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Does Restoration of Urban Riparian Zones Impact Stream Water Quality in Portland, Oregon

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Does Restoration of Urban Riparian Zones Impact Stream Water Quality in Portland, Oregon

by

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1 | Introduction

1.1 | Riparian Zone Features

Riparian zones have many features that make them vital for the health of their stream, from bank stability, shading, nutrient/organic matter addition, and toxin filtering, among others (Swanson *et al*., 1982; Barker *et al*., 2006). As urbanization has increased rapidly over the years, many ecosystems have been degraded, and urban streams (alongside their riparian zones) are no exception. Urbanization in stream watersheds shifts the hydrologic cycle of the stream, reduces the riparian zone's ability to remove excess nutrients, lowers the water table, and reduces plant and tree assemblage; which in turn reduces bank stability, increases water temperature, and reduces allochthonous nutrient production (Groffman *et al*., 2002; Groffman *et al*., 2003; Hession *et al*., 2000; Violin *et al*., 2011). Urban riparian zones are a unique type of ecosystem as they are often some of the only green spaces left and serve as a corridor for plant and animal species (Aronson *et al*., 2017). The corridor functionality starts to become a problem as non-native plant species are introduced and they have the resources and corridor to spread all along riparian zones (Aronson *et al*., 2017). This is why most riparian restoration projects include invasive plant removal in some form; in fact, some projects are exclusively focused on that and planting native species.

1.2 | Study Location

Portland, Oregon (the location of this study) had a 23% increase in population between 1990 and 2000, amounting to 269,928 people, and the decade before only saw a 12% increase (Kentula *et al.*, 2004). In an attempt to limit this urbanization, the city implemented an urban growth boundary in 1978, limiting urbanization by stopping it outside that boundary (Kentula *et al.*, 2004). Portland has a large number of urban streams and has had restoration projects on many of them, in part due to how prominent environmentalist sentiments are among the population. This makes Portland an optimal location to build understanding of restoration, as there are plenty of streams that can be compared to each other without having wide spatial variance. The factors that influence the study streams are much less varied than if this were a nationwide study due to the varied geology and geography seen across the United States not being a factor. Urbanization in the region has changed the morphology of these streams to be less connected with the surrounding area. Urban streams in the region were often channelized, put through culverts, redirected, and had the riparian zone reduced or removed. Urbanization also causes the water table to lower in riparian zones, which impacts the rest of the processes in the riparian zone (Groffman *et al.,* 2003).

1.3 | Importance of the Research

The importance of riparian zones to stream quality is reason enough to continue researching and demonstrating how restoration practices are important. However proper monitoring - which evaluates the water quality in these restored urban streams (in comparison to unrestored urban streams) is vitally important to ensure these projects continue to provide the ecological benefits for which they were designed. There are many factors to consider when determining water quality, but the key parameters that are often impacted by insufficient riparian vegetation and urban proximity are conductivity, temperature, pH, turbidity, and flow rate

(Barker *et al*., 2006; Groffman *et al*., 2002; Groffman *et al*., 2003; Hession *et al*., 2000; Swanson *et al*., 1982).

1.4 | Study Summary and Goals

The goal of this study is to provide an insight not only into riparian restoration practices and effectiveness, but also the effectiveness of these specific projects. The study is being performed in the Portland, Oregon Metropolitan Area, in the Pacific Northwest region of the United States, with control sites also being located in Tillamook State Forest approximately 40 miles outside of Portland. The questions being studied in this project are how restoration projects impact urban stream quality when compared to unrestored and non-urban streams, and what might be a cause for the restorations not impacting the stream quality positively. We hypothesized that stream quality in urban streams would improve (be closer to that of non-urban streams) in restored streams, and if they do not improve that it may be related to how the stream is restored and how long ago the project was performed. The region is located in a temperate rainforest biome, with relatively high rainfall and seasonal temperature variation (Trimble 1963). The geology of the region is a combination of volcanic and marine sediments (Trimble 1963). The regions vegetation is conifer-dominated, with species such as Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), and others, as well as some notable broadleaf species such as Oregon white oak (*Quercus garryan*a), red alder (*Alnus rubra*), and others. Land use in the Portland Metropolitan Area is largely developed (although with more natural areas than other urban areas), and this study will refer to urban areas as a region with a developed land use proportion of 20% or higher. Development is extensive within the urban growth boundary but limited outside of there.

It is important to continue to study these streams to build the body of work surrounding effective restoration practices, to monitor the water quality in streams (especially restored ones), and to have more data on these projects that can be brought to funding sources to assist in approval for future restoration projects. This study not only contributes more data on that to the current body of work, but also helps build up knowledge on the instances where the EPA rapid stream assessment is effective and where it may not be effective. If a riparian restoration project improved stream quality it will have lower temperature, lower turbidity, lower conductivity, a more neutral pH, and slower flow than urban streams with unrestored riparian zones. These values will be closer to the values seen in streams not impacted by urban development if the streams respond to the riparian restoration in a positive way.

2 | Background

2.1 | Methods in Riparian Restoration

Even with the benefits of riparian zones being common knowledge in related fields, stream restoration projects in the USA have largely focused on in-stream modifications (Bernhardt *et al*., 2005). On top of this issue, many restoration projects do not undergo sufficient post-project monitoring, resulting in a lack of information on the long-term effectiveness of these projects and instead claiming success or failure a short time after completion (Collins *et al*., 2013; Purcell *et al*., 2002).

Most methods used for riparian restoration are effective (Brown 2011). The general categories of restoration being bank protection (rootwad and boulder revetment), grade control (step pools and log drop), flow deflection and concentration (wing deflectors and log vanes), and bank stabilization (riparian planting) (Brown 2011). This effectiveness is seen through the impacts on water quality parameters, such as stream velocity and turbidity. On top of that, riparian restoration has been shown to be more effective at improving fish habitat than in-stream restoration projects (Opperman *et al*., 2003). The main issues with restoration projects as mentioned before is that they often do not do sufficient monitoring, evaluation, and post-project reporting which can lead to preventable issues causing projects to fail (Brown 2011; Collins *et al*., 2013; Purcell *et al*., 2002). Another concern with these projects is the cost. This is especially prevalent in urban stream restoration as it can cost even more due to the proximity of private property and the cost of permits in these areas (Kenney *et al*., 2012). Even with the cost, the requirements imposed by the Clean Water Act to meet the Total Maximum Daily Loads of common contaminants pushes local governments to act, although this can be more of a burden on less wealthy townships which could lead to insufficient restoration due to lack of funds (Kenney *et al*., 2012). Riparian restoration practices may be a well-researched subject, but much of the research focuses on small streams, instead of looking at the larger-scale highly urban systems, such as the Willamette and Columbia Rivers in Portland, and it has been shown that watershed level restoration is more effective than more localized restoration projects (Francis 2012; Rious-Touma *et al*., 2015).

2.2 | Importance of riparian zones

Riparian zones have a variety of benefits the provide to their stream, the surrounding environment, and animals. The vegetation in riparian zones controls erosion, creates habitat, shades the stream, provides nutrients to the stream, and helps trap nitrate runoff (Moring *et al.*, 1985; Groffman *et al.*, 2009). Many benthic macroinvertebrates rely on the nutrients provided by leaf litter and other organic matter for their nutrient supply, and fish in the same streams will consume those invertebrates for their nutrients (Moring *et al.*, 1985). The riparian zone also filters excess sediment and reduces erosion, and excess sedimentation can result in fish egg die-off (Moring *et al.*, 1985). In addition to the turbidity control, riparian zones also control temperatures with shade from the canopy, and the reduced temperature helps avoid a decline in surface dissolved oxygen associated with warming water (Moring *et al.*, 1985). Temperature is of concern not only due to the reliance of species on specific temperatures (such as salmonids requiring colder streams), but the temperature can also influence dissolved oxygen and dissolved carbon dioxide, which in turn influences stream pH. Riparian zones also typically have higher species richness, abundance, and diversity than the surrounding non-riparian areas (Palmer and Bennett, 2006). Additionally, bird species benefit from the diversity in habitats provided by the moisture conditions in riparian zones, which is a more prominent occurrence in arid regions (Palmet and Bennett, 2006).

2.3 | Lag Time

One common cause of public, political, and financier frustration regarding restoration projects is the expectation of quick results (Meals et al., 2010). This frustration arises when projects are completed and the lag time results in years passing without beginning to see the benefits of that restoration project (Meals et al., 2010). Changes to environmental conditions (both positive and negative) take time to take effect, this occurence is known as lag time, and the length of time that these effects take vary widely based on aspects such as scale, the specific change, pollution source types, type of management, and more (Meals et al., 2010). Beyond that, the lag time also is different for each response, fish may respond to changes at a different rate than nutrient levels, sediment conditions, and many other stream and watershed features (Meals et al. 2010).

3 | Methods

3.1 | Study Region

Portland, Oregon's climate does not experience extreme temperatures (although this has begun to change in recent years), and has high precipitation throughout most of the year causing the climate to be moisture abundant, although snowfall is low in the winter (Western Regional Climate Center, 2022). The geology of the region is a combination of volcanic basalt, alluvium, and marine tuffaceous sandstone and siltstone (Madin, 2009). The soil composition tends to be silt, sand, and gravel, with less clay content (Madin 2009). The majority of forestland in the Portland region is mixed evergreen and deciduous forest, with trees like Douglas-fir and western Redcedar commonly making up the conifers, and Oregon white oak, red alder, and bigleaf maple as common broadleaf trees (Portland Parks & Recreation, 2022). Common understory vegetation included grasses and forbs, ferns (such as sword fern), vine maple, and a variety of shrubs such as snowberry, Oregon grape (all varieties), salal, huckleberry, and many more. Portland is heavily urbanized, with some natural areas dispersed throughout, some parts of Portland have more natural areas than others. The region outside Portland and its suburbs is primarily farm and ranchland, contributing to a nitrogen pollution issue in many streams in the region.

