REDUCING THE CUMULATIVE EFFECTS OF TIMBER HARVEST AND LIVESTOCK GRAZING USING DEBRIS BARRIERS

by

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ABSTRACT

The cumulative effects of timber harvesting and livestock grazing can affect water quality and quantity, hydrologic function and other important resource values near small headwater streams. Following timber harvest in British Columbia, Canada, small streams are often left without a reserve zone, likely because of the lack of a legislative requirement in B.C.. On a multiple use land base with livestock grazing, this can lead to increased use of unprotected riparian areas where quality forage and water exist. The objectives of this study were to test the effectiveness of using coarse woody debris barriers to minimize the cumulative effects of livestock grazing and timber harvesting on small stream, riparian values. Debris barriers were strategically placed within four recently harvested cutblocks where livestock graze seasonally on extensive, forested rangeland in the Okanagan region of B.C.. Cover, species richness, bare soil, litter, biomass, trampling, manure and utilization were sampled to determine the effectiveness of the barriers between control and barrier treatments over two grazing seasons. Debris barriers were effective in maintaining higher vegetative cover when compared with control treatments. Other positive outcomes were reduced trampling and utilization in the barrier treatments. This study has shown that debris barriers can be effective at minimizing some of the negative effects of livestock grazing following timber harvest. With this greater understanding of debris barriers and their effectiveness in protecting small, headwater streams the goal is to promote their use and adoption by forest licensees as another tool to mitigate the loss of riparian vegetation. The results suggest that debris barriers ought to be a best management practice as a cost-effective tool to mitigate the potential negative cumulative effect of timber harvest and livestock grazing in and around small headwater streams.

keywords: riparian protection, grazing management, livestock, timber harvest, coarse woody debris, headwater streams, British Columbia

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DEDICATION

I would like to dedicate this work to my dad who made significant contributions to agricultural practices and zero tillage farming and soil conservation in the prairies. He taught me a strong work ethic from a young age and I never could have got to where I am today without his guidance, love and support. His career in soil management and conservation led me to pursuing a career that also manages our natural resources and for that I am grateful.

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CHAPTER 1. INTRODUCTION

Conflicting uses on the land base can often confound management outcomes amongst users (Wikeem et al. 1993; Wheeler et al. 2002). Livestock grazing and timber harvesting are both parts of a multiple use land base and often overlap on a large proportion of Crown land in British Columbia, Canada. There is no legislated requirement to retain a buffer zone of trees adjacent to small streams during timber harvest. This often leads to increased use by livestock in riparian zones in cutblocks due to the presence of forage and water (Beschta and Elmore 1987; Johnson et al. 2016) where range agreements and timber licenses occur on the same landscape.

Awareness to maintain the presence and function of riparian reserves was heightened when large tracts of land were affected by the mountain pine beetle epidemic that started in the early 1990s. Extensive harvesting across the landscape exposed riparian areas, especially those adjacent to small streams to a higher level of impact from livestock. Since that time, there has been an increased need for planning and management of livestock and communication between timber companies and range agreement holders to minimize the effects to important resource values.

Headwater streams in the upper reaches of our watersheds are often formed by groundwater inputs and start the formation of first order streams, these streams can be intermittent, ephemeral or perennial (Winter 2007). Small streams often make up greater than 80% of the total stream length in a given area (Bishop et al. 2008) and the riparian areas of these first and second order streams have the ability of buffering the effects of disturbance from the uplands (Rheinhardt et al. 2009). Harvesting of riparian buffers can result in decades of less than adequate ecosystem functioning (Rheinardt et al. 2009) and affect habitat for fish, aquatic invertebrates, amphibians and plants (Kuglerova et al. 2017).

Riparian zones, especially in headwater streams, play a critical role in protecting resource values (Lowe and Likens 2005). The removal of riparian forests and vegetation has a negative effect on bank stability (Correll 2005; Florsheim et al. 2008). Vegetation along streams can provide shade, stabilize banks, trap sediments, filter pollutants (Dadkhah and Gifford 1980; Vought et al. 1995) and leaf litter provides food for aquatic invertebrates (Correll 2005; Hrodey et al. 2009). Overstory and understory riparian vegetation provides shade that helps maintain stream temperatures, which otherwise can become high and lethal to fish and other aquatic organisms (Armour et al. 1991). The riparian forest also acts as a source of coarse woody debris that is important to channel morphology and should remain intact and not harvested (Correll 2005).

Planning of forest harvesting that does not leave a riparian buffer on streams, wetlands or moisture receiving areas, and where there are overlapping grazing tenures, increases the likelihood of disturbance to these riparian areas (Armour et al. 1991). These harvested cutblocks become ideal sites for livestock due to the potential for increased forage and available water until the next generation of trees is established (Beschta and Elmore 1987; Johnson et al. 2016). Livestock are known to use these riparian areas disproportionately as forage biomass is known to regenerate quicker after forest harvesting than the adjacent uplands (Fleischner 1994; Harris et al. 2002; Dwire et al. 2006)

Increased access by livestock to riparian zones can have negative effects on soil properties (Fleischner 1994; Clary 1995), riparian values and hydrologic conditions (Beschta and Elmore 1987). With unimpeded access to small streams, livestock tend to use the stream channel as a trail that can lead to trampling the streambanks and widening the stream channel, reducing plant cover and biomass, raising stream temperatures, compacting the soils and adding increased sediments and nutrients to the system (Fleischner 1994; Belsky et al. 1999; Clary and Kinney 2002; Harris et al. 2002; Callaghan et al. 2018). Trampling can lead to shifts in the plant community (Herbst et al. 2012) by reducing the amount of available moisture for plant production (Dadkhah and Gifford 1980; Willatt and Pullar 1984). This leads to shifts from deeper rooted perennial vegetation to shallower rooted upland and non-native species (Díaz et al. 2007) and adversely affects species composition and richness (Dobarro et al. 2013). Reduced infiltration rates caused by trampling changes the timing of spring flows and leads to increased runoff and erosion affecting water quality and the lands ability to store and release water later in the season (Gifford and Hawkins 1978). Reduced trampling can increase vegetative cover leading to increased infiltration, percolation and soil water storage while reducing runoff, erosion and deposition, as well as helping to dissipate streamflow energy during times of high flows (Dadkhah and Gifford 1980; Rigge et al. 2014).

Sediment inputs that settle into the streambed remove habitat for aquatic invertebrates and spawning areas for fish and has been noted as a major effect on fisheries (Armour et al. 1991). One of the most harmful activities to the aquatic ecosystem and fish habitat is the trampling of over-hanging banks (Fleischner 1994). Sediment moving into the substrate of a stream reduces the amount of dissolved oxygen available to fish embryos and macroinvertebrates and hinders the emergence of hatched fish (Armour et al. 1991). Areas that are ungrazed or with lighter grazing tend to be better fish habitat than heavily grazed zones (Armour et al. 1991).

Water flowing from small, headwater streams are often the origins of domestic drinking water for large populations in valley bottoms. Nutrients from feces and urine can have a negative effect on water quality that can increase the number of coliform bacteria in the water (Clary 1995; Derlet et al. 2010). Livestock can elevate the risk of water borne diseases including Escherichia coli, cryptosporidium, giardia and campylobacter (Newman et al. 2003). Riparian areas adjacent to small streams are the highest risk areas for introducing potentially harmful pollutants into the stream (Buckhouse and Gifford 1976). Anaerobic soil conditions of some riparian areas are effective at removing nitrogen in the ecosystem through the denitrification process (Manis et al. 2014). Forested riparian zones with vegetative ground cover and litter provide a buffer from potential upland non-point source pollutants (Peterjohn and Correll 1984; Groh et al. 2019). Therefore a higher level of management to ensure healthy riparian areas, especially within community watersheds is required (Royce 1989).

