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Macrophyte Abundance and Nitrate Dynamics of Silver Bow Creek

Katelyn Reichle

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Katelyn Reichle
M.S. Ecological Restoration Non-Thesis Project

Committee members:
Joe Griffin, Robert Pal, and Raja Nagisetty

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Abstract

Butte, Montana has an extensive mining history contributing to the contamination degradation of terrestrial and aquatic systems, amongst Silver Bow Creek (SBC). The contamination of the stream and the floodplain created a toxic environment that could not support aquatic life. Although the remediation of the floodplain was successful in removing metal contamination, the recovery of the ecosystem from both the initial pollution and subsequent remediation is ongoing. SBC has also been impacted by the urbanization of Butte, leading to multidimensional ecological disruption. The stream is currently subject to nutrient loading by nitrate, nitrogen, and phosphorus. A possible effect of nutrient loading in the area is the growth of macrophytes (rooted aquatic plants) in Silver Bow Creek, however, the exact mechanisms that govern the distribution of macrophytes in the area are less well understood.

In this study, the relationships between nitrate loading in surface waters and streambed sediments, sediment deposition, and macrophyte and algal communities were investigated in Silver Bow Creek. A variety of macrophyte species were observed and distribution dynamics were correlated with geographic location, season, bed composition, sediment nutrients, and depth of the creek. Furthermore, an inverse relationship was observed between nitrate concentration, as well as macrophyte density, with increased sediment size. The connections between nutrients, macrophyte density, and the stream bed suggested by this study are a possible reflection of nutrient-rich sediments being captured and exploited by macrophytes in Silver Bow Creek.

Introduction

The effects of mining in Butte, MT had catastrophic effects on the nearby Silver Bow Creek (SBC). For much of Butte's history, SBC was used as an industrial sewer, where contaminated wastewater was discharged into the creek. The combination of improper disposal of mine tailings and a series of floods that carried contaminated material into the floodplain created a toxic environment that could not support aquatic life (CFWEP, nd).

In order to address the limiting factors that inhibit recovery of the area, the SBC watershed has undergone substantial remediation and restoration under a Superfund cleanup (EPA, 2021). These modifications included the removal of contaminated sediments, as well as the stream channel and floodplains being reconstructed. Although the remediation of the floodplain was successful in removing metals contamination, the recovery of the ecosystem from both the initial pollution and subsequent remediation is ongoing. Silver Bow Creek has also been impacted by the urbanization of Butte, leading to multifaceted ecological disruption, including nitrate, nitrogen, and phosphorus loading (Nagisetty, 2019). In fact, LaFave (2008) states, "anomalously high concentrations of nitrate occur in the ground water and surface water in the Summit Valley as compared with other parts of the Clark Fork drainage basin." Enrichment of SBC occurs primarily from a single municipal point source that results in excessive primary production, macrophyte growth, large water quality swings, and nightly hypoxic conditions that likely impair aquatic life uses (Uecker, 2016). More potential anthropogenically linked sources include the entry of sewage treatment effluent entering the creek (Gammons et al., 2011, Nagisetty, 2019), as well as non-point sources of nitrates such as contaminated storm-water runoff (Gammons et al., 2005), the nutrient rich groundwater (LaFave, 2008), and fixation and subsequent deposition of atmospheric nitrogen by nitrogen-fixing plants in the present area.

A possible effect of nutrient loading in the area is the potentially excessive growth of macrophytes (rooted aquatic plants) in Silver Bow Creek (e.g. Gammons et al., 2011; Nagisetty et al., 2019). Referring to nutrients loading in a stream generally means evaluating the excess amount of nitrogen and phosphorus since these are almost always the nutrients that limit plant growth. Macrophytes are capable of taking in their required nutrients from both their root systems and foliage (Uecker, 2016). While macrophytes are able to take in nutrients from the sediment, it is important to note that they are also capable of taking in a significant amount of nutrients from the water column (Madsen & Cedergreen, 2002). Potentially, the Silver Bow Creek water column could be the primary source of nutrients instead of the sediments (Uecker, 2016). Macrophytes that are abundant in some streams, such as SBC, can likely contribute to nitrogen cycling and are often characterized by a high biomass of genera such as *Potamogeton* and *Ranunculus*. Macrophytes may also play an important role in the long-term retention of nitrogen, and they may have an indirect effect on nitrogen retention through higher sedimentation rates of particulate organic matter in macrophyte dominated streams. Moreover, the effect of macrophytes in sedimentation will also allow for potentially higher denitrification, which is the only removal mechanism of nitrogen in streams (Riss et al., 2012).

