with bull trout population numbers.

Watershed Descriptions:

Flathead River

The first water body selected for this study was the Flathead River near Columbia Falls, MT (Figure 2). This watershed is comprised of the 7,615 km^2 that drain into the Flathead River and Flathead Lake and beyond the lake to the confluence of the Flathead and Clark Fork Rivers (Flathead, 2014). This area begins north of the Canadian border and extends down to the Clark Fork drainage to the south bounded by the Salish Range in the northwestern boundary and the Continental Divide in the east. The Flathead National Forest administers the largest quantity of public land in the watershed, nearly 60% of forested lands in the North, Middle and South Forks of the Flathead drainages. Recharge areas found in Glacier National Park, the Bob Marshall Wilderness and other undisturbed forested lands provide clean water to the rivers and lakes of the watershed (Flathead, 2014).

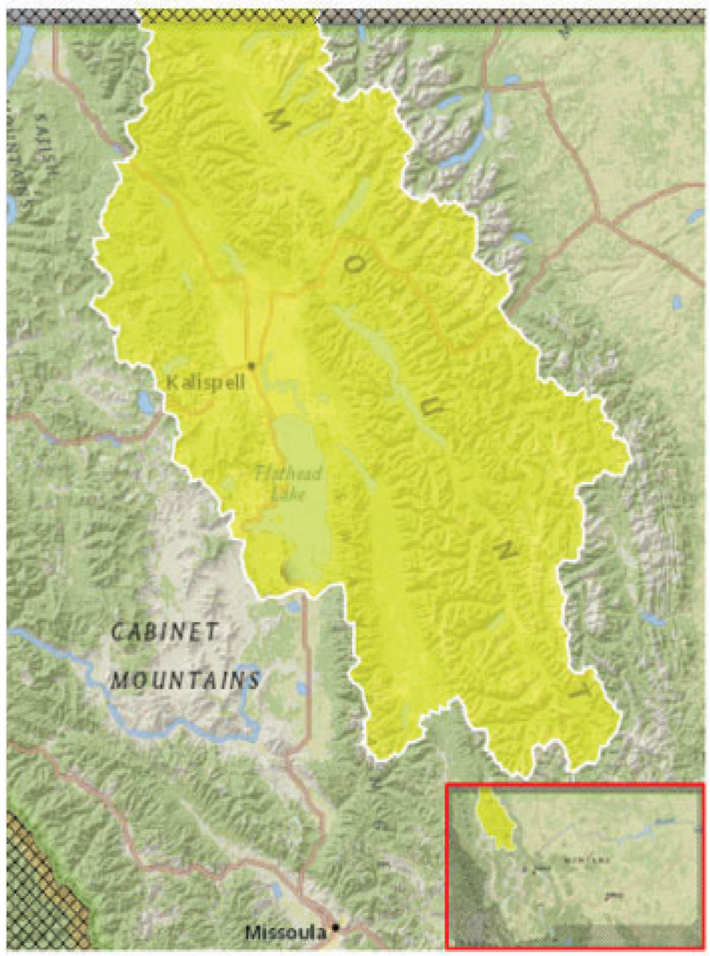

Figure 2: Delineation of Flathead River watershed created at https://streamstats.usgs.gov/ss/ All areas outside of Montana are hashed out to aid in visualization.

Construction Disturbances

During the study period of 2000 to 2014 there were four road construction projects completed along the Flathead River. They are the Columbia Heights East

Surfacing Project, Hungry Horse-West Glacier Overlay Project, and two signaling projects. All construction employed temporary erosion and sedimentation control best management practices (BMPs), dust control, and clearing and grubbing was allowed in most of the project limits. These road construction projects were used to divide each water bodies' data in to pre- and post-road construction disturbance (Table 1).

Warm Springs Creek

Warm Springs Creek is one of the Clark Fork River's major tributaries. Located in Jefferson County, it drains roughly 405 square kilometers and land ownership is split between the Forest Service and private owners and land use is primarily agricultural (grazing, pasture, irrigated agriculture, timber harvest), recreational, and significant historical mining (Watershed, 2012). This watershed depicted in Figure 3, is bounded in the east by the Boulder Mountains, the Flint Creek Range in the west, the Garnet Range to the north, and the Highland and Anaconda Pintler Ranges to the south (MDEQ, 2010). This watershed has been undergoing remediation efforts to address the extensive metal contamination and to aid in the prevention of future erosion and leaching since the early 1990s due to the Anaconda Smelter located nearby (MDEQ, 2010).