3.2 | Study Design

Initially, 45 sites were selected to address question 1, with 15 streams for each of the 3 treatments; restored, unrestored, and control. The sites were considered control and not restored or unrestored if they had a combined development percentage of 20% or below (meaning the sum of open, low, medium, and high intensity development). This information was collected using the United States Geographic Survey's (USGS) service StreamStats (StreamStats 2021). Restored sites were gathered first. The first method to find restored sites was using a GIS map provided by Megan Hanson from the City of Portland Bureau of Environmental Services (BES) (BES 2021 "Watershed Restoration"). This map contained all watershed restoration projects conducted with the involvement of BES in the municipal boundaries of the City of Portland. The criteria for inclusion as a restored study site was that the stream body had a restoration project and was not a slough, manufactured canal, or other non-naturally occurring stream (although modifications are permitted). Additionally, two sites were included from prior knowledge, these sites being the Rock Creek site at Portland Community College and the Crystal Springs Creek site at Reed College. For additional streams, Google was used to track down projects, the remainder were found from websites belonging to: Clean Water Services (CWS), Tree for All, Murray Hill Owners Association, Braun Construction, and Oregon Metro (CWS 2021, Tree for All 2021, Murray Hill Owners Association 2021, Metro 2021). All streams found were entered into StreamStats to determine the combined development percentage. This information alongside the restoration type and time since restoration was logged in Microsoft Excel to address question 2 (StreamStats 2021).

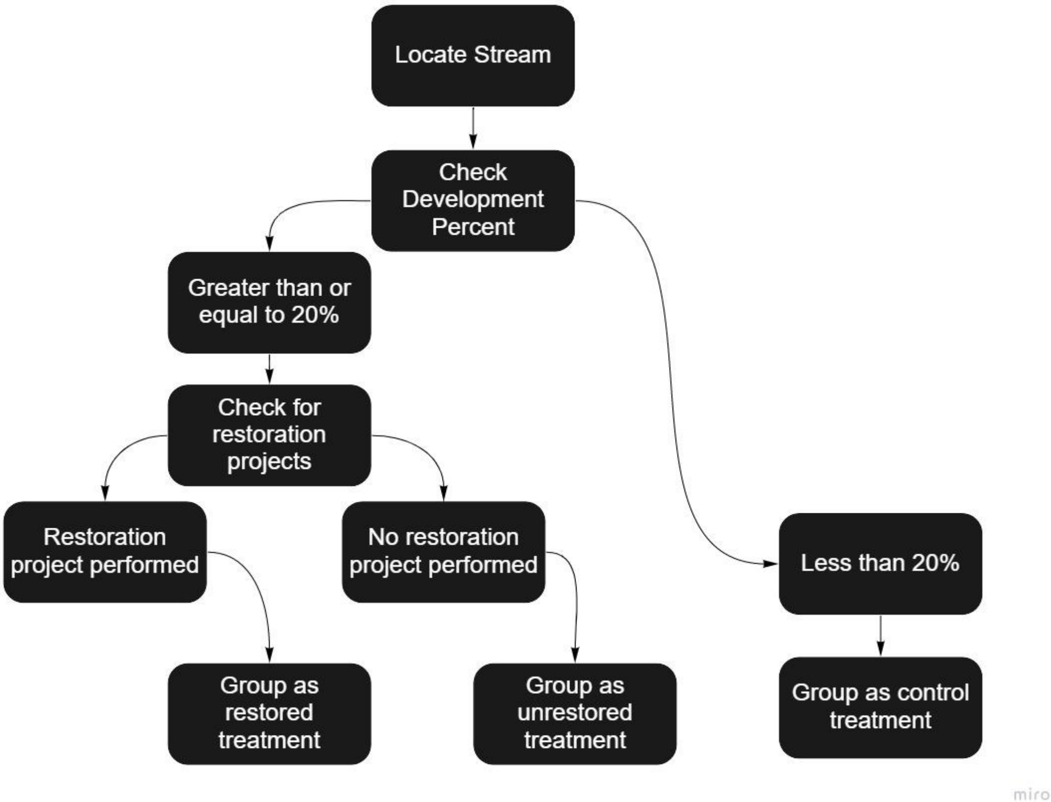

Figure 1. Flowchart demonstrating the study design. Each group had 12 sites.

To determine unrestored sites, Google Maps was used to find streams in the Portland Metropolitan Area. Upon finding a stream, a thorough search on Google was performed to ensure no projects had been performed on that site. Lastly, the combined development percentage was found and logged. The control sites were determined by finding sites outside the Portland Metropolitan Area without notable nearby development on Google Maps, then checking the development on StreamStats (StreamStats 2021). The regions that were initially checked were the Tillamook State Forest and Henry Hagg Lake region due to a relatively high quantity of streams and motor vehicle access. After those sites were exhausted, sites were found closer to the Portland Metropolitan Area while still not being highly developed to create a gradient of development percentages[1].

During the study period, 16 of the predetermined sites were made ineligible due to one of the following factors: no water present, access not permitted by local authorities, no safe path to the site, or unsafe stream conditions. 7 additional sites were found using the

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[1] For figure showing the gradient of developed percentages, see Appendix A.1 Figure A.1-1

methods used to find the initial sites, bringing the final sample size to 36, with 12 streams per treatment group.

3.3 | Field methods

The parameters being measured on site were pH, maximum velocity (m/s), turbidity (NTU), conductivity (µS/cm), temperature (°C), canopy density (%), width of stream (m) depth of stream at the thalweg line (m), distance from left bank to the thalweg line (m), average of the width of the riparian zone on the left and right side of the stream (m), and the total value from performing a Rapid Stream Assessment (RSA) under Environmental Protection Agency guidelines. Time, date, weather conditions, sediment type, dominant tree species, and any features of note were also noted at each site.

The pH was measured using a portable meter (model: Oakton pH30 pH Tested), the maximum velocity was measured using a digital flow meter (model: Global Water FP101), the turbidity was measured using a portable Turbidity Meter (Orion AQUAfast), and the conductivity and temperature were measured using a YSI ProQuatro Multiparameter Water Quality Meter. The RSA was determined based on the protocol from Barbour et al. (1999) with values for 10 different parameters (epifaunal substrate, embeddedness & pool substrate, velocity/depth regimes & pool variability, sediment deposition, channel flow status, channel alteration, frequency of riffles & channel sinuosity, bank stability, vegetative protection, riparian zone width) with 3 of them divided into two sub-categories each with their own value, and the last 3 being divided between left and right, for a total of 16 values. Parameters 1-7 were on a scale of 20, and 8-10 were on a scale of 10, with each parameter having a value for the left and right side of the stream (16 per parameter). The maximum possible value for the RSA is 260. The canopy density was collected with a spherical densiometer, riparian, thalweg distance and stream width were measured with a tape measure, and the depth was measured with a meter stick.

To determine the reach studied at each stream, the width was measured (in meters) and multiplied by 20 to find the total reach. The number of transects at a site was determined based on reach length and variability of conditions along the reach. Samples were taken at the farthest transect downstream first, after all samples were taken at that transect, the next transect upstream was sampled, until all were sampled. Measurements were taken from the thalweg line, which was found by measuring how many meters the deepest point was from the left bank, data was logged when the values stabilized. For velocity, the velocity meter was placed at approximately 60% of the depth below the surface, and left in the stream for 10 seconds, the maximum value detected during that period was logged. The turbidity was sampled from undisturbed water upstream from any point where the data collector entered the stream. The canopy density was measured by determining the number of sub-squares in each square on the densiometer were filled by foliage, this measurement was taken at each cardinal direction, divided by four to find the mean, then multiplied by 1.04 to find the percentage. The RSA was determined by observing characteristics listed on the document. The upstream endpoints of the reaches were chosen to not be in the proximity of features such as bridges and culverts. For occasions where a parameter was not able to be collected at a site, but enough were possible to not exclude the site, the mean of all values for that parameter was used in place of the NA value.

3.4 | Data Analysis

Data analysis was performed in Microsoft Excel and RStudio (Microsoft Corporation 2020, RStudio Team 2020). The packages used were the "car" package (Fox and Weisberg 2019) and "MASS" package (Venables & Ripley 2002). Before being imported to RStudio, the mean of all transects in each site was taken and used for the CSV file instead of the raw data to account for intra-site spatial variation. In RStudio, the data was visualized with box-whisker plots and histograms. Any parameters with large gaps between bins were log-transformed, excluding pH due to already being on the logarithmic scale. The parameters that were log transformed were turbidity, RSA, velocity, percent developed, and canopy density. The dataset used for all further analysis included the site classification and the measured variables, all log-transformed variables were used instead of the untransformed equivalent. Scatterplots with lines of best fit were created for all variables against the percent. A Spearman's ranked-correlation coefficients table was then created alongside a correlation matrix of all response variables (conductivity, pH, RSA, temperature, turbidity, and velocity).

A separate linear regression model was created for each of the six response variables, A full model for each response variable was developed with all predictors, each full model was processed through a hybrid Stepwise-AIC (Akaike information criteria) function to determine the most minimal functional model. The resulting models were compared to the originals using ANOVA with a null hypothesis that there is no difference in means and found to be statistically similar with a p-value of less than 0.05 ($\alpha = 0.05$) failing to reject the null hypothesis. Each of these models were visually represented using a correlation matrix, included alongside that was the multiple-R^2 value, the p-values for each predictor compared to the response variable, the model formula, and the model p-value. ANOVA was performed on each response variable against the treatment type to determine if variance of a response variable could be explained by the treatment.

When each model was created, the summary also showed which predictor variables had a significant relation with the response. For each significant model, a scatterplot with a line of best fit was created with the response variable one the y-axes, and the significant predictors on each x-axis, the dots on the plot were colored according to treatment group. The points on the scatterplot representing restored sites were assigned different shapes depending on how long it had been since the restoration project. In the legend for each figure that showed the treatment, treatments that were statistically different were denoted by having the same letter in superscript at the end of the word. This difference was determined using a Tukey-HSD test.

Lastly, each restored stream was grouped based on restoration type, with the time since the restoration in years as a predictor variable and RSA for that stream as the response variable. Each of the significant response variables had boxplots made for each of the restoration age groups (0-10 and 11-20 years) and the unrestored and control groups to answer the second question, this was expanded on by performing an ANOVA test between the age of restoration and each of those response variables. The time since restoration data was not included in the primary models as there is no data for time since restoration on the unrestored and control treatments. Each group was also set as its own predictor variable and compared against the mean RSA each group using ANOVA to determine if the type of restoration project could explain variation in RSA. Additionally, a variable was added to each restored stream that was a factor representing if the "Morphology Change" broad restoration type was present, this was compared to the RSA and temperature of all restored streams. The 4 broad restoration types classified were: Morphology Change, Riparian Plant Assemblage, Habitat Enhancement, and Pollution Control.