Furthermore, recent research has focused on macrophyte growth and its impact on dissolved oxygen levels which are being investigated as well as the occurrence of macrophytes downstream of the Butte Waste-Water Treatment Plant (BWWTP) (Nagisetty et al., 2019). It was shown that wastewater treatment plants in the Clark Fork Basin are recognized as major contributors of nutrients to surface water. Furthermore, ground-water contamination may also be one of the most probable nitrate sources to the streams above the wastewater treatment plant. The elevated nitrate concentrations that occur in the baseflow of Silver Bow Creek, suggest that little, if any, natural attenuation of nitrate occurs in the aquifer. As SBC lacks natural attenuation, the only way for nitrate concentrations to be reduced may be through natural flushing concurrent with a reduction in nitrate loading to the aquifer (LaFave, 2008). As macrophyte abundance has been linked to diurnal fluctuations of dissolved oxygen levels (Nagisetty et al., 2019), reductions in biodiversity, declines in ecosystem health, and displacement of native species (e.g. Duarte, 1995; Torn and Martin, 2012), the macrophyte ecology may provide valuable insight into the factors that are currently limiting aquatic ecosystem health and the impact of the ongoing restoration. In this study, the relationships between nitrate loading in surface waters and streambed sediments, sediment deposition, and macrophyte and algal communities were investigated to uncover the ecological mechanisms that govern the distribution and abundance of macrophytes in Silver Bow Creek.

Methodology

Field Surveys

Seven reaches of Silver Bow Creek were sampled during the study (Figure 1). Each sampled reach was examined along three transects distributed perpendicular to flow, with the first transect starting at from the middle of the sampled reach (Figure 2). Transects began on the upstream end of each reach, starting on the left bank and continuing to the right. Each transect was divided into five equal points based upon the channel width at the transect. Following the examination of the most upstream transect, the methodology was subsequently repeated on transects 50 m, and 100 m below the most upstream points. The streambed was examined, using a hydroscope, for the dominant macrophyte species present at each point location, and for sediment type. The hydroscope has a set area of approximately 1/3 m^2, which was split into percentages based off of the percent of macrophytes, algae, silt, sand, gravel, or cobble.