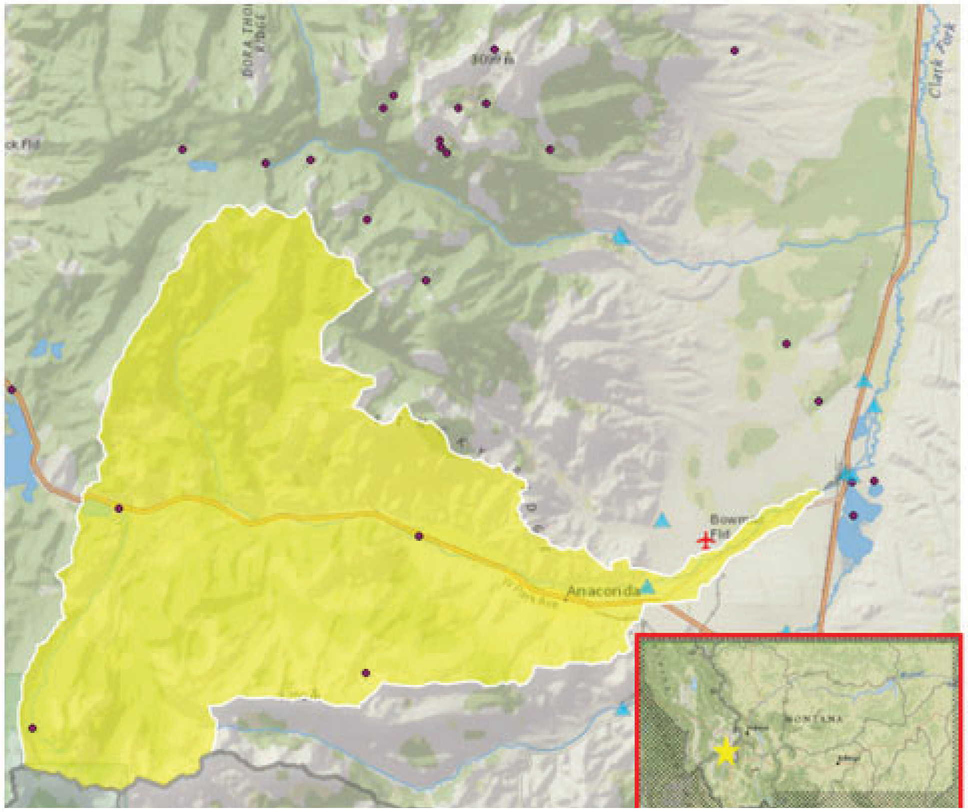

Figure 3: Delineation of Warm Springs Creek watershed created at https://streamstats.usgs.gov/ss/ Dots represent regulation points and triangles are locations of stream gages.

Construction Disturbances

Warm Springs Creek experienced two road construction projects during the 2000 to 2014 study period, the Logan Area I-90 Bridge Deck project and the Anaconda Interchange Rest Area Project. Both disturbances employed erosion and sedimentation BMPs, dust control, replaced topsoil and conducted seeding, and allowed clearing and grubbing with in the project limits. The rest area project did impact adjacent wetlands and the contractors were responsible for all mitigation and remediation (MDT, 2019). The approximate locations of these projects are also found on Figure 5 and both projects were used to divide Warm Springs Creek's data in to pre- and post-road construction disturbance which is shown in Table 2.

<u>Blackfoot River</u>

The Blackfoot River watershed is located in Lewis and Clark County in western Montana (Figure 4). With a drainage area of 5,931 square kilometers and cattle graze the lower reaches of the Blackfoot River but middle areas, where spawning occurs, have received little anthropogenic disturbance (Swanberg, 1997). The Blackfoot River is one of Montana's most used and popular streams due to its picturesque natural features, wildlife, and cultural history. Public uses of the area range from fly fishing, hiking, and floating.

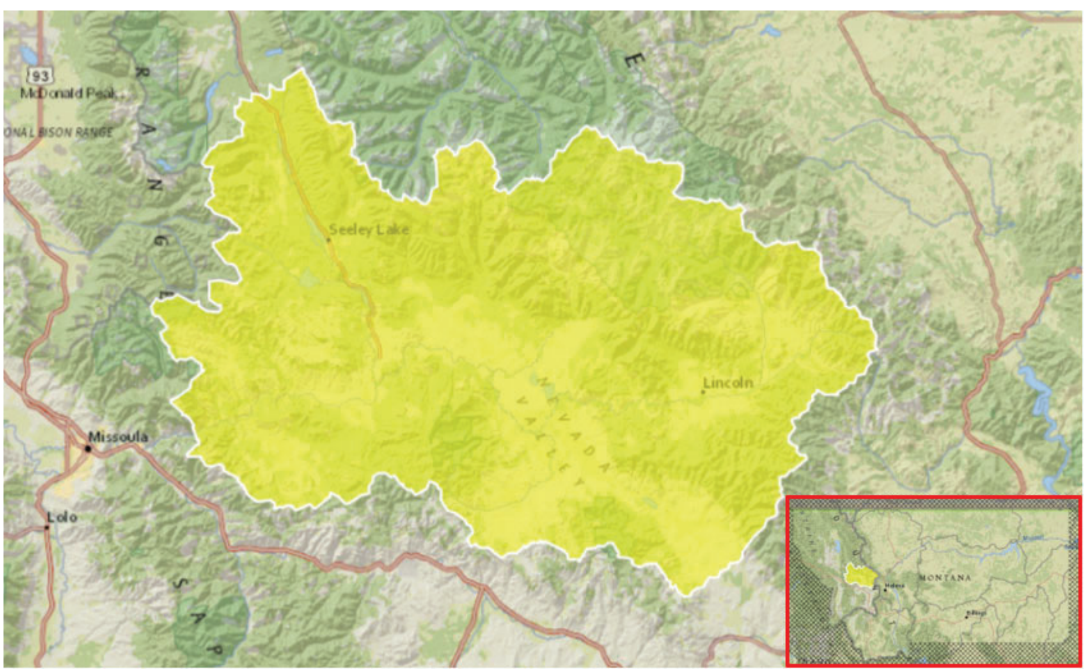

Figure 4: Delineation of Blackfoot River watershed created at https://streamstats.usgs.gov/ss/

Construction Disturbances

No road construction related disturbances occurred along this water body during the study period. It was chosen to serve as a control water body to allow for a comparison against the other two streams that were affected by road construction. The data used for the Blackfoot River were split in half at 2006 (Table 3).

Data

The relationships among bull trout population numbers, water quality parameters, and road construction disturbances were assessed by comparing water quality data with species abundance derived from surveys conducted on each of the selected water bodies. The bull trout population data sets were only available as annual averages and were conducted between 2000 and 2014 by the Montana Fish, Wildlife, & Parks (MFWP) as part of a long-term monitoring project utilizing electrofishing. Water quality parameters were obtained from the USGS Water Resources Database (nwis.waterdata.usgs.gov), available as daily observations which were converted to annual averages for the study period. Annual hydrologic conditions varied greatly during the study time period as it encompassed multiple seasonal runoff periods. Tables 1 through 3 depict the collected data for the study locations with pre-construction disturbance data highlighted in gray. Data for the Blackfoot River were split in half as there were no road construction projects during the study period. Information on road construction projects was gathered using the State of Montana Department of

Transportation website (mdt.mt.gov). Maps of construction project locations were created using the State of Montana Department of Transportation Spatial Data Map (mdt.maps.arcgis.com).

Statistical Analysis

Data obtained from the USGS Water Resources Database and the MFWP database were tested for normality using the Shapiro-Wilk normality test, kurtosis, skewness, and by the creation of Q-Q plots in R version 3.4.1. These tests indicated that the data were not normally distributed, therefore a nonparametric statistical analysis was needed.