4 | Results

4.1 | Data Summary

To best provide a general understanding of the data and how it varies between parameters it is important to examine the summary statistics. Because some of the parameters are non-normal, the summary statistics used were median and range. The restored median was not typically closer than the unrestored medians to the control medians, however the restored sites also saw more range than the unrestored sites (Table 1). The sampled streams were characterized by generally being shallow and narrow with a median width of 1.8m and median depth of 0.2m. The control streams were typically wider than the urban streams and the thalweg line was typically farther from the left bank (Table 1). The streams overall were relatively shaded with a median of 66% canopy density, although the unrestored streams were higher at 71% and the restored lower at 55%. The riparian zones were typically wider at restored (19m), and control (20m) sites than the unrestored sites (14m). The unrestored sites were typically in more developed regions with a median % developed of 90% compared to the restored sites median of 70%. The median depth was the same at all sites at 0.20m. Some points of note from the summary is that the conductivity was lower than the control in the unrestored sites, and that while the depth and velocity were similar between all three treatments, the unrestored had the least range for velocity and the most for depth (Table 1).

Table 1. The median and range (in parentheses) of each parameter for each site classification and for all data. Matching superscript letters indicate statistical difference between treatments based on p-value from Tukey-HSD.

	Restored	Unrestored	Control	All
Width (m)	1.90(7.40)	1.35(3.40)	2.40(5.80)	1.80(7.80)
Thalweg (m)	0.80(4.05)	0.60(2.20)	1.10(3.57)	0.80(4.27)
Depth (m)	0.20(0.80)	0.20(1.00)	0.20(0.89)	0.20(1.00)
Conductivity (μs)	169.60(225.50)	113.35(170.20)	141.05(266.30)	147.50(266.30)
pH	7.61(1.43)	7.63(1.39)[a]	7.83(0.76)[a]	7.68(1.55)
Temperature (°C)	20.50(15.30)[a]	18.85(7.50)[b]	15.75(4.40)[ab]	18.35(15.70)
Turbidity (NTU)	6.63(256.75)	4.69(50.45)	2.80(271.47)	4.65(271.47)
Velocity (m/s)	0.00(0.70)[a]	0.00(0.40)	0.20(0.70)[a]	0.00(0.70)
Canopy Density (%)	55%(100%)	71%(100%)	66%(100%)	66%(100%)
Riparian Width (m)	19.00(21.00)	14.00(23.00)	20.00(25.00)	18.00(25.00)
RSA	213.5(105)	198(93)	217.5(67)	214.5(113)
% Developed	70%(66%)[a]	90%(52%)[b]	6%(17%)[ab]	64%(94%)

4.2 | Conductivity

The conductivity in all the sampled streams was high (median = 147.5 µS/cm). There was substantial variation among stream sites (range = 266.3 µS/cm). Restored stream sites had the highest median conductivity (169.6 µS/cm) while unrestored had the lowest (113.35 µS/cm). After the hybrid Stepwise-AIC exclusion function, the stream width and distance of the thalweg line from the left bank were the two remaining predictors for the conductivity model. Neither of those predictors had a significant relationship with conductivity due to having p-values higher than the significance level, and only 3.4% of variance in conductivity can be explained by these two variables. The overall correlation of the model was quite low as well, corroborating the fact that these predictors do not influence in-stream conductivity (Table 2).

Table 2. Conductivity model summary table. Model is not significant as the p-value is greater than 0.05 for both non-intercept predictors. 3.4% of the conductivity outcome can be explained by the model.

Response	Predictor (Coefficient)	p-value
Conductivity	Intercept (171.90)	1.77E-09
	Width (-59.37)	0.0876
	Thalweg (108.03)	0.0944

adjusted R^2 = 0.034047

4.3 | pH

The pH of all sites was alkaline (median = 7.68), and the control sites were the most alkaline (median = 7.83) while the restored and unrestored had a similar pH (unrestored median = 7.63, restored median 7.61). The pH was influenced by urbanization and stream morphology as the remaining predictors in the final model were the log transformed development percent, width of the stream, and depth of the stream. Both the % developed and depth predictors significantly influenced the pH level of the stream ($P<0.05$), while width did not (Table 3). The predictors account for 27.35% of the change in stream pH (Table 3).

The relationship between pH and both the log transformed % developed and log transformed depth is negative (Figure 2). The pH value around 6.8 seen in one restored site and one unrestored site occurred at two quite different depths, however both streams had similar % developed values. The two highest (most alkaline) pH values seen were similar in terms of % developed, but different in depth, however one of them (the more alkaline one) was in a stream with a restoration project that occurred 10-15 years ago, while the second most alkaline was in a stream that was restored 20 years ago (Figure 2). The unrestored and control treatments were statistically different ($p > 5$).

Table 3. pH model summary table. Model is significant due to the log % developed and depth predictors p-values being less than 0.05. 27.35% of the pH outcome can be explained by the model.

Response	Predictor (Coefficient)	p-value
pH	Intercept (7.65)	2.00E-16
	logDev (-0.09497)	0.02204
	Width (0.08619)	0.06436
	Depth (-1.10358)	0.00943

adjusted R^2 = 0.2735

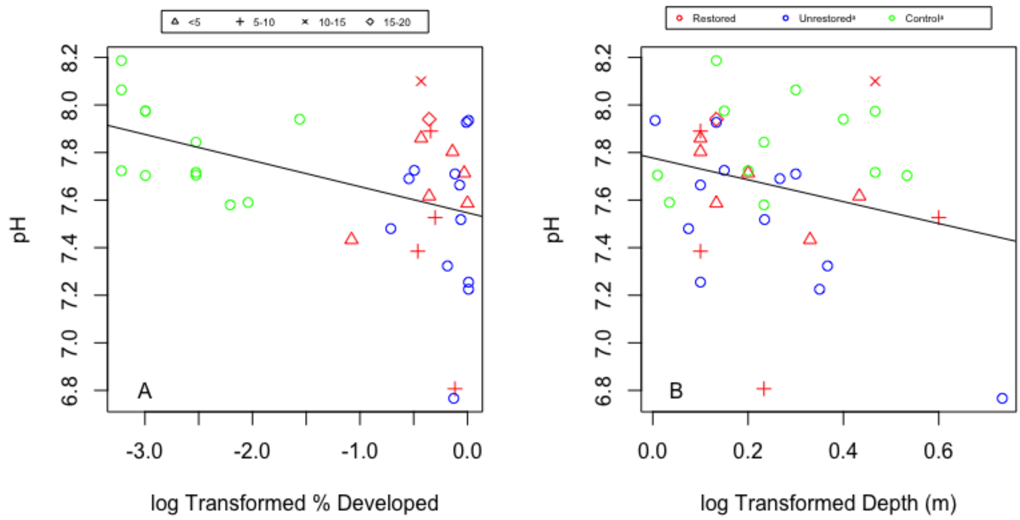

Figure 2. Scatterplots of pH against A) log % developed, and B) log depth). Colors denote treatment, shapes denote time since restoration with classifications shown in the legends. Lines of best fit included.

4.4 | Rapid Stream Assessment

The score of Rapid Stream Assessment (RSA) was high in all sites (median = 214.5). The unrestored sites had the lowest RSA (median = 198), while the restored and control were close in value. The restored sites had higher variance (105) than the unrestored (93) and control (67) sites. The maximum possible RSA score is 260, and each individual category is considered optimal in the top 25% of scores, when that is applied to total RSA it indicates that the optimal RSA score range is 195 and above (Barbour *et al.* 1999). This means that each treatment was considered in optimal condition according to the median, however the unrestored sites were only 3 above the minimum for optimal conditions. The remaining predictors for the response model were log-transformed % developed, log-transformed canopy density, and riparian width. The canopy density and riparian width predictors were significantly related to the RSA. It is worth noting that due to the nature of the RSA, riparian width and canopy density have a notable impact on the RSA score itself, one of the categories scored is riparian width and another category is related to vegetation in the riparian zone (quantity and quality).

The scatterplots for the RSA model show high variation. There does not appear to be a pattern to the distribution of points, nor are they clumped around the lines of best fit. Additionally, the points are not grouped with other points of the same treatment. There does not appear to be a connection between this model and whether the stream is non-urban, restored urban, or unrestored urban (Figure 3). None of the treatments were statistically different. Because of that, while the restored sites have not been brought back to values similar to the control sites, they have been impacted by the restoration projects as Table 1 showed the RSA was higher in the restored sites than the unrestored sites.

Table 4. RSA model summary table. Model is significant due to the log canopy cover (%) and riparian width predictors p-values being less than 0.05.

Response	Predictor (Coefficient)	p-value
RSA	Intercept (4.927525)	2.00E-16
	logDev (-0.028792)	0.143174
	logCanopy (0.209669)	0.042615
	RipWidth (0.015449)	0.000447

adjusted r^2 = 0.3329

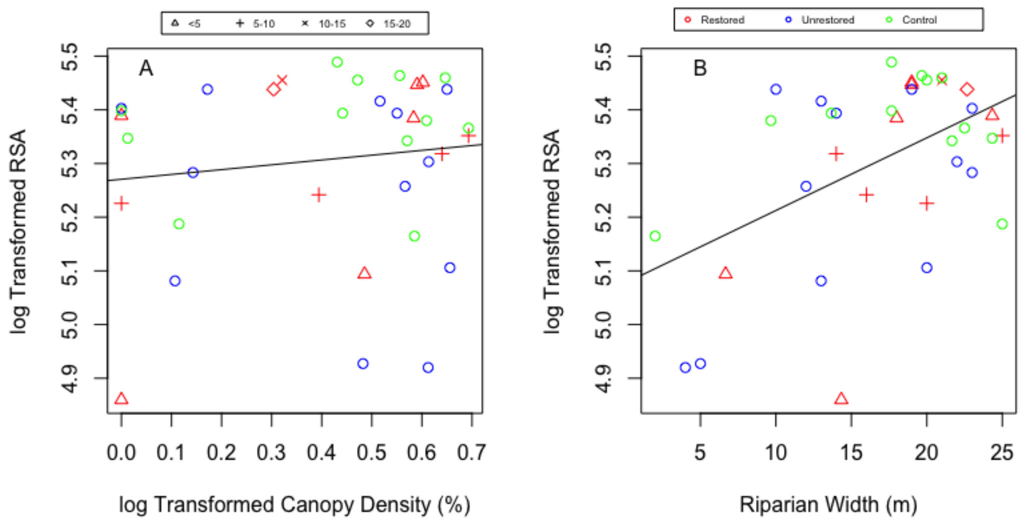

Figure 3. Scatterplots of log RSA against A) log canopy density, and B) riparian width. Colors denote treatment, shapes denote time since restoration with classifications shown in the legend. Lines of best fit included.