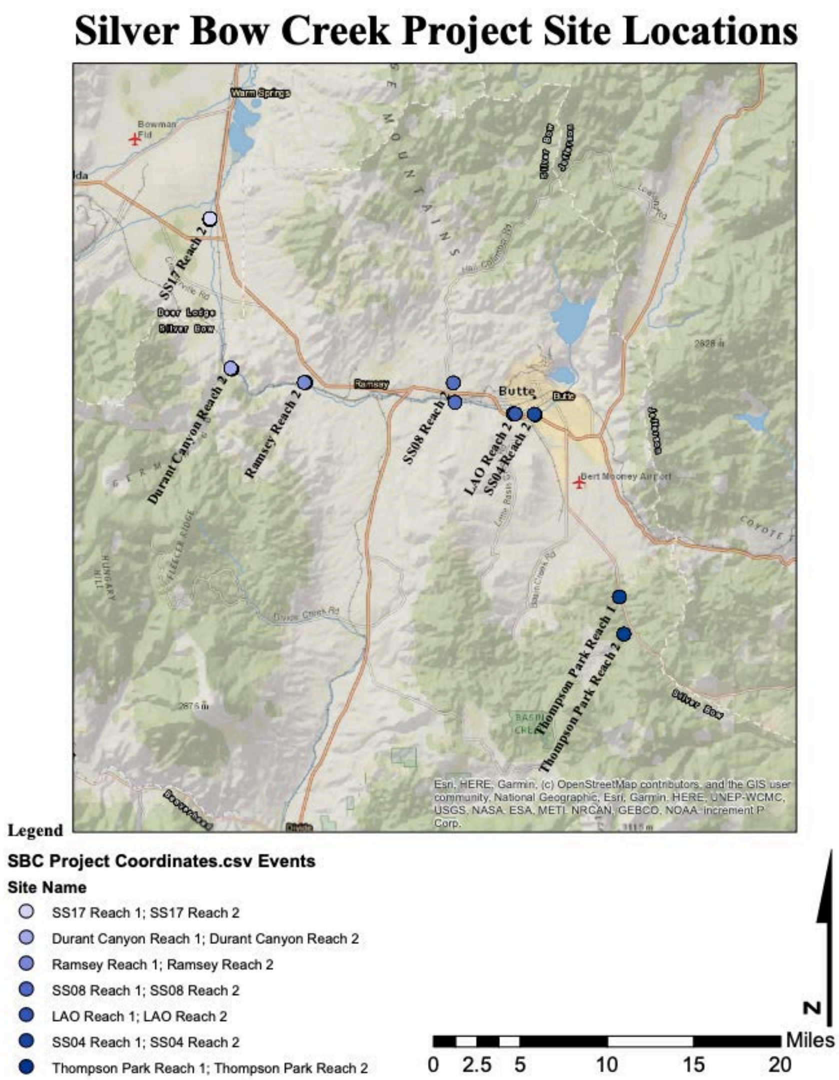

Figure 1. Map of Silver Bow Creek and the site locations within this project

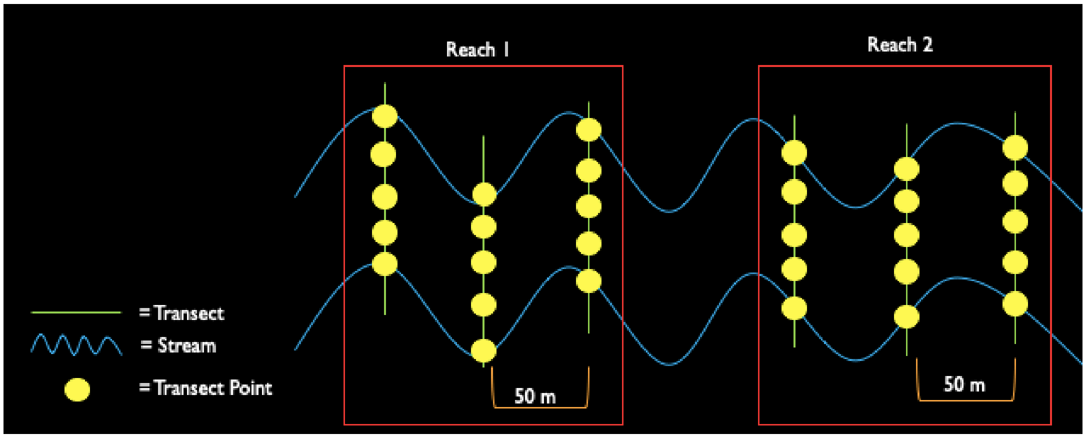

Figure 2. Diagram displaying the sampling design along Silver Bow Creek consisting of seven total sampling reaches split into two additional reaches consisting of three transects and five transect sampling points

During the vegetative survey at each sampling point, sediment samples were analyzed for nitrate (NO^-_3) concentrations. Sediments at each sample were collected approximately at a depth of 5 cm below the streambed surface. All sediment samples were directly placed on and chemically analyzed by a HORIBA LAQUAtwin NO3-11 Compact Nitrate Ion Meter. Surface water was also collected at the center point-transect at sampling point 3 and chemically analyzed by the HORIBA LAQUAtwin NO3-11 Compact Nitrate Ion Meter.

Statistical Analysis

The entirety of data pretreatment and analysis was conducted in MINITAB statistical software version 21.1 (Minitab, State College, PA). Data were arranged according to month and sampling location and visualized for descriptive analysis of temporal and spatial variation using box plot diagrams. Dominate stream bed type was then calculated according to which sediment class accounted for >50% of each plot, as either silt, sand, gravel, or cobble dominated. Plots containing no dominate sediment class were labeled as mixed plots. A multivariate linear model was then employed based on the distribution of macrophytes (i.e. percentages of plots covered in macrophytes) as the dependent variable and the dominate bed type, sampling month, and sampling site as explanatory variables to assess the significant factors related to macrophyte abundance. Optimized models were created using backward elimination to assess variable importance and their significance. Model fit and performance were assessed and optimized according to adjusted sum of squares, R-sq, and goodness of fit tests.

The averages of each sediment type, water column NO^-_3, bed sediment NO^-_3, and percent macrophyte coverage was analyzed using Principal Component Analysis (PCA) in PAST Statistical Software. Principal components analysis is a method in determining the inherent structure of data. When data is first gathered, and with each set of data added, the morphological structure of data when projected into a 3D plane becomes increasingly complex as the dimensionality increases. Changes in dimensionality of data can make the structure immensely difficult to understand. When the data is projected into a sufficiently higher dimensional space, it is nearly incomprehensible. In order to solve this, PCA causes a rotation of the data in order to retain the maximum amount of variation and structure within fewer dimensions, extracting characteristics of the environmental data for representation as a set of combined orthogonal variables of the principal component.

Results

Macrophyte Abundance and Species

Five genera of macrophytes that were observed and evaluated during this study. Macrophytes included *Potamogeton spp., Veronica spp., Ranunculus spp., Elodea spp., and Cladophora spp.* (Figure 3).

Figure 3. Photographs of each aquatic vegetation type in SBC

Average Surface Water and Sediment Nitrate and Percentages of Sediment Type

Average surface water and sediment nitrate concentrations were lower in site locations, Thompson Park, LAO, and Durant Canyon, and the average percent of macrophytes at these site locations was also lower (Figure 4; Figure 5; Figure 6). Areas where surface water and sediment nitrate concentration are higher such as at SS04 and SS08 are seen to have higher percentages of macrophytes.

Increased growth of macrophytes in the summer and fall seasons was observed along SBC. A subsequent die off of macrophytes during the winter season as the average percent of macrophytes peaked in the summer and fell in the winter (Figure 6).

Examination of the streambed revealed areas that exhibited higher percentage of silt such as in sites SS04 and SS08 also demonstrated higher percentages of macrophytes (Figure 6; Figure 7). Whereas in areas that presented a higher percentage of a larger sediment type such as gravel and cobble as in sites Durant Canyon, LAO, and SS17, demonstrated lower percentages of macrophytes.