The null hypotheses (H_0) for each water quality parameter and bull trout survey for each water body was that the pre-construction disturbance median of the given parameter/survey is not significantly different from the post-construction disturbance median of the parameter/survey. The alternative hypotheses (H_1) was that pre-construction disturbance medians are significantly different from post-construction disturbance medians for each parameter/survey. For example:

> H_0=Pre-construction median of water temperature in the Flathead River is not significantly different from the post-construction water temperature median.

H_1=Pre-construction median of water temperature in the Flathead River is significantly different from the post-construction water temperature median.

The level of significance was set to 5% (α=0.05) for all water quality parameters and bull trout surveys for each of the water bodies during the study period. A Mann-Whitney U test was used in R for each parameter to establish if there were any significant differences between population medians before and after road construction disturbances. If the generated p-value from the Mann-Whitney U analysis was greater than the level of significance, we failed to reject the null hypothesis (if p-value >0.05: fail to reject H_0) and conversely if the p-value was less than the level of significance, we rejected the null hypothesis (if p-value<0.05: reject H_0).

RESULTS

Evaluation of Water Quality Parameters:

Flathead River

The statistical analysis indicated that only cadmium concentration medians differed significantly from pre-construction disturbance to post-construction disturbance (Table 2). All the other water quality parameters had Mann-Whitney U p-values greater than the chosen level of significance of 5%. Box plots were created as a graphical representation of these data for each water quality parameter and bull trout population survey for the Flathead River.

Table 1: Flathead River Water Quality Parameter and Bull Trout Population Data with Pre-Construction Data Highlighted in Gray

Year	Bull Trout Population Count	Water Temperature (°C)	Instantaneous Discharge (m^3/s)	Suspended Sediment Concentration (mg/L)	Zinc Concentration (µg/L)	Cadmium Concentration (µg/L)	Lead Concentration (µg/L)	pH (Standard Units)
2000	32	7.73	99.73	17.67	5.00	0.10	1.00	8.20
2001	22	8.59	72.77	7.00	4.33	0.10	1.00	7.74
2002	12	6.36	165.55	145.00	24.0	0.30	4.21	8.33
2003	12	8.80	105.30	13.00	2.00	0.20	0.37	8.23
2004	11	7.43	101.57	-	1.50	0.03	0.24	7.85
2005	15	7.83	106.83	-	3.00	0.05	1.61	8.10
2006	37	11.17	84.00	-	8.00	0.08	1.37	8.20
2007	40	7.79	126.50	39.73	3.40	0.02	0.50	8.19
2008	21	6.61	169.57	53.70	11.55	0.06	2.05	8.21
2009	23	7.85	194.33	-	1.50	0.06	0.11	8.08
2010	8	7.12	33.00	-	2.00	0.04	0.06	8.18
2011	9	5.10	287.00	-	2.60	0.04	0.12	8.27
2012	6	5.61	122.57	-	5.88	0.05	2.00	8.20
2013	8	7.61	164.71	-	2.75	0.02	0.07	8.28
2014	7	-	20.97	-	2.00	0.07	0.10	8.30

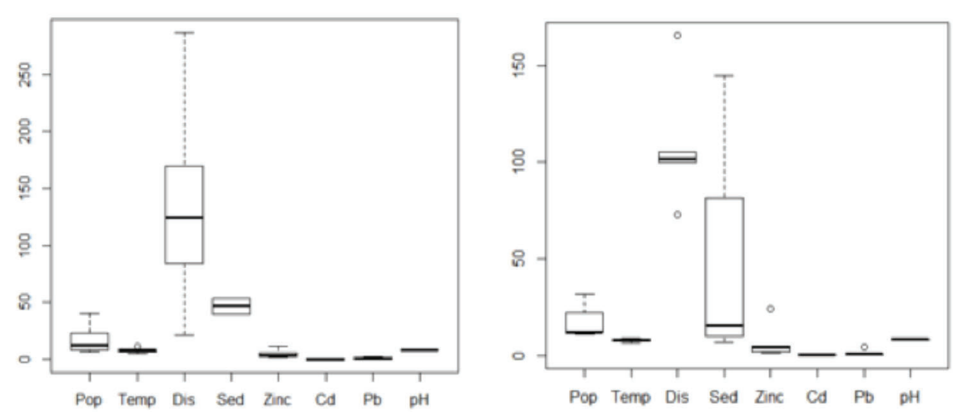

Figure 5 & 6: Boxplots of Flathead River Pre- and Post-road construction disturbance data for water quality parameters and bull trout population numbers (From left to right on Pre and Post: population numbers, water temperature, instantaneous discharge rate, SSC, Zinc concentration, Cadmium concentration, Lead concentration, and pH.

The association between the water quality parameters and bull trout numbers was visually examined with scatter plots created in R where the Y-axis was population numbers and the X was the water quality parameter. The plots were then fit with a linear regression line and from this a visual interpretation of the association and strength of said associated was determined. Figures 7 through 10 are the plots for instantaneous discharge rate, SSC, Cadmium concentration, and pH. For the Flathead River these were the only water quality parameters that displayed the anticipated negative association with bull trout population numbers and the associations were weaker than hypothesized strong negative association. Because R2 is described as the goodness of fit for regressions, the negative R2 of the plots indicate the fit of the regression equations are poor.