Currently there are many management practices being employed in B.C. on Crown land to manage livestock in community watersheds and to protect riparian values. These include off-stream watering, cross fencing, salting, riding and rotational grazing which have proven effective in increasing riparian vegetative cover (Bailey 2004; Rigge et al. 2014). All these practices require a financial and time commitment on the part of the province and the range agreement holder. Range developments such as fencing and off-stream water troughs are owned by the Crown in B.C.. The maintenance obligation is the responsibility of the range agreement holder. It is not practical or necessary to fence out livestock from streams on extensive rangelands in most cases when large herds disperse into smaller groups within large pastures. Past studies have shown livestock prefer to use off-stream water sources where available which minimizes direct access to surface water sources (Royce 1989). Riding to herd livestock to get good distribution and use of available forage is effective (Bailey 2004) but comes with a time commitment on the part of the range agreement holder that can conflict with other ranch duties during the grazing season.

Using coarse woody debris to reduce the presence and effects of livestock is a known, yet unquantified practice that needs further confirmation of its effectiveness where the timbered reserve zone has been removed through harvesting. A pilot study conducted in 2011 in the same geographical location of my study on the Aberdeen Plateau south-east of Vernon, B.C. showed positive results for riparian health and function and provided guidelines that this study has adopted (2015 conversations with Andrew Pantel, unreferenced see “Notes”). The pilot did not collect quantitative data on vegetative and non-vegetative variables and utilization. More focused data collection and analysis is necessary to show whether debris barriers are effective at reducing use and effects of livestock on unprotected small streams in cutblocks. Coarse woody debris barriers may provide one more level of protection by minimizing the direct access and linear movement within small streams while not requiring the financial and management costs of building and maintaining fences.

The evolution of forest and range practices to reduce the potential disturbance to riparian areas on cutblocks are necessary. Coarse woody debris placement as a management practice may work as an effective barrier to livestock (Rawluk et al. 2014). Depending on how the debris is used it can provide full exclusion or partial exclusion to allow reduced access. Windrows of debris parallel to a stream can potentially be as effective as a wire fence in preventing access. This treatment would require much more debris and may not be wildlife friendly and be a potential fire hazard. It is not the preferred method for this experiment as full exclusion was not the goal. The purpose of my research was to test the effectiveness of using coarse woody debris criss-crossed over the stream channel to reduce the effects of livestock grazing on small streams following timber harvest. This can be a low cost, operational management option that can be applied on small, headwater streams and non-classified drainages. The protection of these riparian areas from the cumulative effects of timber harvesting and livestock grazing can help to maintain vegetative cover, filter sediments and pollutants, increase infiltration, recharge groundwater, protect fish habitat, and a streams ability to protect against flooding (Belsky et al. 1999).

Four sites were chosen for this study south-east of Vernon, B.C. in an area known as the Aberdeen Plateau. In a larger context, the headwater streams (<1.5 m wide) within the sites flow into larger streams that are the sources of domestic water supply in Vernon, Kelowna and Lake Country in the Okanagan Valley. For this reason, resource users of these community watersheds are monitored closely by resource stewardship staff, water purveyors and the public to ensure that standards are being met. The area is forested, and land uses include timber harvesting, livestock grazing, recreation, water storage and delivery and mineral and gravel extraction. All four sites occur in the montane spruce (MSdm1) biogeoclimatic zone (A Guide to Site Identification…2007). This zone is characterized by cold winters and moderately short summers. Elevation at the sites was 1428, 1380, 1475 and 1375 m respectively with slopes between 1 and 7%. The sites were harvested between 2005 and 2011 and selected based on having active range agreement overlap and the sites were sampled over the 2016 and 2017 grazing seasons.

My thesis aims to examine whether coarse woody debris barriers are effective at reducing the cumulative effects of timber harvesting and livestock grazing on small stream and riparian values. The thesis layout is as follows:

Chapter 1: Introduction. This chapter introduces the topic and the issues created on a multiple use land base and the values that are at stake and important to protect.

Chapter 2: Reducing the cumulative effects of timber harvesting and livestock grazing using debris barriers. This chapter goes into depth on how the experiment was set up and methods used to collect the data to test the effectiveness of coarse woody debris barriers. Results of the study and discussion close out the chapter.

Chapter 3: Management implications and ideas for future research are discussed in the final chapter. This chapter focuses on the practicality and cost savings of using this method versus other traditional management techniques to protect riparian values and minimize the negative cumulative effects of timber harvesting and livestock grazing on stream and riparian values.

The objective of this research study is to test whether coarse woody debris barriers can be effective at minimizing the cumulative negative effects that timber harvesting and livestock grazing can have on small stream and riparian values.

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CHAPTER 2. REDUCING THE CUMULATIVE EFFECTS OF TIMBER HARVEST AND LIVESTOCK GRAZING USING DEBRIS BARRIERS

INTRODUCTION

A forested landscape often acts as a natural barrier to livestock as there is little forage value and use in the understory of closed canopy forests. When these areas are harvested, livestock access is created and there is generally a flush of vegetation that attracts livestock to areas they previously did not have access to or benefit from. In many cases there are classified streams and non-classified drainages within forest cutblocks that attract livestock due to the presence of water and forage (Harris et al. 2002; Fleischner 1994). In British Columbia, Canada an S4 stream is less than 1.5 m wide and is fish bearing and/or within a community watershed. There is no legislated requirement for timber companies to retain a riparian buffer of trees on this stream class. Streams that are not fish bearing or within a community watershed (S5 and S6) also do not require a reserve zone. Larger streams (S1/S2/S3) all require a fixed-width buffer of at least a 20 m to be left intact. The S4 stream class is often the small, headwater streams that make up the majority of stream length in the province and are important moisture receiving areas that when functioning properly help to protect against early season flooding, maintain water temperature and stream flows and protect against drought later in the season. They also provide a food source for fish and other aquatic species (Lowe & Likens 2005).

While these additional grazing opportunities can benefit range agreement holders, they can have negative effects on riparian health and soil properties (Fleischner 1994; Clary 1995). Excess livestock use on riparian soils can lead to compaction, affect infiltration rates, change the timing of spring flows and cause alterations of the plant community (Huang et al. 2014; Herbst et al. 2012). Habitat requirements for aquatic invertebrates and spawning areas for fish are affected by increased sedimentation which can be confounded by the trampling of streambanks and excessive use by livestock (Fleischner 1994). Degradation of water quality is also a concern with increased use of livestock within the riparian zone and stream channels (Agouridis et al. 2005; Derlet et al. 2010).

A recent pilot project looked at the efficacy of using linear logging debris barriers versus criss-crossed logging debris over stream channels. Linear barriers have been found to significantly minimize livestock movement in riparian areas where livestock exclusion is the goal (2020 conversation with Lisa Zabek, unreferenced, see “Notes”). The goal of criss-cross barriers is not full exclusion, the main objective is to reduce the linear movement of livestock up and down the stream channel and minimize use within the riparian area. Criss-cross barriers still allow livestock access to the stream and riparian area for water and forage but minimize the linear movement parallel or within the stream channel and the associated trampling and negative effects to water quality, soil properties and riparian health.