4.5 | Temperature

The temperature was high for all sites (median = 18.5°C), it was highest in the restored sites (median = 20.5°C) and lowest in the control sites (15.75°C). Stream temperature was highly varied in the restored sites (range = 15.30°C), but not as varied for the unrestored (range = 7.5°C) and control (range = 4.4°C). For the temperature model, the log-transformed % developed, log-transformed canopy density, thalweg line distance, and depth were retained. The % developed and thalweg distance were significantly related to temperature while canopy density and depth were not. 41.66% of changes in temperature can be explained by this model, leaving 58.34% of the causes unknown (Table 5). Both the restored and unrestored treatments were statistically different from the control (p>0.05).

In Figure 4A, the control treatment sites temperature values were close to the line of best fit, and as the control sites got more developed, the temperatures went up. The urban sites had much higher variation, with the restored sites experiencing more variation and higher maximums than the unrestored sites. Additionally, the two sites with the oldest restoration projects (as mentioned previously) have similar temperatures to the warmest unrestored site, with other restored sites being warmer than those. The unrestored sites were more closely clumped together around the line of best fit.

In Figure 4B, the control treatment sites' temperatures were not impacted by the thalweg line's distance from the left shore. The values were scattered around below the line of best fit without any notable groupings. The restored sites were scattered around the plot, with high variation in the thalweg line and in the temperature. The unrestored sites were grouped relatively closely around the line of best fit and typically had a lower value for the thalweg distance.

Table 5. Temperature model summary table. Model is significant because the log % developed and thalweg predictors are less than 0.05.

Response	Predictor (Coefficient)	p-value
Temperature	Intercept (21.67)	2.00E-16
	logDev (1.6383)	6.16E-05
	logCanopy (-3.3653)	0.618
	Thalweg (1.5582)	0.037
	Depth (-6.731)	0.0628
	adjusted R^2 = 0.4166	

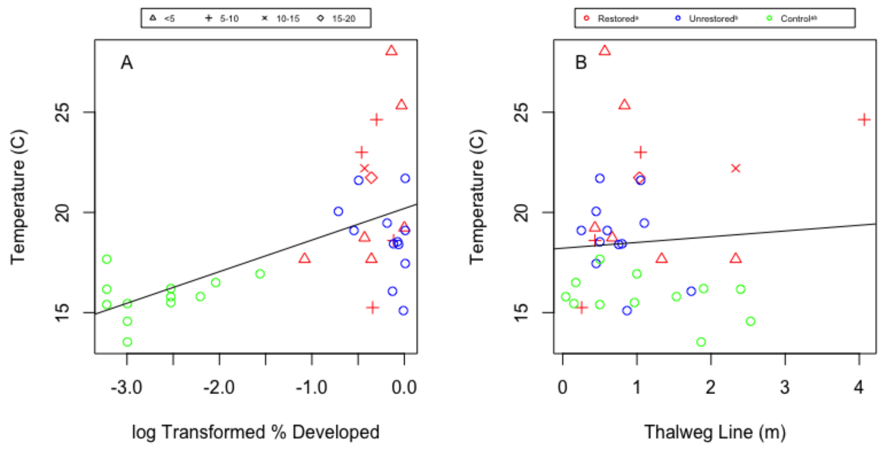

Figure 4. Scatterplots of temperature against A) log % developed, and B) distance of thalweg line from left shore. Colors denote treatment, shapes denote time since restoration with classifications shown in the legend. Lines of best fit included.

4.6 | Turbidity

The turbidity was quite low for all sites (median = 4.65 NTU). The restored site had the highest turbidity (median = 6.63 NTU) while the control had the lowest (median = 2.8 NTU). The turbidity was highly varied for the restored (range = 256.74 NTU) and control (range = 271.47 NTU) sites, while it was much less varied for the unrestored sites (range = 50.45 NTU). For the turbidity model, only log-transformed canopy density remained after the hybrid Stepwise-AIC function and was not significantly related to turbidity. The correlation between the predictors and the response for the model was low as well with only 3.229% of the change in turbidity explained by the remaining predictor (Table 6). There is not enough data to determine if the restoration projects impacted in-stream turbidity, and the range is too wide on each treatment for the medians to make any predictions about what future research may find.

Table 6. Turbidity model summary table. Model is not significant because all non-intercept predictors are greater than 0.05. 3.229% of turbidity outcomes can be explained by the model.

Response	Predictor (Coefficient)	p-value
Turbidity	Intercept (2.5336)	6.93E-08
	logCanopy (-1.1423)	0.15

adjusted R^2 = 0.03229

4.7 | Velocity

All of the streams were slower than the meter could detect (median = 0m/s). The restored and control sites had the same variance (range = 0.7m/s) and the unrestored sites had less variance (range = 0.4m/s). For the velocity model, the stream width, thalweg distance, and stream depth predictors remained. All 3 predictors were significantly related to velocity. 32.98% of the change in velocity can be attributed to the predictors in this model, with the other 67.02% unknown (Table 7). The restored and control treatments are statistically similar across all 3 predictors.

Figure 5A shows that the model trends slightly upwards when comparing velocity to stream width, indicating streamflow is slightly faster in wider streams. That relationship is most prominent in the control streams as shown by the green points on the graph. It is worth noting that there was more variation in stream width among control streams than in restored and unrestored, and all the wider urban streams had 0m/s velocity. The thalweg line measure and the stream width are going to be related in many instances, since a thalweg line cannot be farther from the left shore than the stream is wide, so Figure 5B is somewhat similar to 5A, however the relationship is weaker and close to neutral. Figure 5C is also similar to 5A and 5B, however the relationship was negative and stronger than 5B. The restored sites in Figure 5 were clustered together in all 3 sub models more than in the unrestored, the control sites did not cluster together.

Table 7. Velocity model summary table. Model is significant because all predictors' p-values are less than 0.05. 32.98% of velocity outcomes can be explained by the model.

Response	Predictor (Coefficient)	p-value
Velocity	Intercept (0.08825)	0.008618
	Width (0.22184)	0.000113
	Thalweg (-0.35266)	0.000411
	Depth (-0.34064)	0.031797

adjusted R^2 = 0.3298

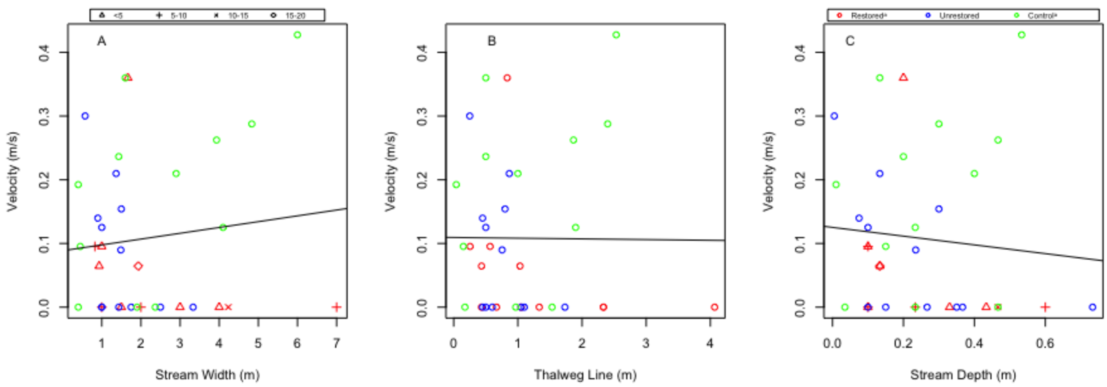

Figure 5. Scatterplots of velocity against A) stream width, B) distance of thalweg line from left shore, and C) stream depth at thalweg line. Colors denote treatment, shapes denote time since restoration with classifications shown in the legend. Lines of best fit included.

4.8 | Restoration Project Traits

The restoration projects sampled were primarily relatively young (median = 4.5 years) but ranged from 1 year old to 20 years old. While the RSA in these restored sites is close to the RSA in control sites, none of the other significant response variables had the same trend. The pH is similar at all of the ages examined, although the median pH is slightly more alkaline in the older streams (Figure 6A. The median RSA is slightly higher in the older restored sites than the younger restored sites indicating it may be improved as restoration sites age, however the two are close together and the range is similar as well (Figure 6B). The median temperature in Figure 6C is surprisingly higher in the older restoration sites than the younger restoration sites, and the younger ones have a lower median than the unrestored sites which indicates that restoration age may not influence the success of temperature restoration. The median turbidity is very similar between the two restoration age groups, and the range is also very similar and both are higher than the unrestored sites (Figure 6D). The p-values for all 4 variables when compared to the age of restoration with ANOVA was above the significance level, indicating that the variances do not have a significant relationship.