Table 2: Flathead River Statistical Analysis Data

Parameter	**Mann-Whitney U Test**
Water Temperature	W = 29, p-value = 0.6679, p-value > α (0.05)
Instantaneous Discharge Rate	W = 18, p-value = 0.4396, p-value >α (0.05)
Suspended Sediment Concentration	W = 2, p-value = 0.5333, p-value > α (0.05)
Zinc Concentration	W = 26.5, p-value = 0.9021, p-value > α (0.05)
Cadmium Concentration	W = 42, p-value = 0.04274, p-value < α (0.05)
Lead Concentration	W = 32, p-value = 0.4256, p-value > α (0.05)
pH	W = 22, p-value = 0.7586, p-value > α (0.05)

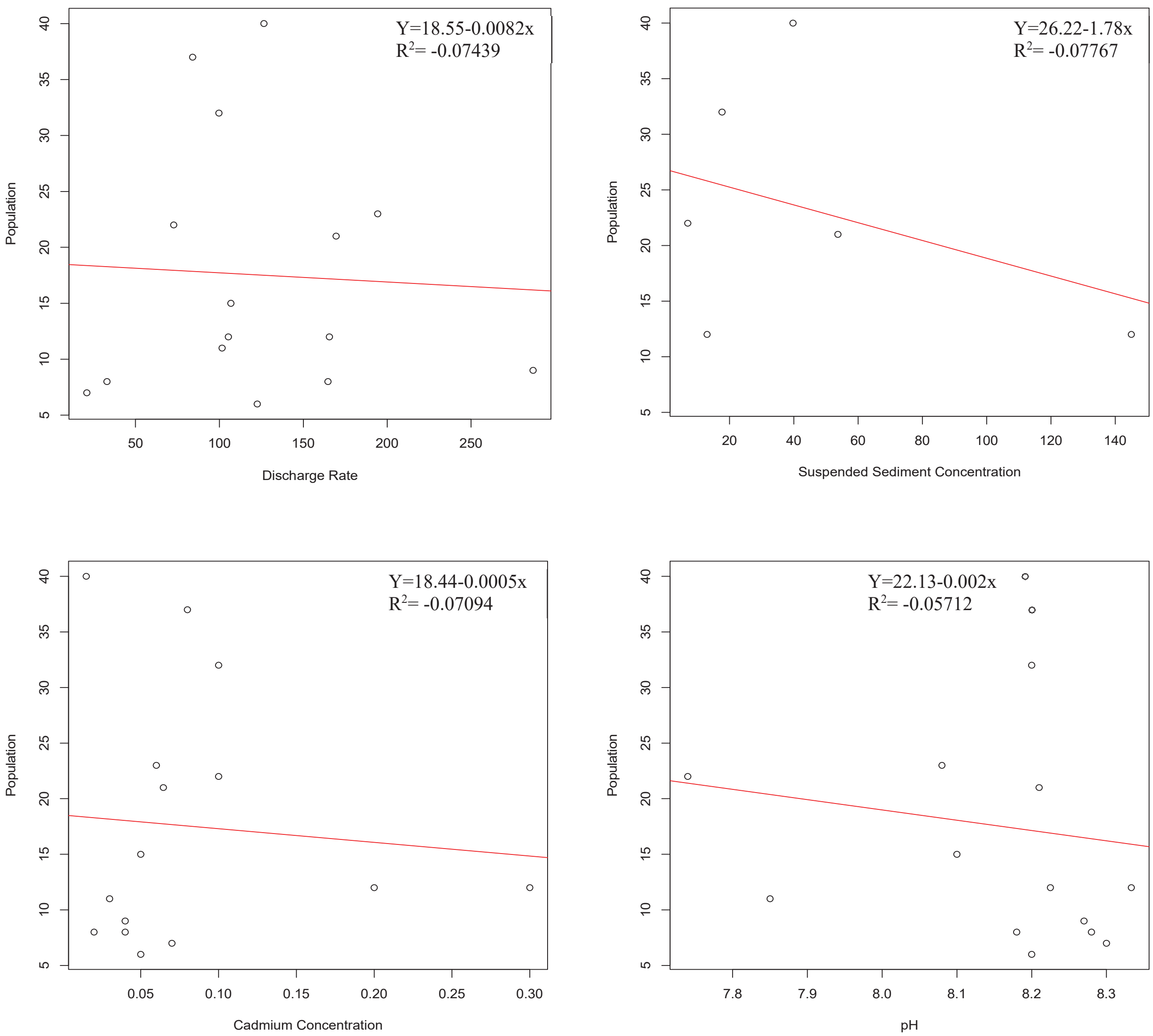

Figure 7-10: Scatter plots of Flathead River water quality parameters that displayed negative association with bull trout population numbers.

<u>Evaluation of Water Quality Parameters: Warm Springs Creek</u>

The statistical analysis yielded three parameters (water temperature, pH, and instantaneous discharge) that had medians that differed significantly between pre-construction disturbance and post-construction disturbance (Table 4). All the other water quality parameters had Mann-Whitney U p-values greater than the chosen level of significance of 5%.

Table 3: Warm Springs Creek Water Quality Parameter and Bull Trout Population Data with Pre-Construction Data Highlighted in Gray

Year	Bull Trout Population Count	Water Temperature (°C)	Instantaneous Discharge (m^3/s)	Suspended Sediment Concentration (mg/L)	Zinc Concentration (µg/L)	Cadmium Concentration (µg/L)	Lead Concentration (µg/L)	pH (Standard Units)
2000	7	10.95	0.84	5.33	3.50	0.10	1.08	8.37
2001	28	9.37	1.09	5.67	2.50	0.10	1.00	8.43
2002	12	9.00	1.40	8.00	4.00	0.07	1.13	8.34
2003	8	8.73	3.18	21.00	9.44	0.10	2.26	8.39
2004	10	8.53	0.87	3.50	2.33	0.05	0.37	8.45
2005	26	8.31	2.14	26.50	11.17	0.14	2.67	8.22
2006	11	8.17	1.95	7.43	5.29	0.07	0.83	8.23
2007	8	9.59	2.51	8.50	4.37	0.06	0.88	8.25
2008	29	6.99	2.63	8.83	4.43	0.05	0.87	8.12
2009	15	5.98	3.40	32.17	14.10	0.14	3.56	8.05
2010	21	7.86	2.77	28.83	11.52	0.10	2.68	8.12
2011	8	5.03	4.91	14.83	6.47	0.08	1.21	8.10
2012	12	6.14	2.54	22.67	9.05	0.11	1.89	8.13
2013	20	9.17	1.26	5.14	3.67	0.06	1.10	8.13
2014	16	7.69	2.68	13.00	6.73	0.08	1.38	8.13