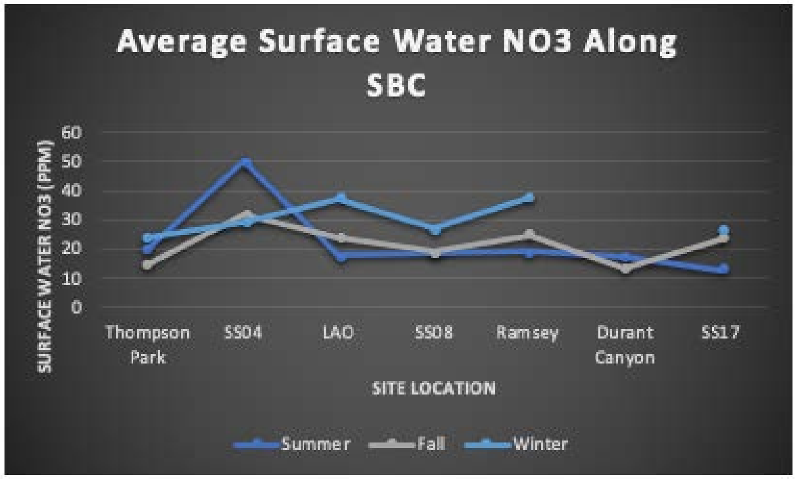

Figure 4. Graph Displaying the Average Surface Water NO3 (ppm) Along SBC

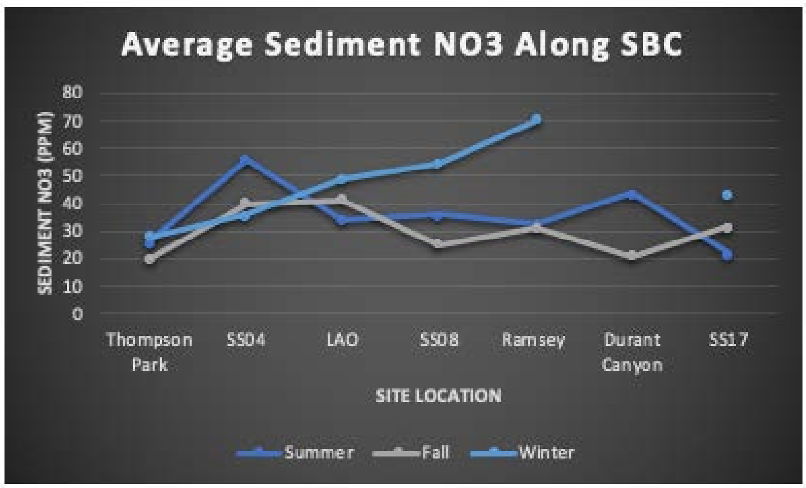

Figure 5. Graph Displaying the Average Sediment NO3 (ppm) Along SBC

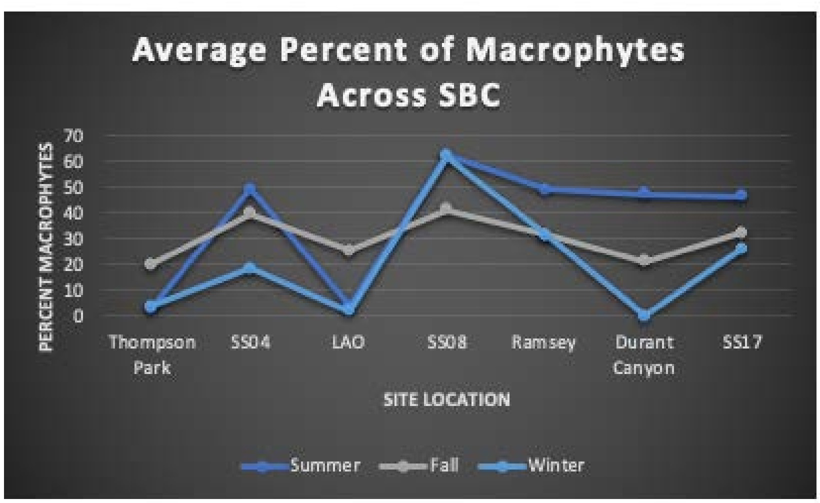

Figure 6. Graph Displaying the Average Percent of Macrophytes Along SBC

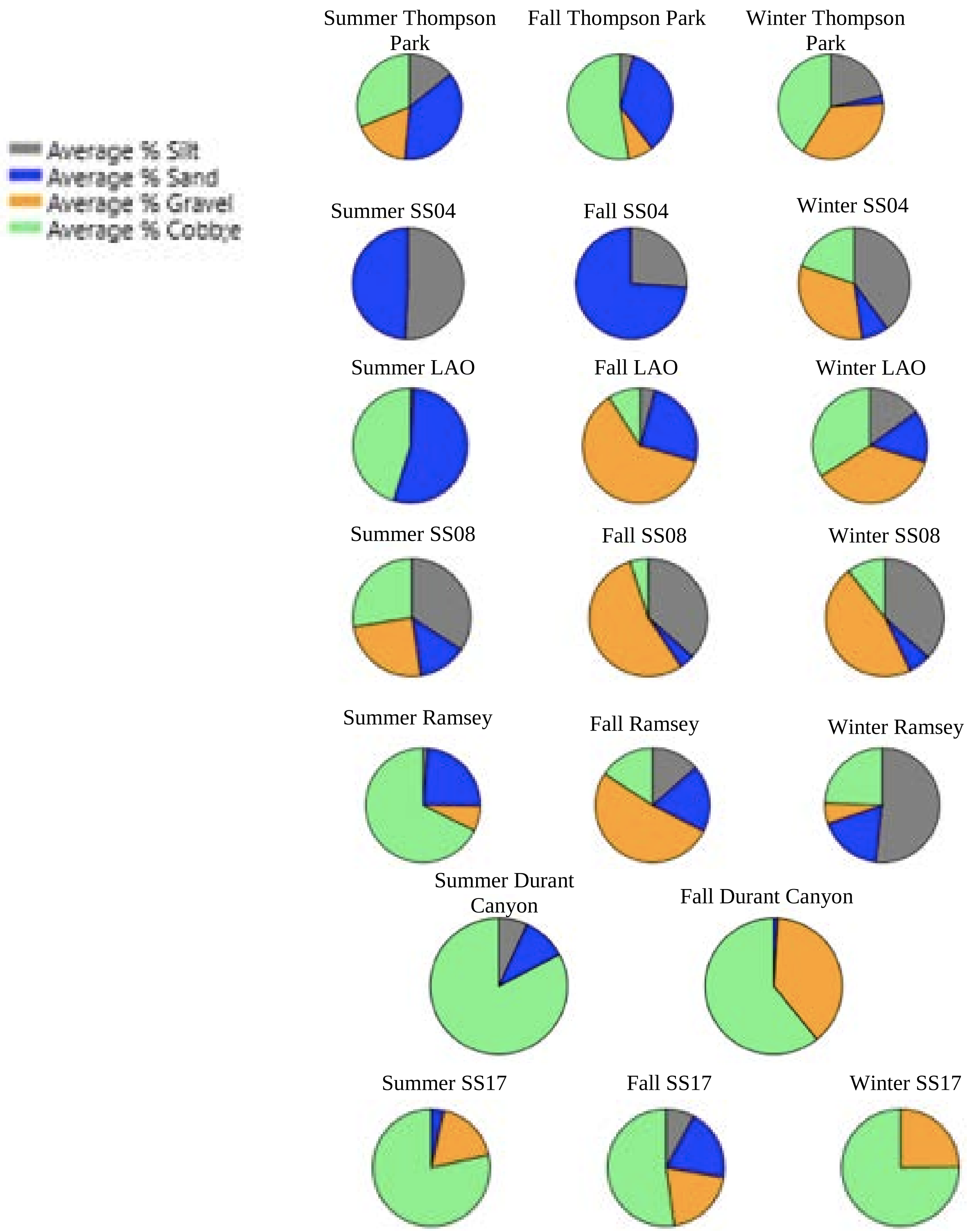

Figure 7. Average percentage of bed cover (silt, sand, gravel, cobble) along each site during each season (summer, fall, winter)

Principal Components Analysis

Results from the Principal Components Analysis (PCA) revealed relationships between environmental variables and the presence and abundance of macrophytes. The multidimensional analysis suggests that the percentage of silt, the surface water Nitrate, and the sediment Nitrate, were correlated with macrophyte presence and abundance. The PCA further suggests that cobble, gravel, and sand dominated areas have an inverse relationship with the presence and abundance of macrophytes (Figure 8; Table 1).