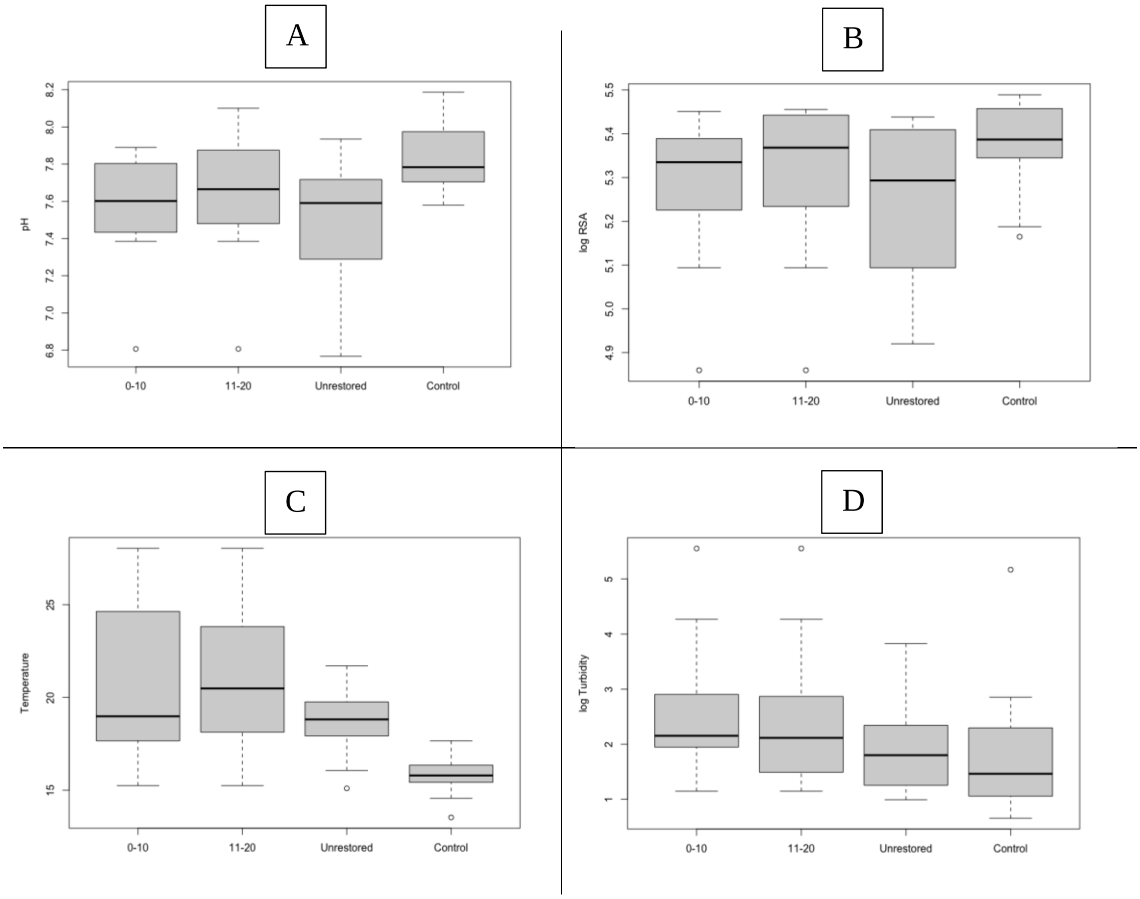

Figure 6. Boxplots showing A) pH, B) log transformed RSA, C) Temperature, and D) log transformed Turbidity at different restoration ages, alongside unrestored and control sites.

To investigate more specifically into which broad restoration type may impact restoration success most, the morphology change restoration type was examined. It was chosen due to not being included in all projects and having a strong connection to many different water related parameters, using RSA as a response due to its broad overview of riparian conditions. When a restoration project included morphology change (such as culvert removal or improvement, meander enhancement, floodplain enhancement, and other similar projects) the RSA was significantly higher than when they did not as shown in Figure 7. The lowest RSA value of a stream that underwent morphology change is higher than the highest RSA value of a stream that did not with one statistical outlier that is lower than the mean of no morphology change. The p-value comparing these two groups of data with an ANOVA test was below the significance level, indicating a significant difference between the two groups.

The temperature was also analyzed related to the morphology change since it did not appear to be impacted by the age of restoration. Figure 7 also shows the range of temperature data in restored sites that have had morphology change and have not had morphology change. The group that has had morphology change had a maximum value higher than no morphology change's maximum, and a minimum lower than no morphology change's minimum. The p-value of 0.7066 from an ANOVA test shows that there is no significant difference between the two groups. While the trends tend to indicate that the age of restoration, number of broad restoration types, and whether the morphology change restoration type was performed could be related to the lack of success seen in the restoration projects, further research is needed to determine if this is accurate for streams in the region in general rather than this specific set of streams.

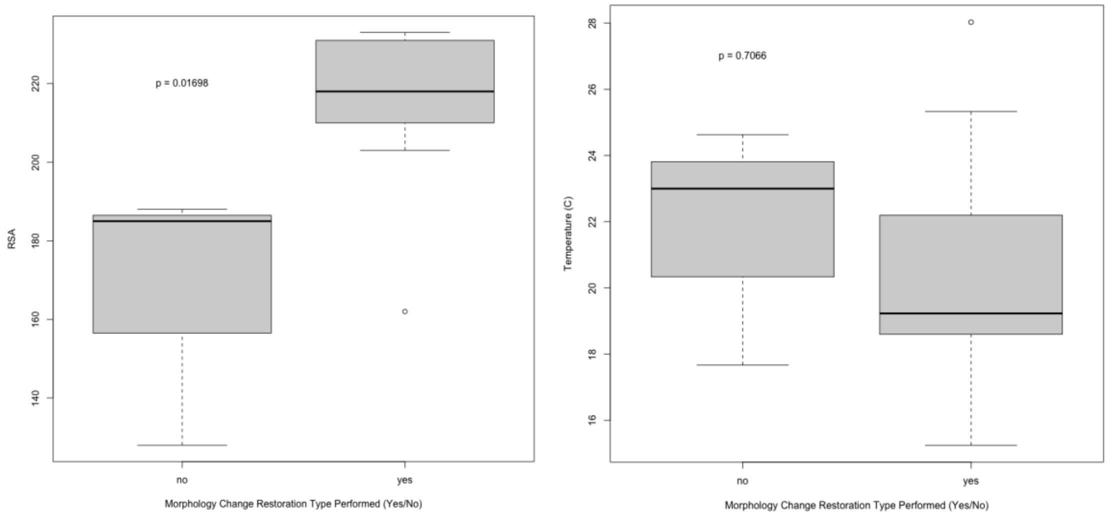

Figure 7. Boxplots of the RSA total score (left) and temperature (right) for when the “Morphology Change” broad restoration type was performed and for when it was not. The p-value is also included.

5 | Discussion

5.1 | Hypotheses and the Data

The basis for this study was to examine whether riparian restorations in urban streams improve stream quality by testing for temperature, turbidity, conductivity, pH, and velocity and comparing those values to unrestored urban streams and non-urban control streams. Additionally, time since restoration and restoration types were studied to determine how they impact water quality. All of this is with the goal of not only determining if the restoration projects performed in Portland Oregon have been effective, but also showing why they may not seem effective at present. Understanding these factors helps with defending projects that are not yet good quality and with funding monitoring efforts. The predictors chosen were modeled against the various response variables to test which ones had a significant correlation with each other. The hypothesis tested was that water quality parameters will change based on changes in predictors, if those changes are related to the treatment (such as restored streams having a higher canopy density than unrestored) then those changes in water quality could be connected to the treatment. Another hypothesis tested was that the RSA, temperature, and pH would change as a restoration project ages, and that the types of restoration projects performed will influence the RSA. The researcher predicted that when a predictor variable in an urban stream got closer to the levels in a control stream, any response variables that have a significant relationship with that predictor would also be closer to the control levels. Additionally, older restoration projects should have a higher RSA, and the temperature and pH levels should get closer to the median values seen in control treatments.

These predictions are based on how water quality is impacted by urbanization. Figure 8 provides an overview on what the specific direct effects of urbanization are and how those effects impact water quality. For example, increased urbanization directly causes a reduction in vegetation (and indirectly through increasing the impervious land use), thic in turn reduces the shade on the stream and increases the temperature (Figure 8). When a stream is warmer, the stream is more likely to be acidic as it can hold less dissolved oxygen (which buffers acidity) and more dissolved carbon dioxide (which acidifies water). The direct impacts of less vegetation and increased impervious land use also then increase the turbidity of an urban stream. The vegetation in the riparian zone stabilizes the soil and the banks, and the increased impervious land increases runoff (and how fast that runoff moves) that pulls the loose soil in to the stream (Figure 8). The combination of all direct impacts that destabilizes the banks also increase velocity (Figure 8). When the destabilized banks are hit by the stream, they get eroded down until the stream has fewer bends, which then speeds up the stream.

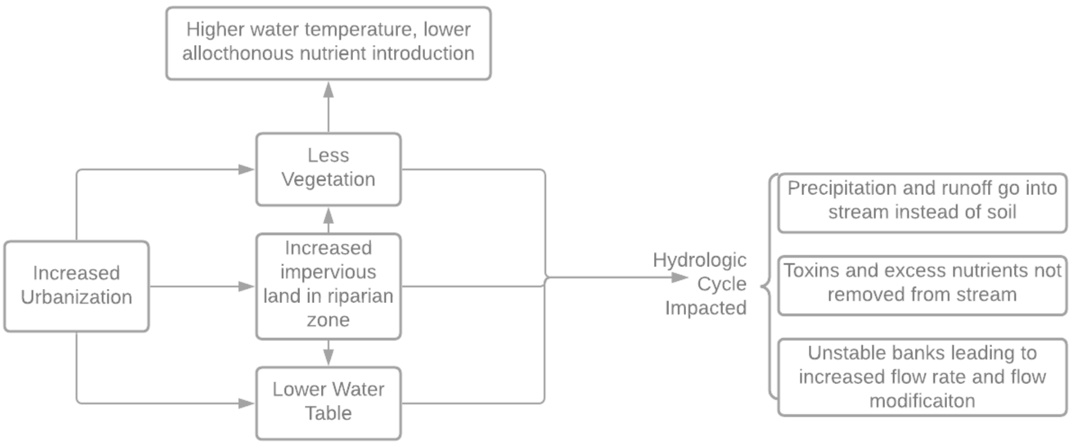

Figure 8. Conceptual model demonstrating the impacts of increased urbanization on streams.

For four of the six response variables, at least one predictor variable had a significant correlation with the response variable. The median RSA for the restored sites was closer to the control sites' median than the unrestored was, and while all 3 treatments were considered in the optimal range for RSA (Barbour *et al.* 1999). This trend indicates that the restoration projects may be able to improve the RSA back to control levels, but more research is needed. The trends seen in Figures 6 indicate that it is possible the pH and RSA will increase slightly as the restoration ages, as will the temperature (which is not beneficial unlike the other 2), and that the turbidity will not change. While the statistical significance does not show a strong relationship this information is still valuable for managers of these sites to see what they may need to consider for their projects. The pH in the two oldest restoration sites were between 7.8 and 8.2, with the values for pH in younger projects being more clustered at lower values. This indicates that it is possible the pH will be more similar to the median control pH (7.83) as a restoration project gets older, however more data is needed. There is no evidence from this data that restoration age impacts temperature. The velocity model saw the restored data being statistically different from the control data. The pH model was different between unrestored and control, and the temperature model was different between restored and control, and unrestored and control. In the context of the hypothesis, it appears that the restoration projects are not effective at returning velocity to levels in less disturbed streams, which is unexpected as the channel should (and often did) have more obstructions and bends. The urban streams tended to have more variation in data, whereas the control streams tended to be more tightly packed. This combined with the amount of data results in there being cases where a trend may support the hypotheses, but there is not enough data to reject the related null hypothesis. The data does not indicate that the restoration projects have been successful at restoring the sites to be closer to control values, and while this may be partially explained by the age of the restoration projects more data is needed with a focus on restoration age instead of restoration success.