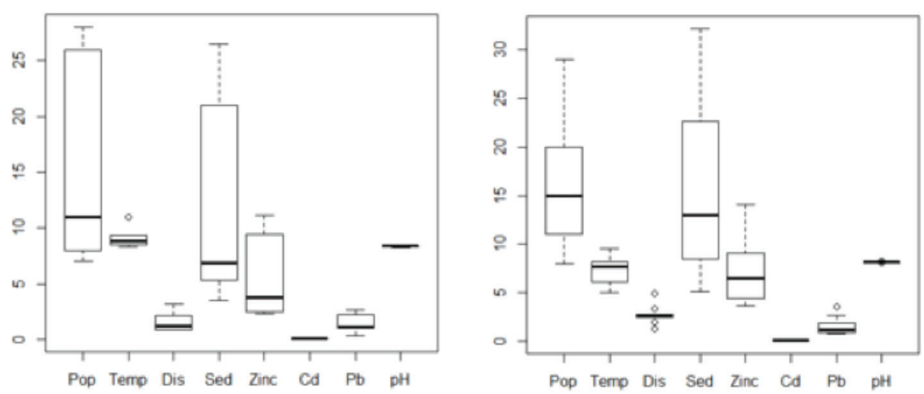

Figure 11 & 12: Boxplots of Warm Springs Creek Pre- and Post-road construction disturbance data for water quality parameters and bull trout population (From left to right on Pre and Post: population numbers, water temperature, instantaneous discharge rate, SSC, Zinc concentration, Cadmium concentration, Lead concentration, and pH.

As with the Flathead River, the relationship between the water quality parameters and bull trout numbers for Warm Springs Creek was assessed by comparing the variables in scatter plots. A linear regression was then fit to the data and from this a visual analysis of the association and strength of said associated was determined. For this second water body water temperature, instantaneous discharge rate, and pH also displayed weak negative associations with population numbers (Figures 13- 15). The negative R2 of these plots also indicate the fit of the regression equations are poor.

Table 4: Warm Springs Statistical Analysis Data

Parameter	**Mann-Whitney U Test**
Water Temperature	W = 51, p-value = 0.02607, p-value $< \alpha$ (0.05)
Instantaneous Discharge Rate	W = 10, p-value = 0.04955, p-value $< \alpha$ (0.05)
Suspended Sediment Concentration	W = 17, p-value = 0.2721, p-value $> \alpha$ (0.05)
Zinc Concentration	W = 15, p-value = 0.181, p-value $> \alpha$ (0.05)
Cadmium Concentration	W = 34, p-value = 0.7032, p-value $> \alpha$ (0.05)
Lead Concentration	W = 24, p-value = 0.7756, p-value $> \alpha$ (0.05)
pH	W = 52, p-value = 0.003853, p-value $> \alpha$ (0.05)

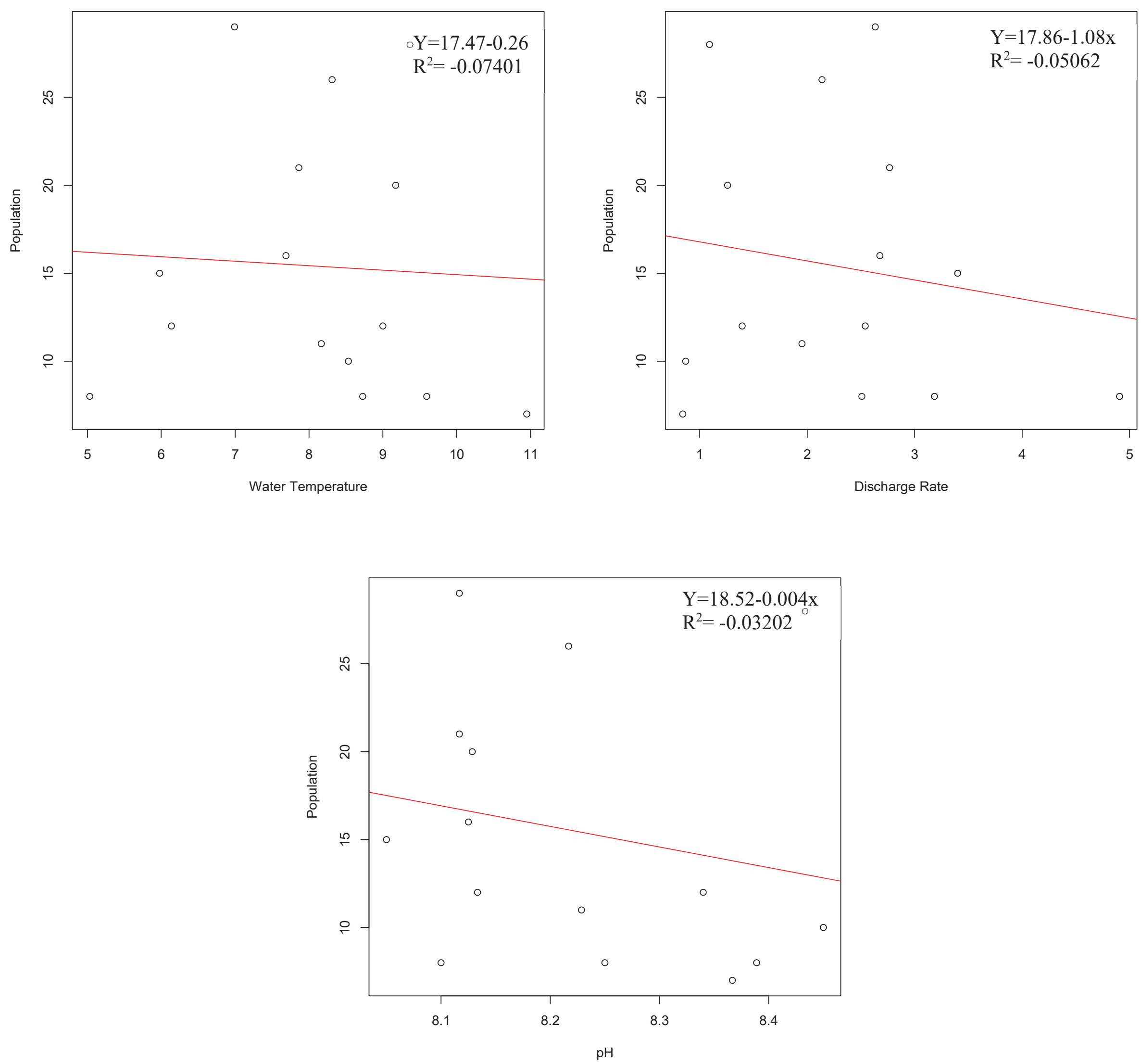

Figure 13-15: Scatter plots of Warm Springs Creek water quality parameters that displayed negative association with bull trout population numbers.