For my research, logging debris was placed across small stream channels in X’s to test if it reduces the effects of trampling and use within the harvested riparian areas of cutblocks. Linear logging debris barriers were not considered in this study. Cutblocks within the study area provide transitional grazing opportunities and are usually a source of forage for approximately 20 years (Clark and Mclean 1980). After this time, competition from trees reduces forage and makes the site less desirable to livestock. The idea of using coarse woody debris is that it is a low cost, temporary mitigation option to fencing and that in the time the forest regenerates and forms a new barrier, the woody debris will settle and decompose and the natural barrier to the stream will be effective once again to reduce impacts to riparian health and water quality. Besides restricting livestock movement, the artificial addition of coarse woody debris can help to bridge the gap between the 50 or more years it can take for natural inputs of trees and shrubs to incorporate by natural windfall and mortality to serve as stability to the stream and habitat for the aquatic ecosystem (Rheinhardt et al. 2009). The potential advantage of this is improved riparian health and water quality during the years of increased livestock use without the high initial costs of fencing and years of maintenance that is a requirement of the range agreement holder.

In this study, four recently harvested cutblocks with small streams (S4) within them were chosen as study sites. The four sites were all within the same biogeoclimatic zone (Biogeoclimatic Ecosystem Classification Program, 2020) within the Aberdeen Plateau and shared similar livestock densities and timing of use. Vegetation sampling including cover, species richness, bare soil, litter, biomass as well as trampling, manure and utilization were studied over two grazing seasons. These attributes were then used to determine whether criss-cross logging debris barriers were effective at reducing the cumulative effects of timber harvesting and livestock grazing on small streams. I hypothesized that criss-cross logging debris barriers would (1) increase cover, species richness, litter and biomass (2) reduce trampling, bare soil and manure and (3) reduce forage utilization, all within the riparian zone of recently harvested cutblocks. The goal is to create best management practices to help minimize the cumulative effects of timber harvesting and livestock grazing on small streams in cutblocks.

METHODS

Study Area

The study area was located south-east of Vernon, B.C., Canada in an area known as the Aberdeen Plateau. The area is forested and uses of the land include timber harvesting, livestock grazing, recreation, water storage and delivery mining and gravel extraction. The four sites selected for this research occur in the montane spruce biogeoclimatic zone. The Okanagan Dry Mild Montane Spruce Variant (MSdm1) is typically found in the Okanagan Highlands with an elevational range of 1300-1600 m (A Guide to Site Identification…2007). Elevation at the sites was 1428, 1380, 1475 and 1375 m respectively with slopes between 1 and 7%.

Recently harvested cutblocks with small streams within them were chosen to be study sites. Brunette 1 is a 30-hectare clearcut that was harvested in 2011 and grazed in the spring and fall. Brunette 2, a 45-hectare clearcut was harvested in 2010 and grazed in late summer. The Echo site is a 37-hectare clearcut that was harvested in 2009, Crescent is a 48-hectare clearcut that was harvested in 2005 and both sites are grazed in the fall (Figure 2. 1). Before harvesting, the sites were occupied by lodgepole pine and some spruce. The understory of the uplands consisted primarily of pinegrass, the most commons species found in the riparian areas were sedge species, mannagrass, bluejoint reedgrass, fescue species and several forbs

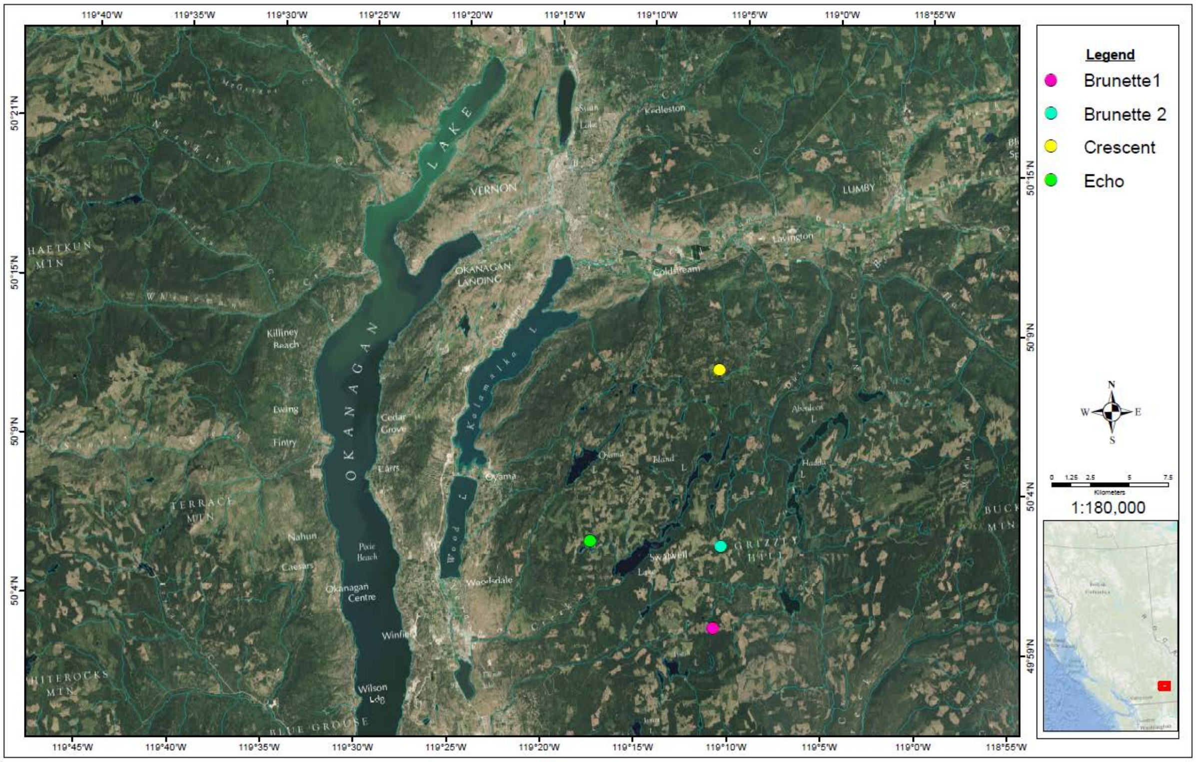

Figure 2. 1 - Map of sites located on the Aberdeen Plateau, south-east of Vernon, British Columbia, Canada.

and shrubs. All four sites were along forest service roads seeded with domestic forage species and were used by livestock to move throughout and between pastures. It was verified that some livestock use was present on all the cutblocks prior to selecting them for use in this study.

Experimental Design and Analysis

The study was analyzed using a 2-way ANOVA. There were four sites and two treatments with each treatment being replicated once at each site. The treatments alternated from the downstream end based on a coin flip that determined which one would go first. One treatment was left untouched as a control, and the other had coarse woody debris barriers criss-crossed across the stream channel.

Coarse woody debris treatments were designed to have four X’s spanning the 30 m treatment length (Figure 2. 2). The barriers were carefully put in place by an excavator with the centre of the X’s at 3.75, 11.25, 18.75 and 26.25 m respectively from the downstream end of the 30 m treatment. The width of each treatment was 10 m, 5 m in both directions perpendicular to the stream channel centreline (Figure 2. 3). Target height for the barriers was 0.75 m but varied between 0.3 m and 1.2 m due to topography and available obstacles such as rocks and stumps at each site.

Figure 2. 2 – Photographs showing the set-up of the coarse woody debris treatments.

The analysis was run separately for each sampling period including fall 2016 and fall 2017 using SYSTAT 13 (2009). Differences because of the site, treatment and site by treatment interactions were tested using a two-way ANOVA for cover, species richness, litter, biomass, tramples, bare soil, manure and utilization.