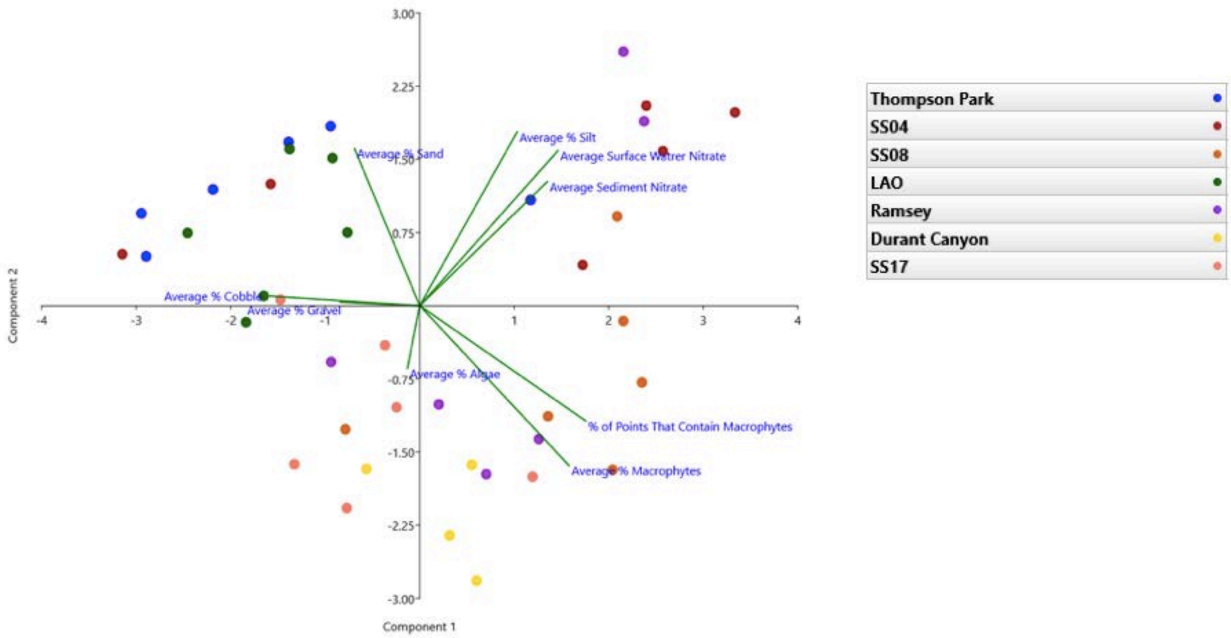

Figure 8. PCA of average percent macrophytes, average percent cover type, and average surface water and sediment NO3

Table 1. Eigenvalues and percent variance for the PCA of average percent macrophytes, average percent cover type, and average surface water and sediment NO3

PC	Eigenvalue	% Variance
1	3.12813	34.757
2	2.11845	25.538
3	1.24351	13.817
4	1.05145	11.683
5	0.624659	6.9407
6	0.494784	5.4976
7	0.176005	1.9556
8	0.14774	1.6416
9	0.0152601	0.16956

Univariate Linear Regression

The results of the univariate linear regression to assess the correlation between average macrophyte coverage and average stream bed sediment size suggest that bed composition significantly affects the abundance of macrophytes. Increasing silt (p = < 0.001) and sand (p = 0.012) composition were significantly positive and negative correlated with macrophyte abundance, respectively (Figure 9; Table 2).