5.2 | Efficacy and Flaws of Examined Restoration Projects

The Rapid Stream Assessment examines aspects of the stream that are often modified during restoration projects, with checks such as canopy cover, meander, pools and riffles, bank stability, and similar features. Because of this, there is a benefit to looking at the RSAs between restored and unrestored urban streams to see if the restoration projects were effective at restoring those conditions. The RSA is not used to determine if the conditions have been effective at restoring water quality conditions. Based on the median RSA values for each treatment, the restoration projects examined were successful at reducing the impact had on stream features typically seen in urban streams. The unrestored RSA median was 198, with the restored RSA median being 213.5, slightly below the control treatment (217.5). Restored sites typically saw higher scores than unrestored in most of the categories, with the ones that have more occurrences of values below 15 (suboptimal or below) being velocity/depth regimes, pool variability, sediment deposition, and frequency of riffles and bends.

While it appears the restoration projects were successful in making those changes, it does not appear that they were successful at improving water quality significantly at this time. It is important to note that most of these projects happened within the last decade, and it takes time for the restoration project to produce an effect, for that effect to be delivered, and for the stream to respond to the effect (Meals *et al*., 2010). From Meals *et al*.'s (2010) findings, projects such as creating a riparian forest buffer took 10 years to respond, wastewater treatment can take less than 5 years, habitat restoration can take 2 years, and nutrient management in small watersheds can take 15-39 years. While only two of the sites did not perform the morphology change restoration type (which includes such projects as culvert removal, creating a meander, and adding structures like logs and boulders) , the lowest and fourth lowest RSA value among restored sites belonging to those two sites[2]. Glencoe Creek, one of the two sites that did not undergo morphology change, had the riparian plant assemblage and pollution control types, it had the lowest RSA value of the restored sites at 128. Morphology change would have been highly beneficial for this site as it was severely channelized. Additionally, one of the banks of the stream had very few trees, which is represented in the low RSA, and so the stream

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[2] The broad restoration sites performed at each restored stream site can be found in Table A-1.1

was relatively warm. That combined with slow flow from beaver dams likely contributed to an algal bloom which was occurring at the time of data collection. The other site that did not undergo morphology change was the Summer Creek site with an RSA of 188. Morphology change would not have provided significant help to this site, as the stream meandered similar to how it would in natural conditions, had a variety of flow regimes, and woody debris and boulders were present in the stream. The main issue that reduced the RSA was related to anthropogenic interference resulting in sections of the bank being trampled and destabilized.

High conductivity is common among streams that have been restored with planted riparian buffers (Collins *et al.* 2013). These projects are effective at removing coarse sediment (which typically lowers the turbidity in these sites) but do not prevent the nutrients that increase conductivity from entering the stream (Collins *et al.* 2013). While this can help explain the fact that the restored sites in this study had such high conductivity it does not explain the turbidity which may be related to restoration lag (as explained in section 5.3). One flaw with many of the restored sites is that restoration was not performed at the watershed scale. By performing stream reach-level restoration instead of watershed-level restoration the projects fail to prevent pollution that occurs upstream and fails to protect reaches upstream. Bohn and Kershner (2002) found that these conservation and restoration projects are insufficient when performed only at a stream reach-level. While watershed-scale projects are not always necessary (and may not be feasible) it is important to carefully consider the scale when designing a project (Lewis *et al.* 1995). This lack of consideration of scale arises from a focus on landscape prioritized site selection where the managers are choosing highly damaged urban sites and restoring exclusively on site instead of using appropriate models to determine the best site and scale for that project (Flanagan and Richardson 2010). The model created by Flanagan and Richardson (2010) can help reduce that occurrence. The model does this by taking regional and watershed-level screening models and running that data through their regression tree/random forest models to determine which variables are most important and where in the watershed those variables impact water quality the most, so those sites can be targeted (Flanagan and Richardson, 2010).

5.3 | Restoration Lag

Once a restoration project is completed, the benefits will not appear overnight, it can take years for the effects to take significant effect, the earliest significant effects often take at least 2 years to respond but many projects can take far longer than that. Restoration projects should undergo monitoring after the completion so that the project team can adapt the project if it does not appear to be having a benefit. The sites in this study were primarily less than 10 years old, as such they may not have had enough time to gain all the benefits of the restoration. One major cause of restoration lag for the RSA value is vegetation. There are multiple aspects of scoring for RSA that are impacted by vegetation, including vegetation cover, tree assemblage, and bank stability. When a restoration project is new, the vegetation planted to replace any possible invasive removal or to augment the ecosystem needs time to grow and cover more ground, to develop deep root systems for bank stability, and for trees to grow and cover more of the stream. Restoration projects can also introduce sediment to the streams. This happens when invasive plants are removed, the channel is changed, features like logjams are added, and any project that exposes and disturbs soil. Once the banks are stabilized and there is less disturbance at the site, the turbidity can begin to decrease. When it comes to accounting for lag time to see positive benefits there is not much that can be done (Meals *et al.* 2010). Restoration projects on downstream sites should be planned to account for the added load from upstream pollution and the physical lag from transportation (Meals *et al.* 2010). Many lag times can be longer than the current typical monitoring period, so extending those monitoring periods would help both ensure that the restoration was successful and detect possible impairments from the restoration project (Meals *et al.* 2010). The public and local political system expects results to be quick after a project is completed, so tempering expectations before projects and being very clear about lag time is vital to maintain support and reduce issues that could arise in future from related doubts (Meals *et al.* 2010).

5.4 | Limitations and Future Research

A key factor that limited this study was the accessibility of streams. There were many sites that could not be accessed safely with the resources available to the researcher, which is a major reason as to why the sample size was 12 per treatment instead of the original 15 planned. Future studies should also include benthic macroinvertebrates to better reflect overall water quality conditions instead of one-time data. Another limitation is specific to velocity (and would impact other parameters that can change alongside velocity), that is that the data was collected during summer, which is typically low in precipitation, and as the control sites were more mountainous that may have caused higher water velocity. Additionally, further research should be done to include other water quality parameters that are relevant to urbanization such as nitrogen, heavy metals, dissolved oxygen, and bioindicator benthic macroinvertebrates. The data from this study corroborated one of the findings (conductivity) from Collins *et al.* but did not match another (turbidity), these sites would benefit from dissolved oxygen testing to build off that study, but also examining if the age of the restoration is responsible for that inconsistency (Collins *et al.* 2013). Further research on how long it can take for restoration projects to positively influence water quality is important to have. That research can be used by project managers to provide to funding sources should they express concern over the timeline of a restoration project (Meals *et al.* 2010). The initial plan for this study and for data collection did not consider time since restoration, this was added late in the process of data analysis. If this study were repeated, having a gradient of restoration ages would improve the significance of the analysis performed on that parameter. Future research on these sites should examine if they are limited by the scale of their study as would be expected according to Bohn and Kershner (2002). Additionally, research should be performed to examine if common restoration methods (such as seen in the sites examined here) would aid in restoring the lowered water table seen in many urban riparian zones (Groffman *et al.* 2003).

5.5 | Conclusions

This study suggests that Urban stream riparian restoration projects in the Portland area do not appear to have a significant impact on water quality. There is reason to believe that the restoration projects may eventually have a significant impact should more time pass, as the methods used in restoration projects did successfully improve the riparian area and morphology in many of those streams. The possible reasons for this lack of significant improvement are:

1. Most of the restoration projects were not performed at a watershed scale, and instead at a stream-reach scale.
2. There was substantial variation in how long ago the restoration projects were performed, and many of those were less than 10 years ago.

3. The methods used to restore by managers varied widely and not all of them directly targeted water quality

This study succeeds at demonstrating the importance of continued monitoring and research to ensure restoration projects are effective. The study also succeeds at demonstrating the importance of further research on restoration lag to reduce frustration among the public, government, and financiers.

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A | Appendix

A.1 | Supplemental Figures - Methods

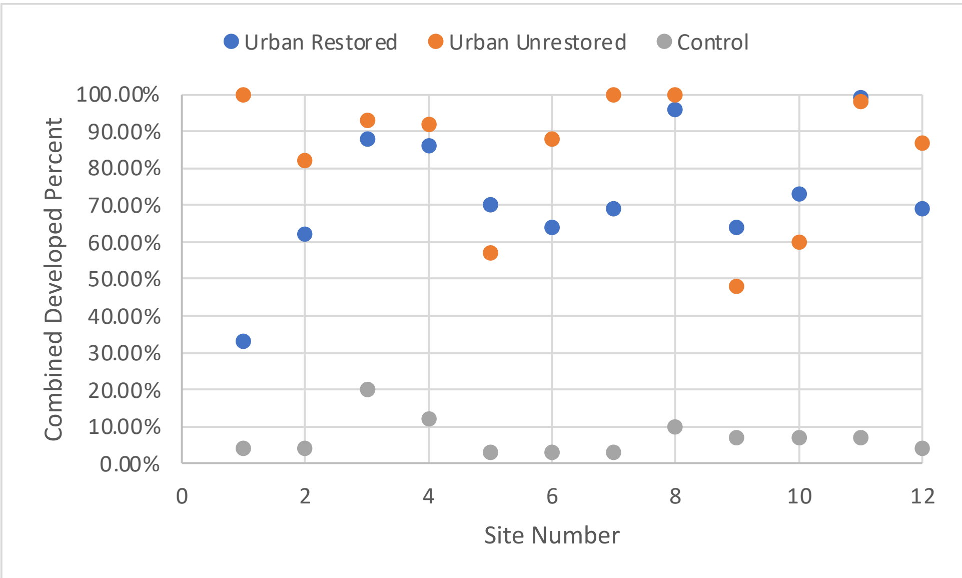

Figure A.1-1. Percent developed for each site as numbered 1 through 12. The legend on top shows which color corresponds to which treatment.