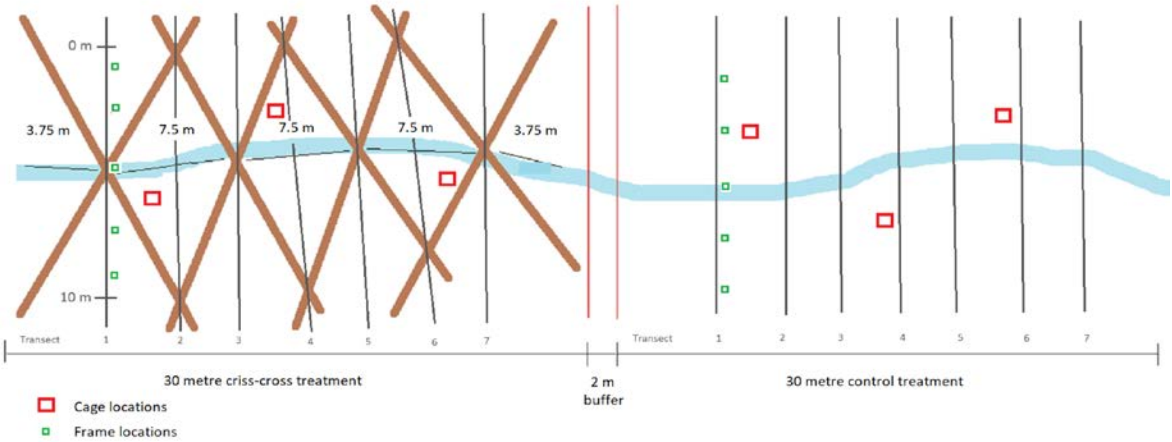

Figure 2. 3– Experimental design showing one replicate of barrier treatment and control. Vegetation, substrate, tramples, bare soil and manure were measured along transects (green squares) and cages (red squares) were positioned to calculate biomass and utilization.

Sampling

Each experimental unit (plot) was 30 m long and 10 m wide (Figure 2. 3) and the plant community was representative of the riparian area. A 10 m transect line was systematically set up at 3.75 m intervals along the length of the plot and perpendicular to the stream resulting in seven transects per treatment (3.75, 7.5, 11.25, 15, 18.75, 22.5, 26.25 m). There was no transect at 0 and 30 m. Five sub-samples were taken along each transect and the average of the sub-samples made up one sample for each transect line. Considering that the vegetation was predominantly low-statured and herbaceous I was confident that the distance between transect lines were sufficient such that they could be taken as independent samples. Each sub-sample measured vegetation, substrates, tramples, bare soil and manure inside a one-quarter metre square frame at 1 ,3, 5, 7 and 9 m. Frame 3 (at 5 m) was always at the centre-line of the stream. Absolute canopy cover of vegetation by species (Appendix A) and absolute percent cover of substrates, tramples, bare soil and manure were measured at these five locations within the frame (Figure 2. 3). This resulted in seven samples (35 frames) that were measured in each treatment for a sample size of 112 (56/treatment). These measurements were initially taken in June and July of 2016 when the project started, prior to grazing as a baseline. Measurements were also taken in the fall of 2016 and fall of 2017 following livestock use. Fall measurements were taken the last week of September and the first week of October in 2016 and the last two weeks of September in 2017. Grazing of these sites both years was variable between years and for shorter periods than expected.

Livestock were moved from pasture to pasture as per the dates in the agreement holder's range use plan. Targeted use of the four sites was not controlled in any way and varied between sites and years (Table 2. 1). Actual levels of use of the sites depended on many factors including weather and management by the agreement holder. On a natural landscape covering hundreds of hectares there were no guarantees as to how much use each site would get.

At the beginning of each grazing season in the spring, cages were set up at each location to measure utilization and biomass. Three cages were set up within each treatment. Within the coarse woody debris treatments, cages were located inside each of the three diamond restriction areas (Figure 2. 3). Cages in the control treatments were placed at random intervals so that if a criss-cross treatment were projected onto the ground as in the barrier treatment there would be one in each of the diamond restriction areas (Figure 2. 3). The location of each 1 m x 1 m cage was selected so that a paired plot was found within 5 m.

Paired (homogeneous) plots were chosen to reflect similar species and density within the plant community (Figure 2. 3). The centre of each paired plot was marked with a nail and washer and the distance (metre) and azimuth was recorded from the centre of each cage location to the uncaged pair. Although grazing could have occurred earlier in the season, these plots were clipped in late September or early October that may have allowed for some regrowth. A one-half metre squared wire hoop was laid down with the nail and washer being the centre point of the hoop. Each hoop was clipped to ground level with clipping shears. All vegetation excluding shrubs was bagged, oven dried and weighed to the nearest gram. Oven drying was completed at 65 degrees Celsius for 24 hours or until constant weight was reached. Weight of the uncaged samples was subtracted from the caged sample to determine utilization in grams. Utilization percent was calculated by taking the difference in weight of the caged and uncaged samples, dividing by the weight of the caged sample and multiplying by 100. The uncaged clippings were used to calculate biomass.

Table 2. 1 – Grazing schedule as per Range Use Plan of Range Agreement Holder.

Site (Size of cutblock)	**Size of pasture**	**Timing, season of use (all years)**	**Estimate of use**	**Number & class of livestock (AUMs)**
Brunette 1 (30 ha)	1816 ha	July 1-14 Sept 15-Oct 7	Moderate	300 c/c & 15 bulls
Brunette 2 (45 ha)	4905 ha	Aug 7-Aug 31	Light	300 c/c & 15 bulls
Crescent (48 ha)	6544 ha	Sept 1-Sept 30	Light	300 c/c & 15 bulls
Echo (37 ha)	5106 ha	Sept 1-Oct 7	Light-Moderate	450 c/c & 21 bulls

RESULTS

Vegetative Variables

Small streams within recently harvested cutblocks showed a range of results for vegetative characteristics and non-vegetative variables associated with livestock grazing between the criss-cross debris and the control treatments over the course of the study (Table 2. 2, Table 2. 3, Table 2. 4 and Table 2. 5). Overall cover of all vegetative species combined was significantly different at the site level (Figure 2. 4) and treatment level (Figure 2. 5) over the sampling periods ($p = <0.05$). Brunette 2 had lower cover in 2016 than the other sites (Figure 2. 4). This result shows differences across sites where cover percent ranged between 36% and 64%. These cover values are consistent with nearby sites with similar plant communities. A range reference area located nearby has cover values that range from 41% to 55% (pers comm with Francis Njenga; unreferenced, see “Notes”). The treatment effect on cover due to differential grazing created by the barriers was significant ($p=<0.05$) over both years (Figure 2. 5).

Table 2. 2 - Results from 2-way ANOVA tests, site (Brunette 1, Brunette 2, Echo, Crescent) x treatment (Control and Barriers) for cover, species richness, litter and biomass (vegetation variables). P-values <0.05 in bold, P-values <0.10 in Italics.

	Year		Df	F-ratio	P-value
Cover					
	2016	Site	3	**16.155**	**<0.001**
		Treatment	1	**7.145**	**0.009**
		Site*Treatment	3	0.446	0.721
	2017	Site	3	**20.647**	**<0.001**
		Treatment	1	**9.686**	**0.002**
		Site*Treatment	3	0.379	0.768
Species Richness					
	2016	Site	3	*2.393*	*0.073*
		Treatment	1	*3.889*	*0.051*
		Site*Treatment	3	1.568	0.201
	2017	Site	3	0.482	0.696
		Treatment	1	*3.027*	*0.085*
		Site*Treatment	3	**3.620**	**0.016**
Litter					
	2016	Site	3	**25.571**	**<0.001**
		Treatment	1	1.112	0.294
		Site*Treatment	3	**2.876**	**0.040**
	2017	Site	3	**16.846**	**<0.001**
		Treatment	1	0.048	0.827
		Site*Treatment	3	*2.166*	*0.096*
Biomass					
	2016	Site	3	**5.311**	**0.004**
		Treatment	1	1.093	0.302
		Site*Treatment	3	1.681	0.186
	2017	Site	3	**3.598**	**0.022**
		Treatment	1	0.850	0.362
		Site*Treatment	3	0.092	0.964

Table 2. 3 - Results from 2-way ANOVA tests, site (Brunette1, Brunette2, Echo, Crescent) x Treatment (Control and Barriers) for trample, bare soil and manure (non-vegetation variables). P-values <0.05 in bold, P-values <0.10 in Italics.