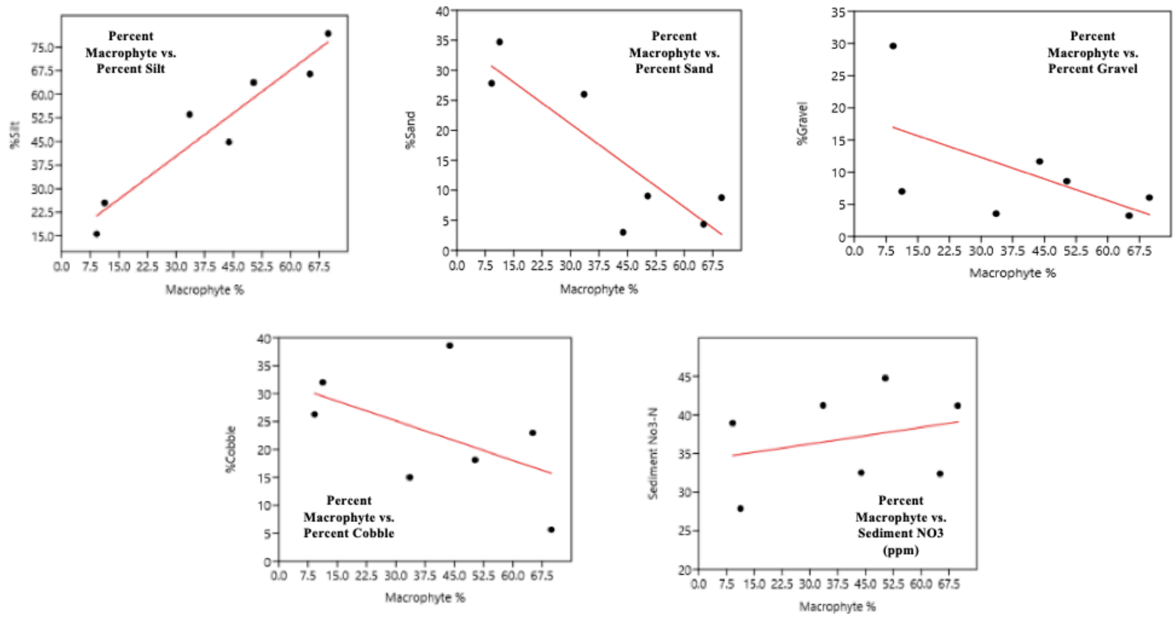

Figure 9. Linear regression displaying percent of macrophytes versus percent cover of silt, sand, gravel, cobble, and sediment NO3 (ppm)

Table 2. Linear regression R and p values of percent of macrophytes versus percent cover of silt, sand, gravel, cobble, and sediment NO3 (ppm)

Variable	r-sq	*p-value*
%Sand	-0.86111	**0.012***
%Gravel	-0.58698	0.1659
%Cobble	-0.51544	0.23641
% Silt	0.95617	< **0.001****
Sediment No3-N	0.28118	0.5413

The results of the univariate linear regression to assess the correlation between sediment nitrate concentrations and stream bed sediment size might suggest that bed composition may affect sediment nitrate composition, as the negative relationship between cobble composition and nitrate concentration approached significance (p = 0.068) (Figure 10; Table 3). However, the correlation between the two is unknown, and the results suggest that there is no significance between sediment nitrate concentrations and stream bed sediment size.