Code	Stream	Time Since Restoration (y)	Broad Restoration Types				Restoration Actions				
R1	Rock Creek at PCC (East Portland)	4	Morphology Change	Riparian Plant Assemblage			Logjams Placed	Invasive Plants Removed	Riparian Planting		
R2	Bronson Creek	5		Riparian Plant Assemblage	Habitat Enhancement		Habitat Logs Placed	Invasive Plants Removed	Riparian Planting		
R3	Hall Creek	5	Morphology Change	Riparian Plant Assemblage			Logjams Placed	Invasive Plants Removed	Riparian Planting		
R4	Fanno Creek	2	Morphology Change	Riparian Plant Assemblage			Culvert Removal	Meander Restoration	Riparian Planting	Invasive Plants Removed	
R5	Dickinson Park Stream	9	Morphology Change	Riparian Plant Assemblage			Removal of Man-made Structures	Floodplain Connectivity Restored	Riparian Planting	Invasive Plants Removed	
R6	Veterans Creek	1	Morphology Change	Riparian Plant Assemblage	Habitat Enhancement		Culvert Removal	Logjams placed	Meander Restoration	Habitat Boulders Placed	
R7	Iron Mountain Bridge on Tryon Creek	20	Morphology Change	Riparian Plant Assemblage	Habitat Enhancement	Pollution Control	Exposed Sewage Pipe Repaired	Meander Restoration	Riparian Planting	Invasive Plants Removed	Logjams Placed
R8	Crystal Springs Creek	4	Morphology Change	Riparian Plant Assemblage	Habitat Enhancement		Culvert Replacements	Logjams placed	Meander Restoration	Riparian Planting	Invasive Plants Removed
R9	Tideman Johnson Natural Area Johnson Creek	14	Morphology Change	Riparian Plant Assemblage			Logjams Placed	Riparian Planting	Invasive Plants Removed		
R10	Summer Creek	7		Riparian Plant Assemblage			Invasive Plants Removed	Riparian Planting			
R11	Derry Dell Creek	2	Morphology Change	Riparian Plant Assemblage	Habitat Enhancement		Logjams Placed	Floodplain Connectivity Enhanced	Riparian Planting	Invasive Plants Removed	
R12	Glencoe Creek	2		Riparian Plant Assemblage		Pollution Control	Invasive Plants Removed	Riparian Planting	Prevention of Point Source Pollution		

Table A.1-1. Table shows the stream, age of restoration, broad restoration type, and specific restoration actions performed for each restored stream site

A.2 | Data Summary Figures

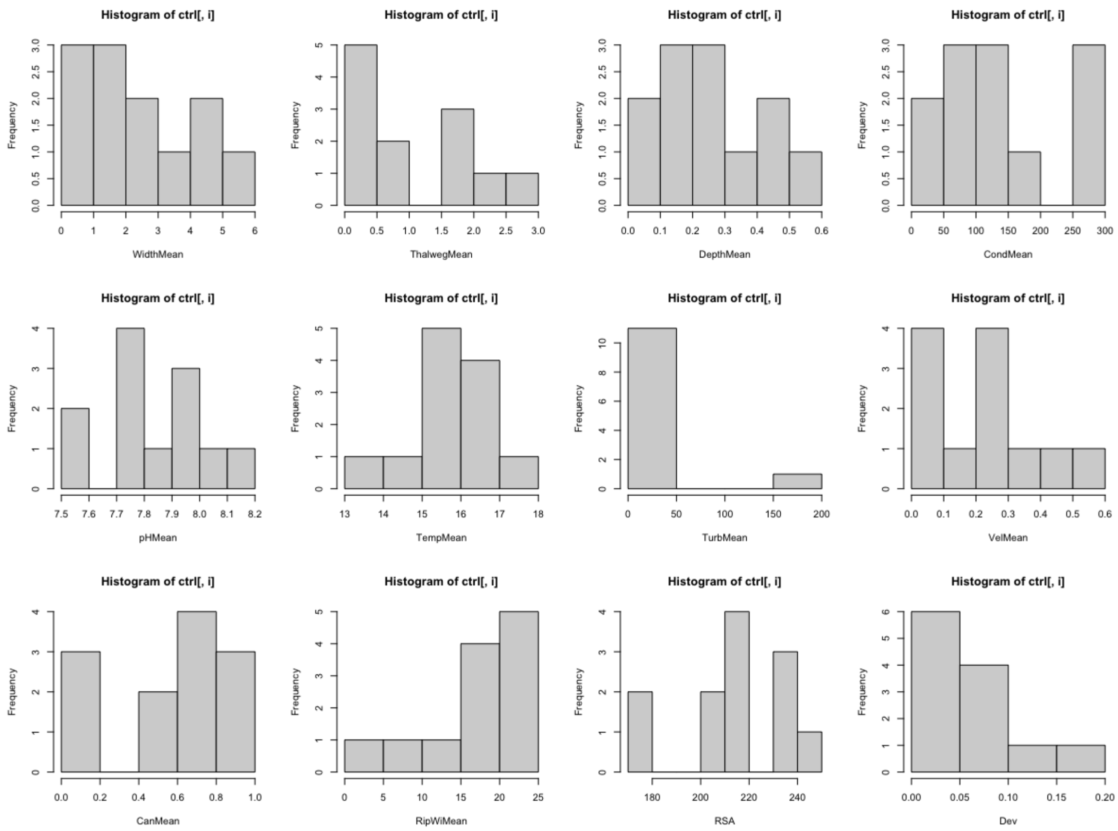

Figure A.2-1. Histograms of each parameter for the control sites.

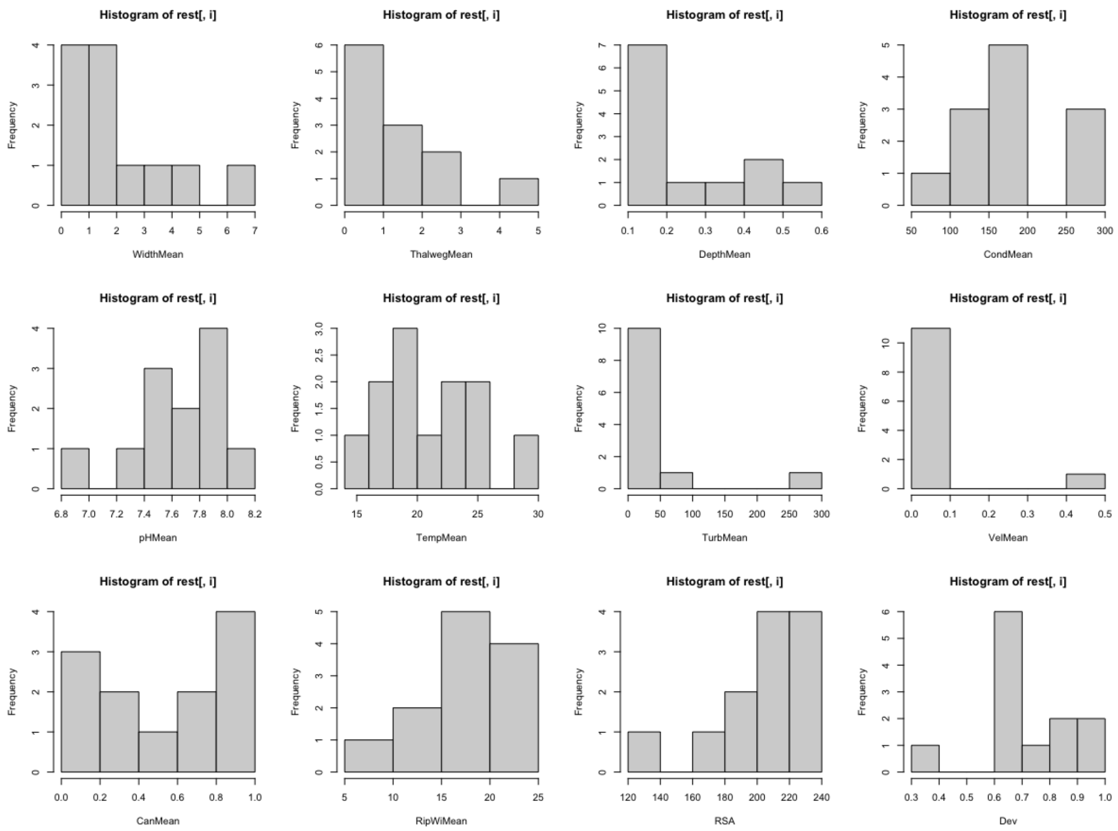

Figure A.2-2. Histograms of each parameter for restored sites.

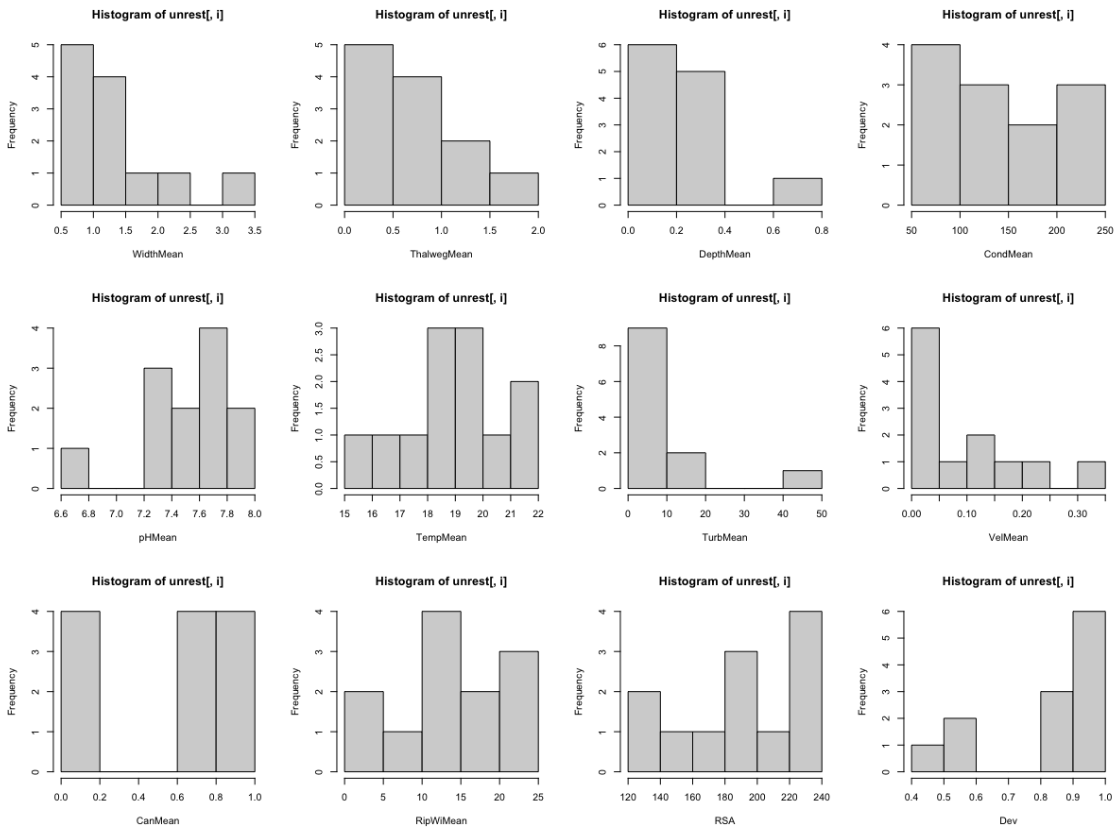

Figure A.2-3. Histograms of each parameter for unrestored sites.