Year		**Df**	**F-ratio**	**P-value**
Trample				
2016	Site	3	**59.968**	**<0.001**
	Treatment	1	**51.392**	**<0.001**
	Site*Treatment	3	**3.338**	**0.022**
2017	Site	3	*2.613*	*0.055*
	Treatment	1	**11.549**	**0.001**
	Site*Treatment	3	0.933	0.427
Bare Soil				
2016	Site	3	**23.373**	**<0.001**
	Treatment	1	2.555	0.113
	Site*Treatment	3	0.224	0.879
2017	Site	3	**32.770**	**<0.001**
	Treatment	1	0.001	0.975
	Site*Treatment	3	0.426	0.735
Manure				
2016	Site	3	**2.901**	**0.038**
	Treatment	1	1.112	0.294
	Site*Treatment	3	1.729	0.166
2017	Site	3	0.816	0.488
	Treatment	1	1.218	0.272
	Site*Treatment	3	0.268	0.848

Table 2. 4 - Results from 2-way ANOVA tests, site (Brunette1, Brunette2, Echo, Crescent) x Treatment (Control and Barriers) for Utilization. P-values <0.05 in bold, P-values <0.10 in Italics.

	Year		**Df**	**F-ratio**	**P-value**
Utilization					
	2016	Site	3	1.456	0.241
		Treatment	1	**8.038**	**0.007**
		Site*Treatment	3	0.506	0.680
	2017	Site	3	1.686	0.185
		Treatment	1	3.590	*0.065*
		Site*Treatment	3	2.150	0.109

Table 2. 5 - Results from 2-way ANOVA tests site (Brunette1, Brunette2, Echo, Crescent) x Treatment (Control and Barriers) for Utilization percent. P-values <0.05 in bold, P-values <0.10 in Italics.

	Year		**Df**	**F-ratio**	**P-value**
Utilization					
	2016	Site	3	2.139	0.110
		Treatment	1	8.668	0.005
		Site*Treatment	3	0.969	0.417
	2017	Site	3	4.379	0.009
		Treatment	1	1.686	0.202
		Site*Treatment	3	0.573	0.636

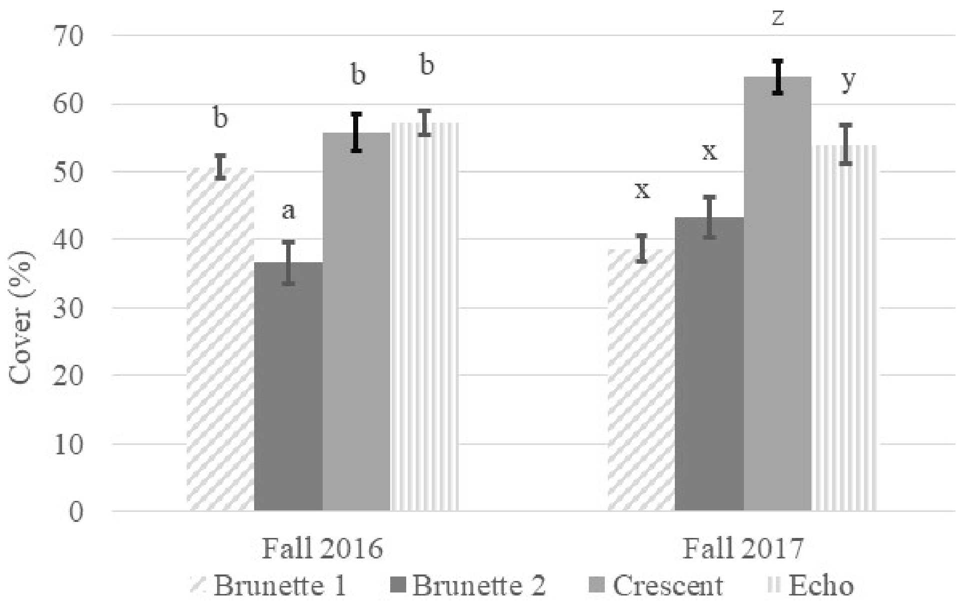

Figure 2. 4 – Mean cover percentage (0.25 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) with treatments grouped, N = 28. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

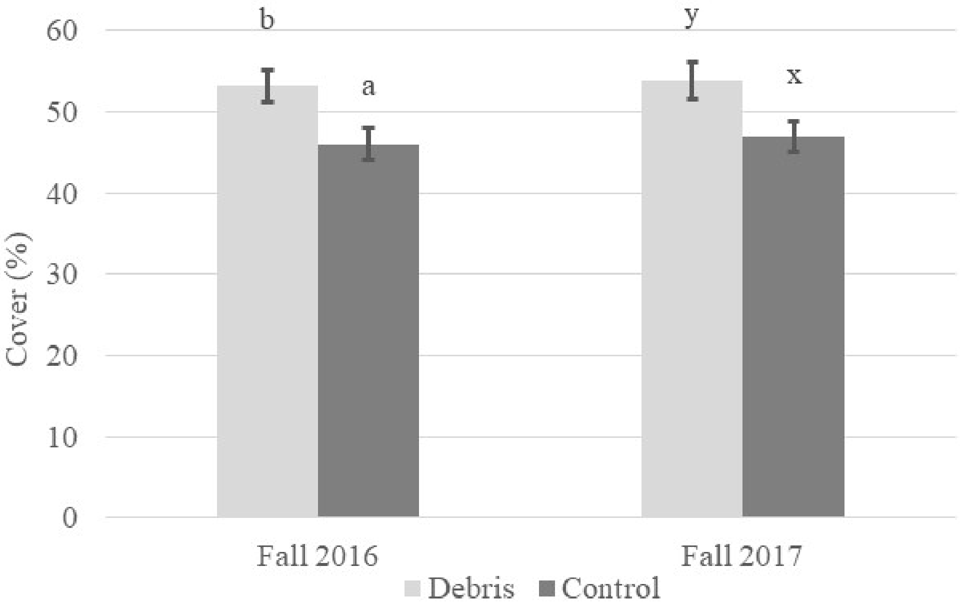

Figure 2. 5 – Mean cover percentage (0.25 m^2) by treatment (debris vs. control) shown by year, N = 56. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

Species richness was similar across all sites and ranged between 5 and 6 except for the Echo site where it ranged from 4.7 to 6.3. Species richness did not respond to the treatment except at the Echo site in 2017 (Figure 2. 6). There was a trend in species richness ($p<0.10$) in terms of treatment in both 2016 and 2017 (Table 2. 2).