Evaluation of Water Quality Parameters: Blackfoot River

The results of the Mann-Whitney U analysis for the Blackfoot River water quality parameters are displayed in Table 6. The statistical analysis yielded that three parameters (instantaneous discharge, pH, and Cadmium concentration) had medians that differed significantly from the first half of the study period (2000-2006) to the second half of the study period (2007-2014) (Table 5). All the other water quality parameters had Mann-Whitney U p-values greater than the chosen level of significance of 5%. Figures 16 and 17 below are the box plots for Warm Springs Creek, which are a graphical representation of the water quality parameter data.

Table 5: Blackfoot River Water Quality Parameter and Bull Trout Population Data with First Half of Data Highlighted in Gray

Year	Bull Trout Population Count	Water Temperature (°C)	Instantaneous Discharge (m^3/s)	Suspended Sediment Concentration (mg/L)	Zinc Concentration (µg/L)	Cadmium Concentration (µg/L)	Lead Concentration (µg/L)	pH (Standard Units)
2000	123	10.50	44.20	7.33	1.50	0.10	1.00	8.53
2001	75	6.60	31.57	10.00	1.33	0.10	1.00	8.37
2002	70	8.04	87.45	40.60	3.60	0.05	1.08	8.28
2003	41	9.60	64.20	29.83	3.25	0.08	0.43	8.45
2004	42	9.58	37.33	4.83	1.67	0.04	0.10	8.40
2005	43	9.50	50.27	18.83	2.83	0.04	0.38	8.38
2006	61	10.04	89.54	26.61	2.61	0.04	0.43	8.38
2007	42	9.96	60.26	17.31	2.09	0.01	0.32	8.38
2008	95	8.03	86.73	36.96	3.48	0.02	0.66	8.33
2009	97	8.17	109.77	37.80	3.38	0.06	0.64	8.30
2010	86	10.86	47.14	14.43	2.37	0.04	0.25	8.32
2011	158	4.67	153.91	15.48	4.46	0.05	0.96	8.16
2012	131	8.34	78.25	24.35	3.03	0.02	0.33	8.27
2013	91	9.28	64.96	6.93	2.83	0.02	0.15	8.22
2014	96	8.07	101.83	21.83	2.57	0.03	0.33	8.30

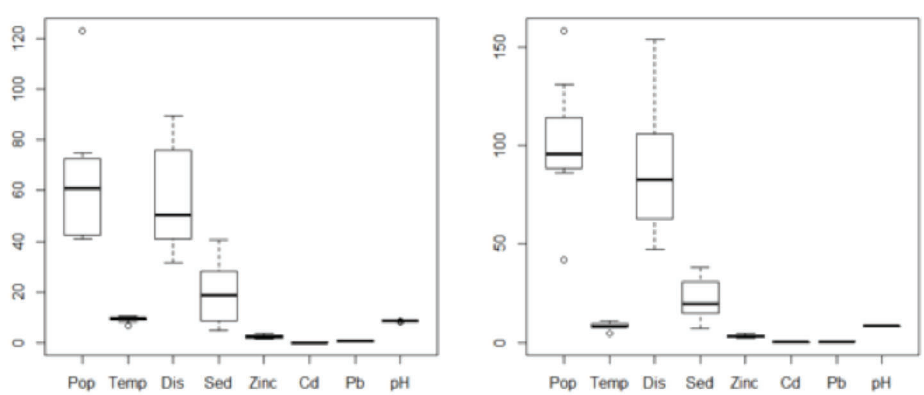

Figure 16 & 17: Boxplots of First and Second half Blackfoot River data for water quality parameters and bull trout population numbers (From left to right on First and Second: population numbers, water temperature, instantaneous discharge rate, suspended sediment concentration, Zinc concentration, Cadmium concentration, Lead concentration, and pH.

As with the previous water bodies, associations between the water quality parameters and bull trout numbers were assessed by comparing parameter levels and species abundance in scatter plots that were then fit with a linear regression and visually interpreted. As shown below in Figures 18 through 20 water temperature, suspended sediment concentration, and pH were the parameters that displayed a negative association with bull trout population numbers for the Blackfoot River, however, this was surprising as this was the control study location. The goodness of fit for SSC and pH linear regressions are poor as they have negative R2 vales, the fit of the linear regression of the water temperature and population data is better than all those previously mentioned.

Table 6: Blackfoot River Statistical Analysis Results

Parameter	**Mann-Whitney U Test**
Water Temperature	W = 29, p-value = 0.8639, p-value > α (0.05)
Instantaneous Discharge Rate	W = 8, p-value = 0.02557, p-value > α (0.05)
Suspended Sediment Concentration	W = 22, p-value = 0.607, p-value > α (0.05)
Zinc Concentration	W = 18.5, p-value = 0.3453, p-value > α (0.05)
Cadmium Concentration	W = 47, p-value = 0.02144, p-value < α (0.05)
Lead Concentration	W = 41, p-value = 0.111, p-value > α (0.05)
pH	W = 46, p-value = 0.02557, p-value > α (0.05)