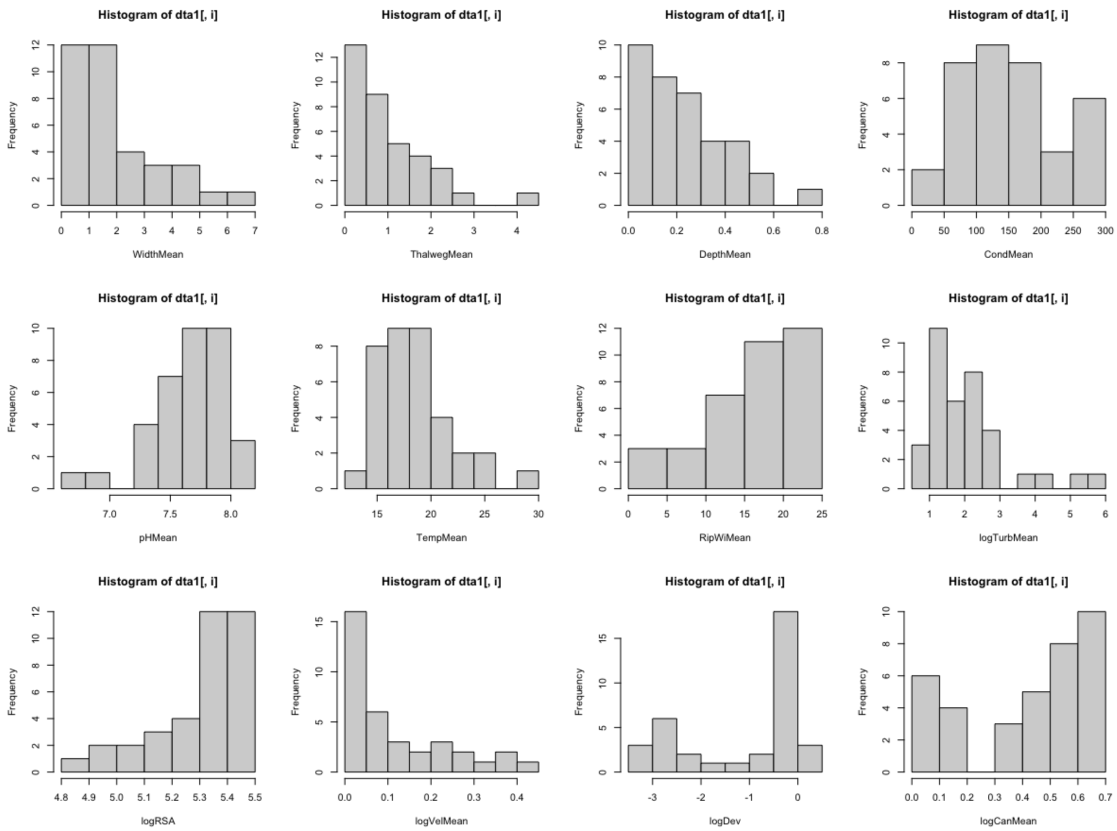

Figure A.2-4. Histograms for each parameter across all treatments.

	Width (m)	Thalweg (m)	Depth (m)	Conductivity (µs)	pH	Temperature (C)	Riparian Width (m)	log Turbidity	log RSA	log Velocity	log Developed
Thalweg	0.97										
Depth	0.75	0.72									
Conductivity	-0.06	0.01	-0.06								
pH	0.06	0.02	-0.25	-0.01							
Temperature	-0.02	0.08	-0.1	0.27	-0.12						
Riparian Width	0.17	0.14	0.13	0.03	0.12	0.11					
log Turbidity	-0.09	-0.05	-0.16	-0.03	-0.53	0.17	0.08				
log RSA	0.13	0.1	0.05	-0.41	0.38	-0.04	0.5	-0.29			
log Velocity	0.12	-0.01	-0.1	-0.36	0.5	-0.24	0.08	-0.35	0.37		
log Developed	-0.23	-0.14	-0.08	0.2	-0.42	0.58	-0.12	0.14	-0.29	-0.45	
log Canopy Density	0	-0.04	-0.06	-0.26	0.21	-0.26	-0.32	-0.24	0.13	0.16	-0.02

Table A.2-1. Spearmans Ranked Coefficient test results for parameters all treatments.

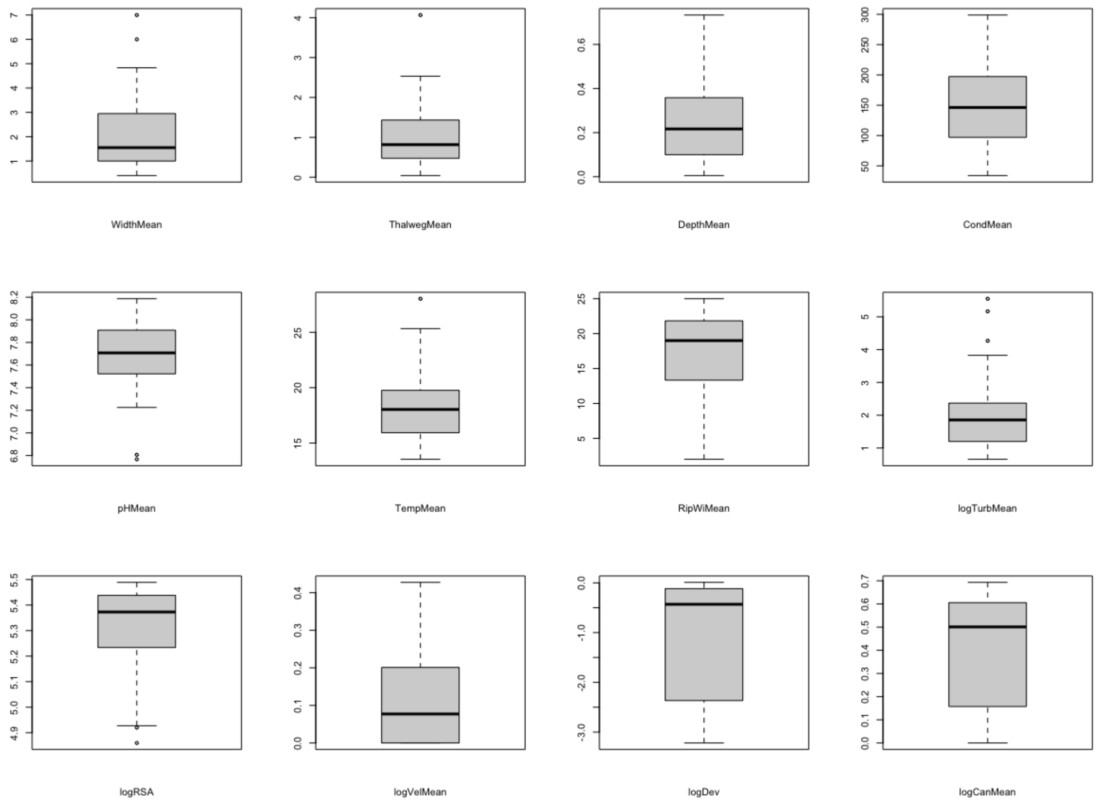

Figure A.2-2. Box plots for each parameter across all treatments.

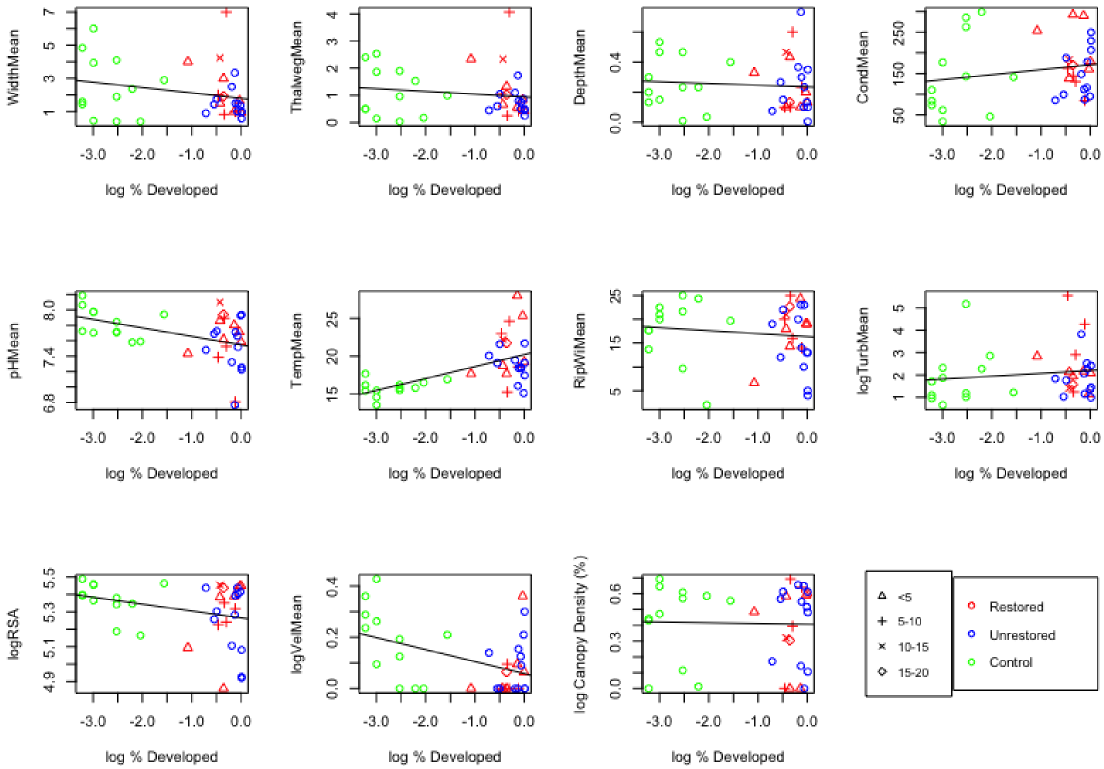

Figure A.2-4. Scatterplots to compare each variable against log % Developed.