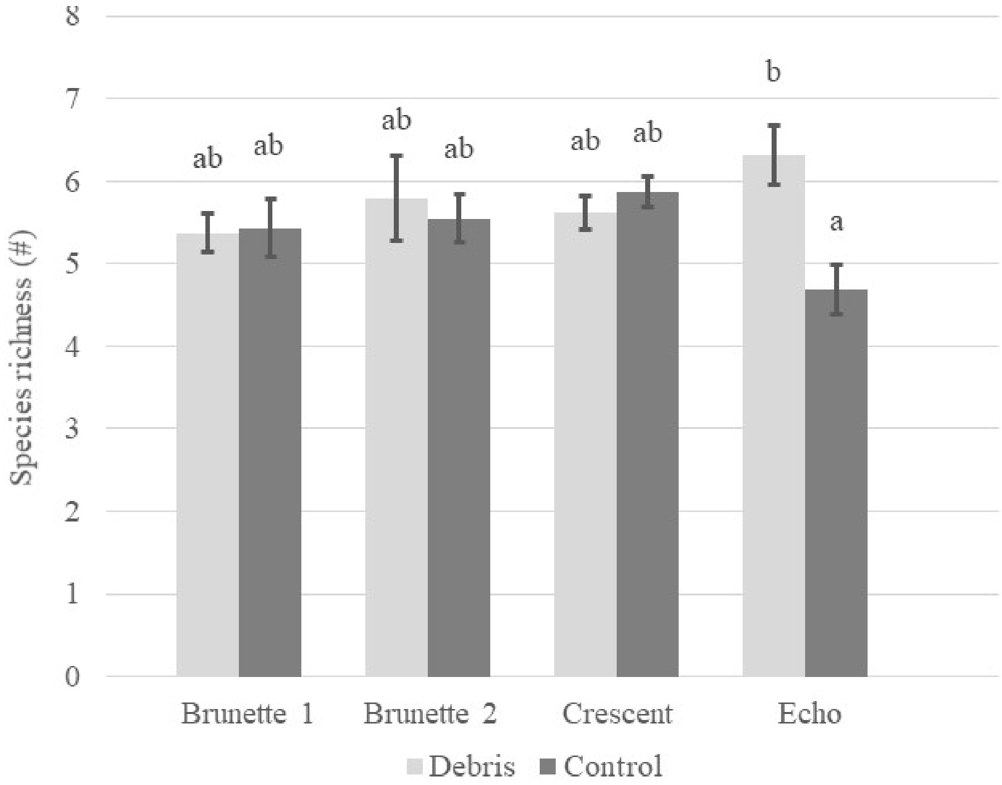

Figure 2. 6 – Mean species richness in 2017 (0.25 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) by treatment (debris vs. control), N = 14. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

Litter was significantly affected by site in both sampling periods. Brunette 1 generally had lower litter than the other sites except in 2017 when it was similar to Brunette 2 (Figure 2. 7). Brunette 2 control had higher litter than Brunette 1 and Crescent controls (Figure 2. 8).

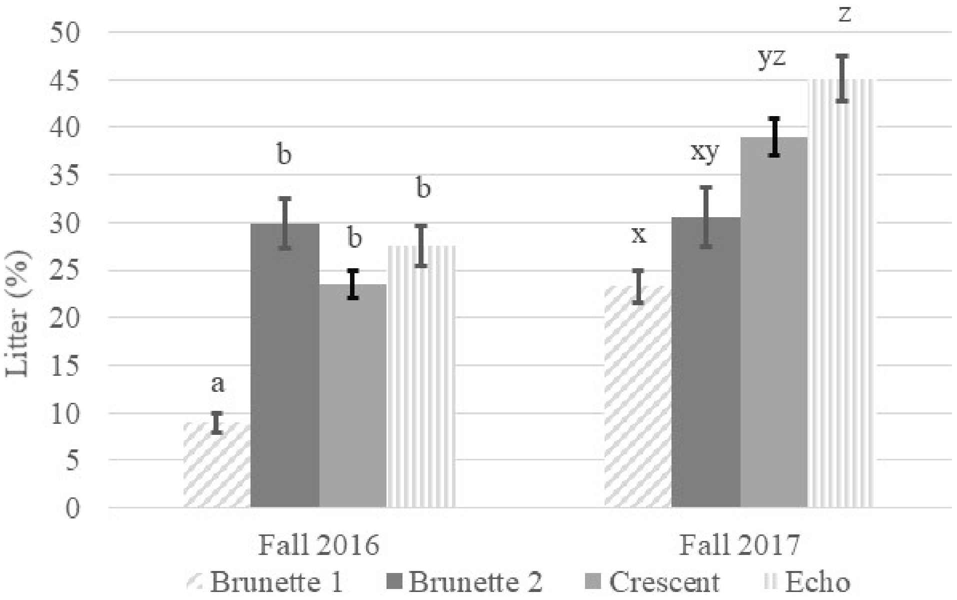

Figure 2. 7– Mean litter (0.25 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) with treatments grouped, N = 28. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

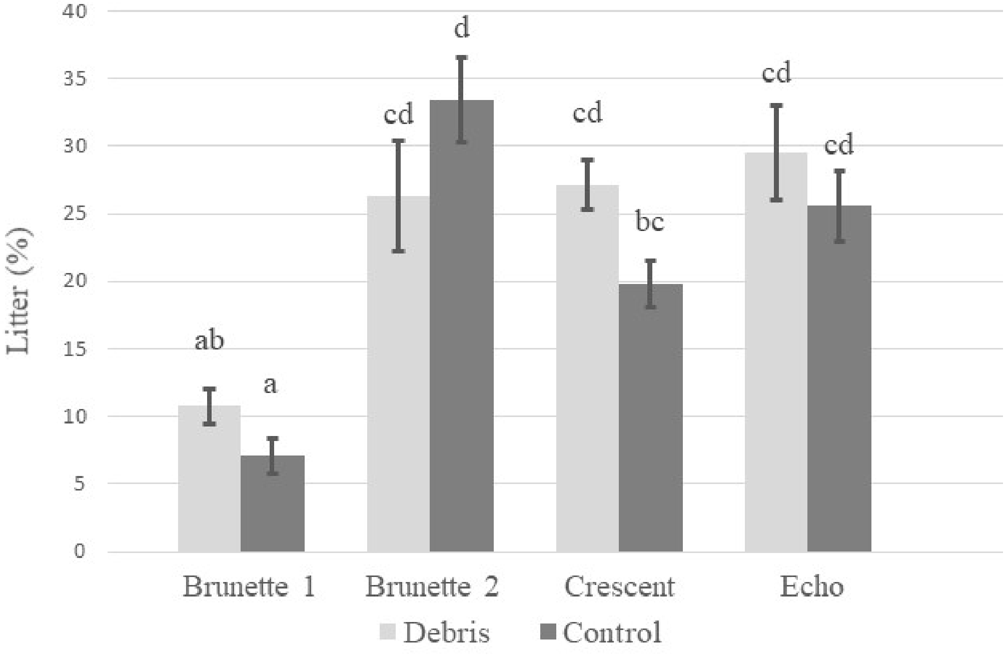

Figure 2. 8 – Fall 2016 mean litter (0.25 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) by treatment (debris vs. control), N = 14. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

Biomass was affected by site in all sampling periods. Brunette 2 had the lowest biomass of the four sites but was only different from Crescent in 2016 and from Echo in 2017 (Figure 2. 9). Biomass values were consistent with forage clipping data completed by the Okanagan Shuswap Natural Resource District and through forage clipping contracts by Range Branch in similar plant communities (pers comm with Kyra Witt; pers comm with Francis Njenga; unreferenced, see “Notes”).