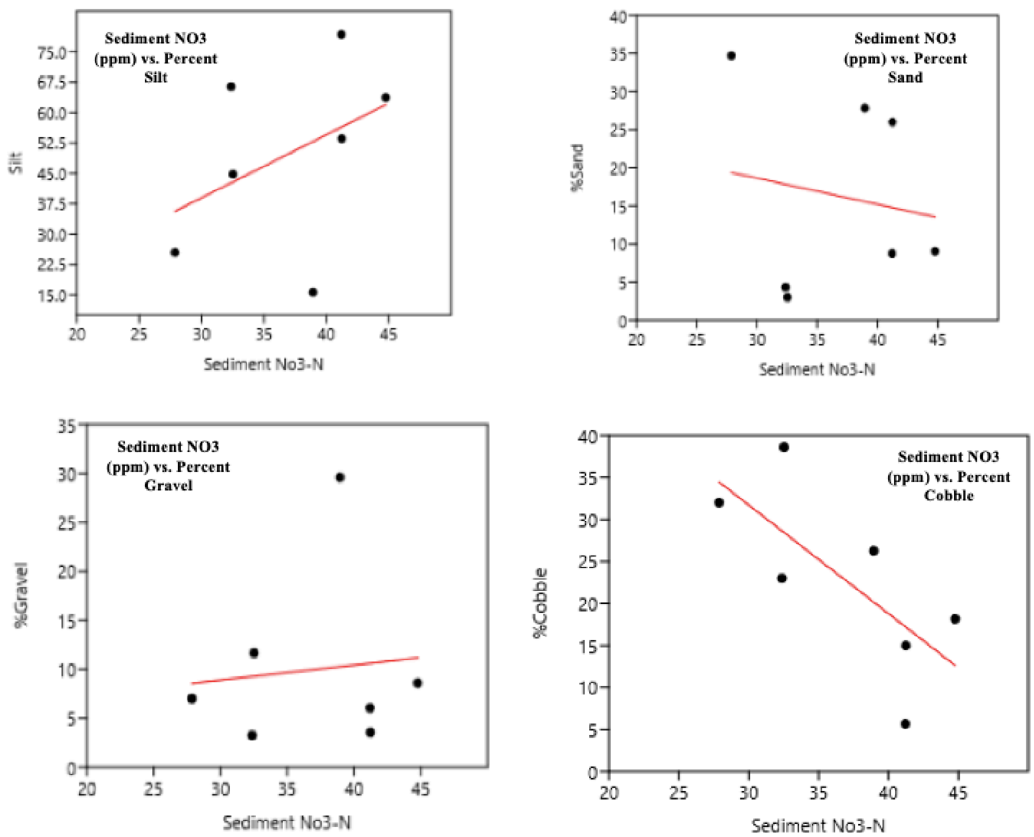

Figure 10. Linear regression displaying sediment NO3 (ppm) versus percent cover of silt, sand, gravel, and cobble

Table 3. Linear regression R and p values of sediment NO3 (ppm) versus percent cover of silt, sand, gravel, and cobble

Variable	r-sq	*p-value*
%Sand	-0.16406	0.725
%Gravel	0.10234	0.827
%Cobble	-0.72038	0.067
Silt	0.41627	0.353

Multivariate Regression Analysis

The multivariate linear regression analysis suggests that the presence and abundance of macrophytes is correlated with multiple environmental variables. Multiple linear regression suggested that site (p = < 0.001), season (p = < 0.001), cross section (p = < 0.001), and primary bed composition (p = < 0.001) are significantly correlated with macrophyte distribution (Table 4; Table 5).

Table 4. Model summary and coefficient table of the regression analysis of percent macrophytes when regressed against sediment NO3 (ppm), season, site, cross-section, and primary bed composition.

S	R-sq	R-sq(adj)	R-sq (pred)
20.3377	73.45%	72.77%	72.06%

Term	Coef	SE Coef	T-Value	*p-value*
Sediment NO3	0.1369	0.0706	1.94	0.053
Season				
Summer	-7.90	2.09	-3.77	**< 0.001****
Winter	-20.73	2.49	-8.32	**< 0.001****
Site				
LAO	-22.74	3.73	-6.09	
Ramsey	-7.06	3.51	-2.01	**< 0.001****
SS04	-20.94	3.51	-5.97	0.045*
SS08	2.39	3.49	0.69	< 0.001**
SS17	-3.56	3.48	-1.02	0.494
Thompson Park	-26.00	3.60	-7.22	0.307
Cross-Section				
Edge	-9.93	2.29	-4.34	**< 0.001****
Mid-depth	-3.06	2.28	-1.34	0.180
Bed Composition				
Non-Dominant	7.81	6.47	1.21	0.228
Gravel	-1.66	3.33	-0.50	0.228
Sand	9.05	2.87	3.16	**0.002***
Silt	52.51	2.32	22.66	**< 0.001****

Table 5. Analysis of variance table of the regression analysis of percent macrophytes versus sediment NO3 (ppm), season, site, cross-section, and primary bed composition

Variable	DF	Adj SS	Adj MS	F-Value	P-Value
Sediment NO3 (ppm)	1	1555	1554.6	3.76	0.053
Season	2	28844	14422.0	34.87	< **0.001****
Site	6	58029	9671.5	23.38	< **0.001****
Cross-Section	2	9558	4778.9	11.55	< **0.001****
Primary Bed Comp.	4	265455	66363.8	160.44	< **0.001****
Total	598	908329			

Discussion

Macrophyte Abundance and Species

The main genus of macrophytes that were observed and evaluated included: *Potamogeton spp., Veronica spp., Ranunculus spp., Elodea spp., and Cladophora spp.* The most common species seen of the *Potamogeton* genus is slender pondweed (*Potamogeton filiformis*). Slender pondweed is a native, rhizomatous, and perennial aquatic plant species to Montana that often has filiform, submersed leaves attached directly to the stipule (MFG, nd a). It often grows in shallow, fresh water of lakes, ponds, and slow streams (Lesica, 2012), and often flowers from June through July (MFG, nd). Slender pondweed is also most often found over moderate ranges of alkalinity and pH and grows in small substrate (Lake Ripley Management District, 2021).

The *Veronica* genus often includes rhizomatous, perennial aquatic species that grow in slow, shallow water or banks of streams and wetlands (MFG, nd b). The aquatic plants of this genus can also grow well in a variety of pH levels as long as the sediment is composed of heavy loam or aquatic soil (MFG, nd b). The species identified most often during our research was *Veronica americana*.