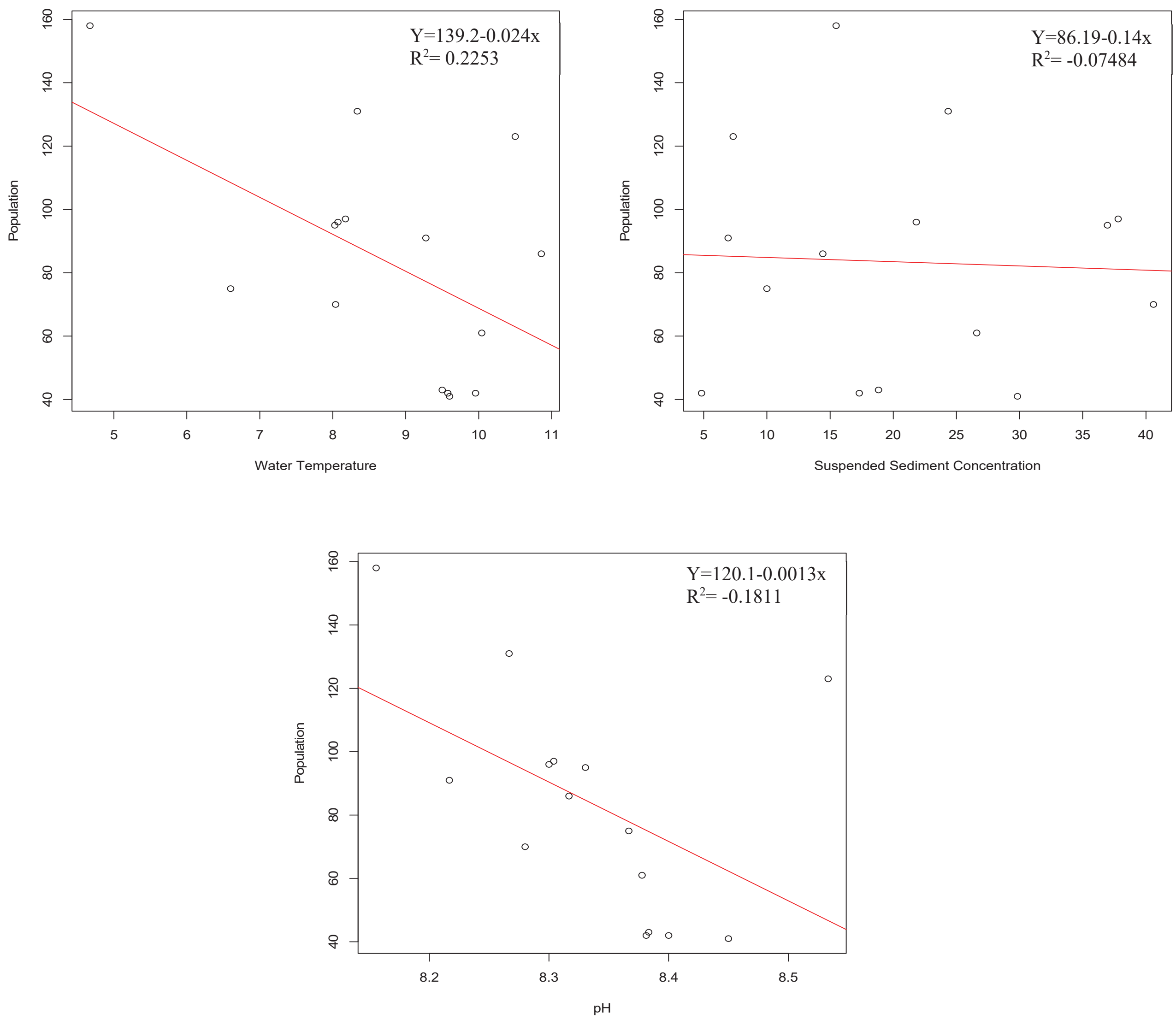

Figure 18-20: Scatter plots of Blackfoot River water quality parameters that displayed negative association with bull trout population numbers.

Population Statistical Assessment: Flathead River, Warm Springs Creek, and Blackfoot River

The results of the Mann-Whitney U analysis on the population counts pre- and post-construction disturbance for the Flathead River during the fifteen-year study period yielded no significant differences between the medians (Table 7). The generated p-value (0.5809) was greater than the level of significance set at 5% (α=0.05), so we fail to reject the null hypothesis that the pre- and post-construction disturbance medians differ significantly. Analysis for the population counts of Warm Springs Creek (Table 7) pre- and post-construction disturbance returned a p-value of 0.6358, which is greater than the established level of significance of 5% (α=0.05). This signifies that no significant difference was found between the two medians and, therefore, we fail to reject the null hypothesis. The Mann-Whitney U test for the population counts of the Blackfoot River (Table 7) during the 2000-2014 study period generated a p-value of 0.04894, which is less than the chosen level of significance 5% (α=0.05). This p-value indicates that there is a significant difference between the two medians.

Table 7: Mann-Whitney U analysis on Population Counts for All Three Water Bodies

Water Body	**Mann-Whitney U Test**
Flathead River	W = 30, p-value = 0.5809, p-value > α (0.05)
Warm Springs Creek	W = 22.58, p-value = 0.6358, p-value > α (0.05)
Blackfoot River	W = 10.5, p-value = 0.04894, p-value < α (0.05)

DISCUSSION

Analysis of Associations

I expected that the results of the statistical analysis on the water quality parameters and population numbers for the Flathead River and Warm Springs Creek would result in statistically significant differences between the pre- and post-road construction disturbance medians. The water temperature, instantaneous discharge, suspended sediment concentration, zinc concentration, cadmium concentration, and lead concentration were all hypothesized to increase, while population numbers were hypothesized to decrease, and pH was hypothesized to have significant differences between pre-and post-construction. The water quality parameters and bull trout population numbers for the Blackfoot River were hypothesized to show no significant differences as there were no road construction-related disturbances during the study period.

The results of the analysis somewhat contradicted the hypothesized results as several of the water quality parameters in both the Flathead River and Warm Springs Creek did not yield any significant differences between their pre- and post-road construction disturbance medians. For the Flathead River, only cadmium concentration resulted in a significant difference between pre- and post-construction disturbance medians. The Flathead River is an important river in western Montana for recreation, wildlife, and fish so a comprehensive management plan is implemented to sustain the yield of the products and services the river offers. Such a management plan could explain the lack of significant difference between pre- and post-road construction disturbances. Another possible explanation for these results could be the coarseness of the data sets and the duration of the chosen time period.