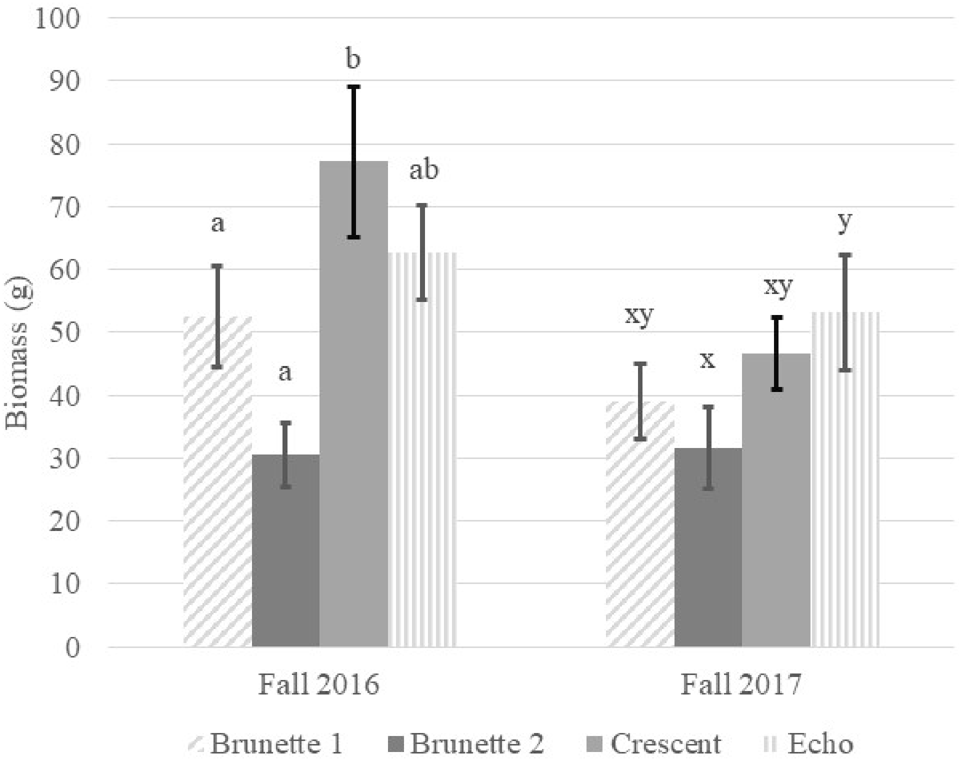

Figure 2. 9 – Biomass (0.5 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) with treatments grouped, N = 12. Significant differences ($p<0.05$) are indicated by different letters according to Tukey’s post-hoc test. Error bars represent standard errors of the mean.

Trampling/Bare Soil/Manure

There was only a site difference in 2016 where Brunette 1 had much higher trampling than the other sites (Figure 2. 10). In both sampling periods the results show that debris barriers reduced trampling although this affect was much greater in 2016 (Figure 2. Figure 2. 11).

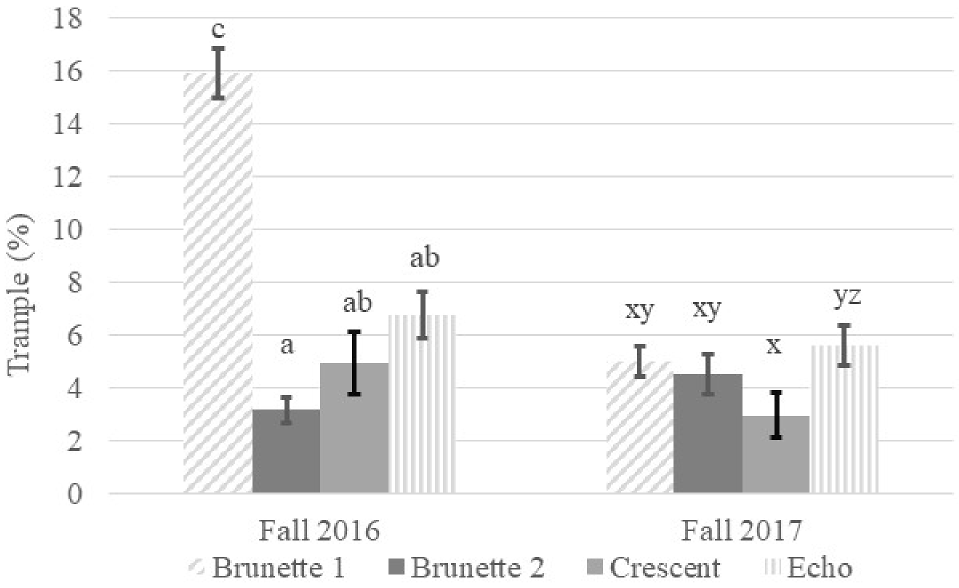

Figure 2. 10 – Mean tramples (0.25 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) with treatments grouped, N = 28. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

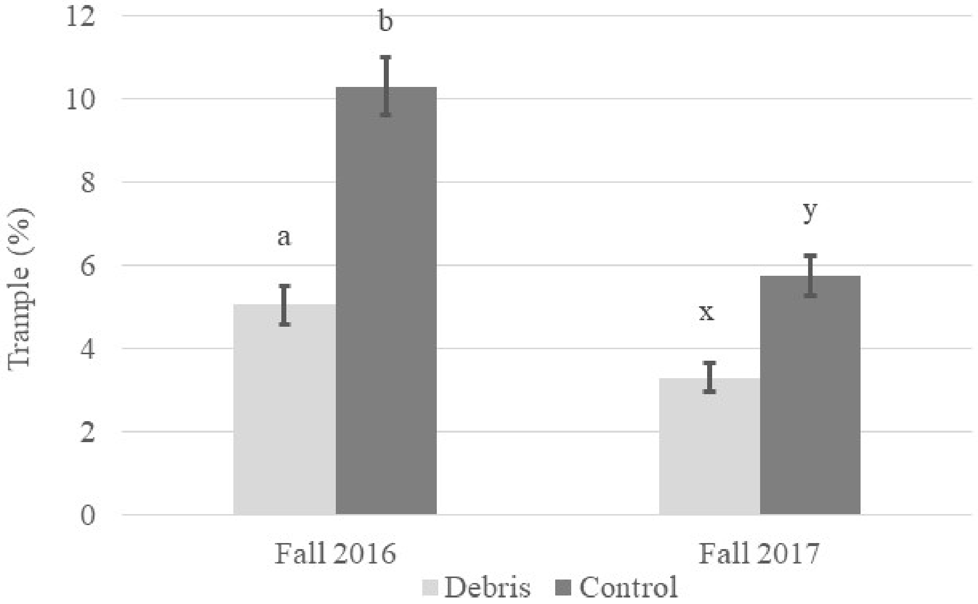

Figure 2. 11 – Mean tramples (0.25 m^2) by treatment (debris vs. control), N = 56. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

Trampling increased (p<0.05) in the control at each site except for Brunette 2 which showed no difference (Figure 2. 12).