The most common species seen of the *Ranunculus* genus is white water crowfoot (*Ranunculus aquatilis*). White water crowfoot is a native, aquatic plant species of Montana that is composed of floating stems with glabrous hairy foliage (MFG, nd c). It is often found in the shallow water of ponds, lakes, and stream at all elevations (MFG, nd c). White water crowfoot often inhabits lakes and streams with higher alkalinity and prefers soft sediment (Lake Ripley Management District, 2021).

The most common species seen of the *Elodea* genus is broad waterweed (*Elodea canadensis*). Broad waterweed is a native aquatic plant species consisting of leaves that are minutely serrate, narrow, lanceolate, and opposite (MFG, nd d). Broad waterweed is often found in shallow to deep water of lakes, ponds, sloughs, and slow streams (MFG, nd d). This species often prefers soft, silty substrate and it is tolerant of turbid water conditions (Lake Ripley Management District, 2021).

Cladophora spp. are a type of macroalgae consisting of single cells that are connected end-to-end (Lake Ripley Management District, 2021). Filamentous algae do not have roots, stems or leaves; it is frequently attached to rocks or other plants (Lake Ripley Management District, 2021). Abundant growth identifies aquatic habitats polluted with excessive nutrients (Lake Ripley Management District, 2021).

Macrophyte Distribution

The results of this study suggest that macrophyte distribution in Silver Bow Creek is highly variable and correlated with both geographic location, season, bed composition, sediment nutrients, and depth of the creek. As both site and season were significantly correlated with macrophyte abundance, the activity of macrophytes in Silver Bow Creek appears to go through seasonally linked growth patterns in which a bloom occurs during the summer and fall, followed by a die off during the winter. Interestingly, as not all sites were significantly correlated with changes to abundance of macrophytes, the site locations closest to Butte, MT appeared to have the most change of macrophyte abundance over time.

Macrophytes and the Physical and Chemical Stream Conditions

The correlations between observed densities of macrophytes and physical and chemical stream conditions may point to macrophytes acting as ecosystem engineers due to their ability of transforming the physical conditions within a stream (Helfrich & McGowan, 2020). *R. aquatilis,* which was ubiquitous in shallow areas at the study sites, is known to alter streambed roughness, which in turn alters stream velocity and increases deposition of fine sediments and suspended materials. (e.g. Gessner, 1955, Cotton et al., 2006). This activity of this macrophyte and others significantly modifying flow patterns, sediments, nutrients, and water velocity within and between macrophyte mats (e.g. Wharton et al., 2006, Cotton et al., 2006). This trend is further supported by the inverse relationships observed between nitrate concentration, as well as macrophyte density, with stream bed composition. Therefore, the connections between nutrients, macrophyte density, and the stream bed suggested by this study is a possible reflection of nutrient-rich sediments being captured and exploited by macrophytes, thus contributing to the increased macrophyte biomass at these locations.

Although macrophyte distribution and sediment nitrate exhibit a clear trend, the exact mechanisms governing these relationships is less well understood. However, as the areas immediately downstream of Butte exhibited vastly different stream bed composition and macrophyte abundance, anthropogenic factors may be influencing the activity of macrophytes in this area. Potential changes to nitrogen content through anthropogenic influences, as well as restoration activity to change streambed composition may be linked to the growth of macrophytes in Silver Bow Creek. Further study to uncover the sources and fate of fine sediments and nutrients in Silver Bow Creek may provide useful insight into the ecological status of this recovering area.

Study Limitations

Based on recent monitoring data completed for Montana DEQ and US EPA that includes laboratory results for nitrate (RESPEC, 2020), it is apparent that the nitrate values derived from the field instrument used in this study (HORIBA LAQUAtwin NO3-11) for both water and sediment are not accurate. The true concentrations of nitrate in this area are substantially lower than shown in this studies results. However, the results of this study seem to qualitatively represent temporal and spatial trends that are similar to trends demonstrated by the validated laboratory data. The external validity of the analyses is likely low; however, the internal validity may provide insight into the ecology of Silver Bow Creek.

Lessons Learned in Restoration

As this project on SBC has monitored macrophyte abundance and possible nitrate eutrophication post-restoration and remediation actions, it has brought insight into the restoration and remediation practices obtained on SBC. Silver Bow Creek has been considered as an aquatic ecosystem, a riparian zone, and even as a wetland environment; all of which can be restored in a vast number of ways. The effects that industrial mining had on SBC were detrimental, but the restoration practices done in the past may be the key as to why SBC has an abundance of nutrients and macrophytes. For example, nutrient loading, especially with nitrogen, can make wetland establishment difficult as it can create trade-offs between reduced export of nutrients downstream and enhanced greenhouse gas emissions (Brinson, M. & Eckles, S., 2011). Therefore, when approaching a restoration site and deciphering a restoration action, both positive and negative effects need to be addressed given he trade-offs between enhancement of the ecosystem services and lack of knowledge of thresholds at which ecosystem, functions are no longer ecologically sustainable (Brinson, M. & Eckles, S., 2011). This is a lesson well learned for the SBC project. Restoration and remediation actions are still new and upcoming, what was done then may not have been done now on SBC. However, when going forth on this project in hopeful future studies, this will be considered and more lessons will be learned.

Acknowledgments

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