Warm Springs Creek statistical analysis yielded results that were closer to expected. Water temperature, pH, and instantaneous discharge all displayed significant differences between pre- and post-construction disturbances; however, the bull trout population numbers, suspended sediment concentration, cadmium concentration, lead concentration, and zinc concentration did not show significant differences. These results could potentially be due to a historical mine located in the area and the associated remediation. The area is also less populated than the Flathead, the creek is smaller than the Flathead River, and there does not appear to be a comprehensive management plan in place. As with the Flathead River, the coarseness of the data and the chosen study period could also be possible explanations for the unexpected results.

One of the most surprising results of the statistical analysis was that some of the water quality parameters and the bull trout population numbers did exhibit significant differences for the Blackfoot River, which was meant to act as a control. These changes could potentially be due to climate, the coarseness of the data, or to recreational and management activities. For the Blackfoot River, bull trout population counts, instantaneous discharge, pH, and cadmium concentration exhibited significant differences between the first and second halves of the study period. These unexpected results could stem from the coarseness of the data and study period as with the other water bodies but could also be due to the large amount of recreation it experiences. Road construction environmental BMP's could be also be meeting their intended goals and acting protectively and may be working relatively well in some areas and instances. This is another possible reason why results weren't completely in line with those originally anticipated. Perhaps in these instances the erosion and sedimentation protection were effective enough to prevent extensive accumulation of pollutants.

The changes documented here in certain water quality parameters could be consequential to bull trout population numbers, because the species is incredibly sensitive and resides in a narrow band of habitats Therefore any alterations to the ecosystem could cause stress. Zinc and cadmium pollution are highly toxic to bull trout as is lead and large pH fluctuations. The parameters that did display expected outcomes (cadmium concentration in the Flathead River; water temperature, pH, and instantaneous discharge in Warm Springs Creek; and instantaneous discharge, pH, and cadmium concentration in the Blackfoot River) were not all strongly associated with decreased bull trout populations. The water quality parameter common to all the study rivers that presented a negative association with bull trout numbers was pH. This was assessed by creating scatter plots in R and fitting them with a linear regression line. Plots with down sloping regression lines displayed the hypothesized negative association with bull trout population numbers.

Previous analyses of bull trout populations have suggested that there are significant correlations between bull trout numbers and road system construction. Our results support the conclusions of such studies as Chen et al. (2009), Hansen et al. (2002), and Lagerwerff (1970) that roadway construction impacts stream chemical conditions which in turn impact bull trout. Despite the unexpected outcomes of this analysis, the results of this study are consistent with that of the aforementioned. This analysis demonstrates the existence of a potential association between some of the water quality parameters and bull trout in the three selected water bodies, though the associations were found to be weaker than hypothesized. This study emphasized the impact anthropogenic disturbances such as road construction can have on an aquatic species while underscoring the need for additional study with a longer time period and more fine-grained data.

Implications for Bull Trout Management

Increases in bull trout population numbers have been shown to be positively correlated with decreased road densities, construction, traffic, and associated pollution. Protection of critical habitat by minimizing disturbances and associated pollution while limiting the effects of land use activities will be vital to management strategies for bull trout in Montana. Conservation of bull trout will require that managers consider the organisms within the context of their connections in a dynamic ecosystem that includes anthropogenic disturbances and activities and working with road construction planners and engineers to help mitigate and prevent pollution of adjacent water ways (Baxter et al., 1999). Accurate assessment of current conditions and the conservation of species and ecosystems depend on adopting a contextual perspective and combining this with any ongoing evaluation of scientific and management schemes.

Implications for Road Construction

Stream ecosystems within highway right-of-way are vulnerable to impacts from road construction activities. As one of the major nonpoint pollution sources, the construction of roadways can have both short- and long-term effects on stream biotic and abiotic conditions. Such effects are generally a result of sedimentation, habitat degradation, changing of leaf processing, and inputs of toxins from construction materials. For roadway and urban pollution, vegetated buffers and mulches, porous pavement materials, retention or detention basins and ponds, silt fence, seeding, and natural riparian wetlands have been implemented as Best Management Practices (BMPs) to treat runoff and control soil erosion. These BMPs can be quite effective in some instances and environments; however, the effectiveness of some of these is still vague. Refining these BMPs for future roadway construction is vital and should be based on a thorough understanding of the environmental impacts from current construction methods and materials.

Based on the results of this and other studies, the management of suspended sediments, pH fluctuations, and heavy metal pollution may be an effective strategy for protecting adjacent aquatic ecosystems from future road construction. Construction projects should consider these impacted water quality parameters and develop mitigation and prevention strategies while continually refining their currently implemented BMPs. Employing a specialist to monitor such water quality parameter levels throughout construction could also be of great benefit to future road construction activities.

Study Limitations

I identified several potential limitations of this study, including the coarseness of the data sets, the length of the study period, and the possibility of not accounting for other disturbances or management that could have occurred with the selected water bodies. Converting the daily water quality parameter observations to annual averages smoothed the data and decreased the overall resolution, potentially leading to a loss of some true variability in the data. The chosen study period could also be a limitation, in that fifteen years may not be long enough to demonstrate the relationships between the water quality parameters and the bull trout population numbers. Other potential disturbances or management such as floating, fishing, traffic, hiking, etc. could also lead to increases in pollution, erosion, sedimentation, and fluctuations in bull trout population magnitudes, but these were not accounted for.

Road construction environmental BMP's could be acting protectively and work relatively well in some areas and instances. This is another possible reason why results weren't completely inline with those originally anticipated. Perhaps in these instances the erosion and sedimentation protection were effective and enough to prevent extensive accumulation of pollutants.

CONCLUSION

Road construction and ensuing clearing of timber and shrubs can lead to alterations in the dynamics and morphology of channel features and water chemistry that provide habitats for aquatic biota (Baxter et al., 1999). This study illustrates the importance of the specific habitat requirements influencing the overall abundance of bull trout in management and conservation schemes. This was in agreement with the results of previous studies and points out the importance of future projects focusing on bull trout and the effects of pollution and changing ecosystems. The numbers of bull trout have been in steady decline and with their addition as a threatened species under the Endangered Species Act in 1999, management is vital to the species survival.

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