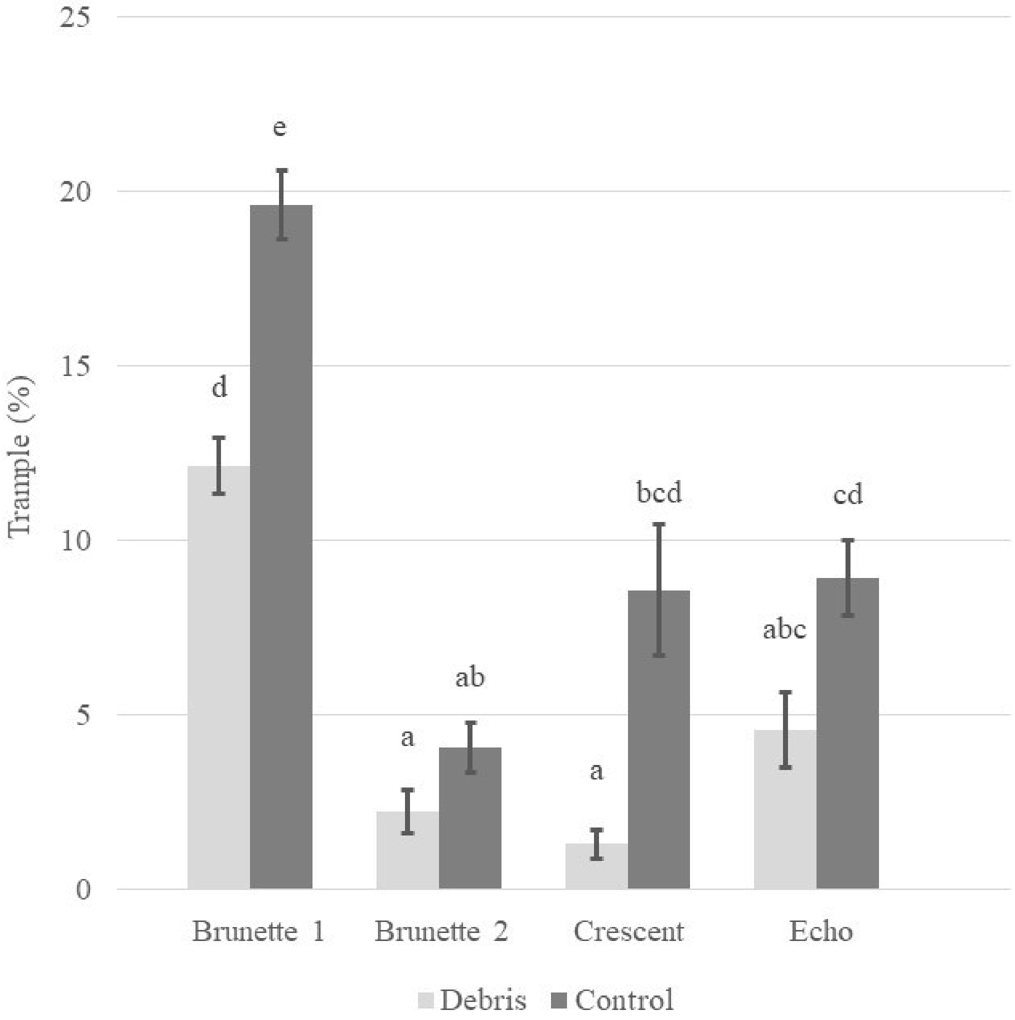

Figure 2. 12 – 2016 mean tramples (0.25 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) by treatment (debris vs. control), N = 14. Significant differences (p<0.05) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

All sites had different amounts of bare soil, but this effect was mostly due to the large difference at Brunette 1 (Figure 2. 13).

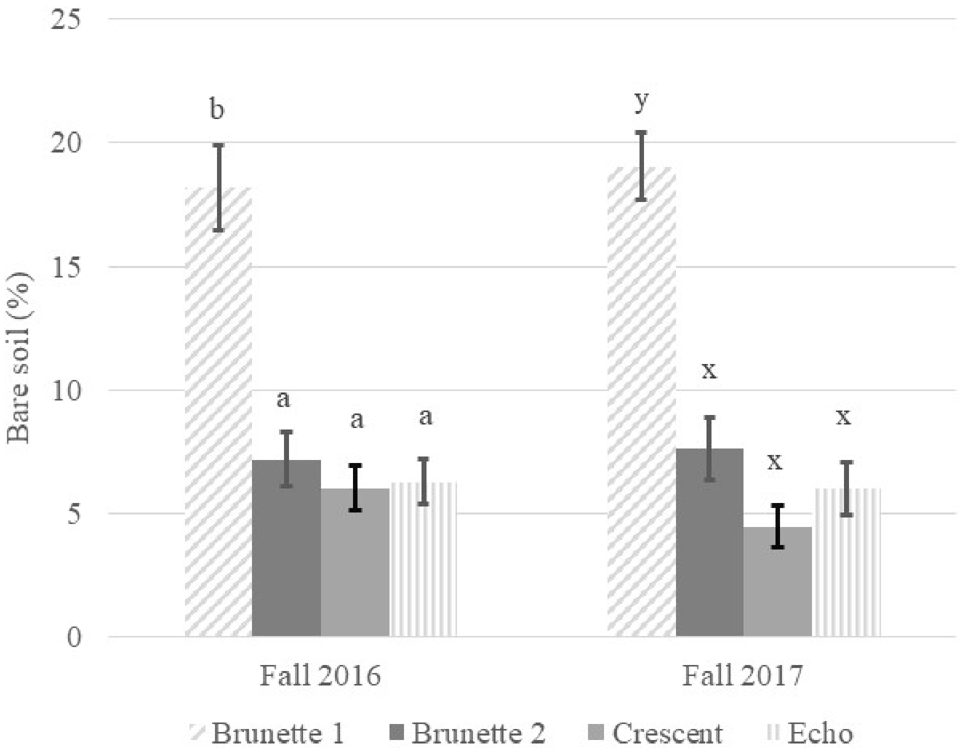

Figure 2. 13 – Mean bare soil (0.25 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) with treatments grouped, N = 28. Significant differences ($p<0.05$) are indicated by different letters according to Tukey’s post-hoc test. Error bars represent standard errors of the mean.

There is a site effect in 2016 only with Brunette 1 having higher manure than Echo (Figure 2. 14).

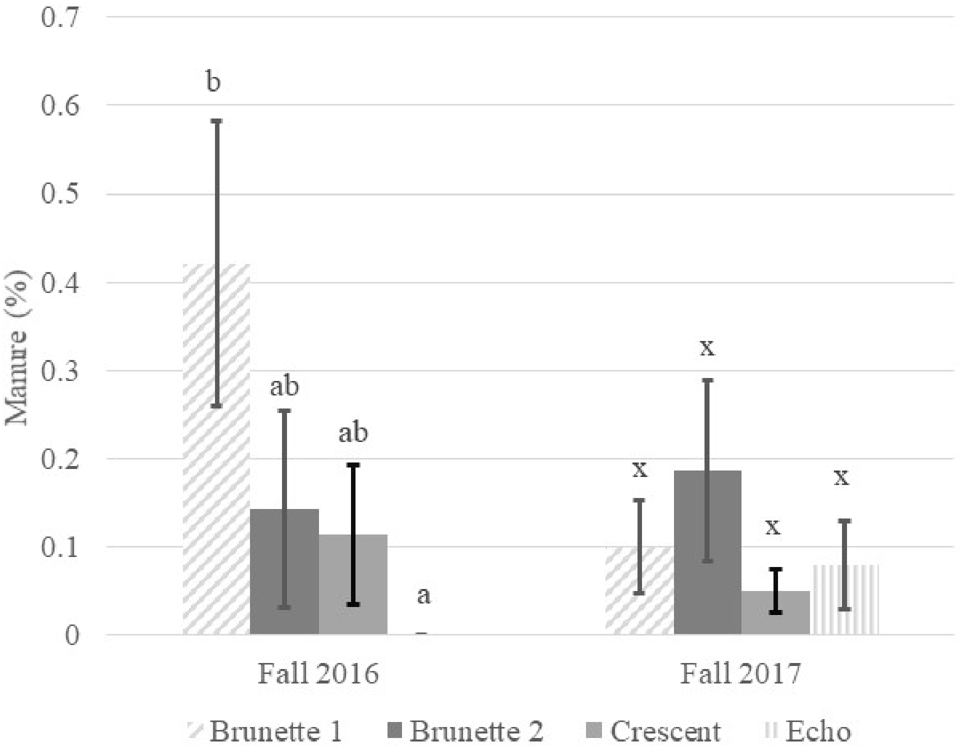

Figure 2. 14 – Mean manure (0.25 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) with treatments grouped, N = 28. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

Utilization

There was a difference ($p<0.05$) in overall utilization between treatments in 2016 (Figure 2. 15). Utilization results at the treatment level were trending in 2017 ($p <0.10$) (Table 2. 4).

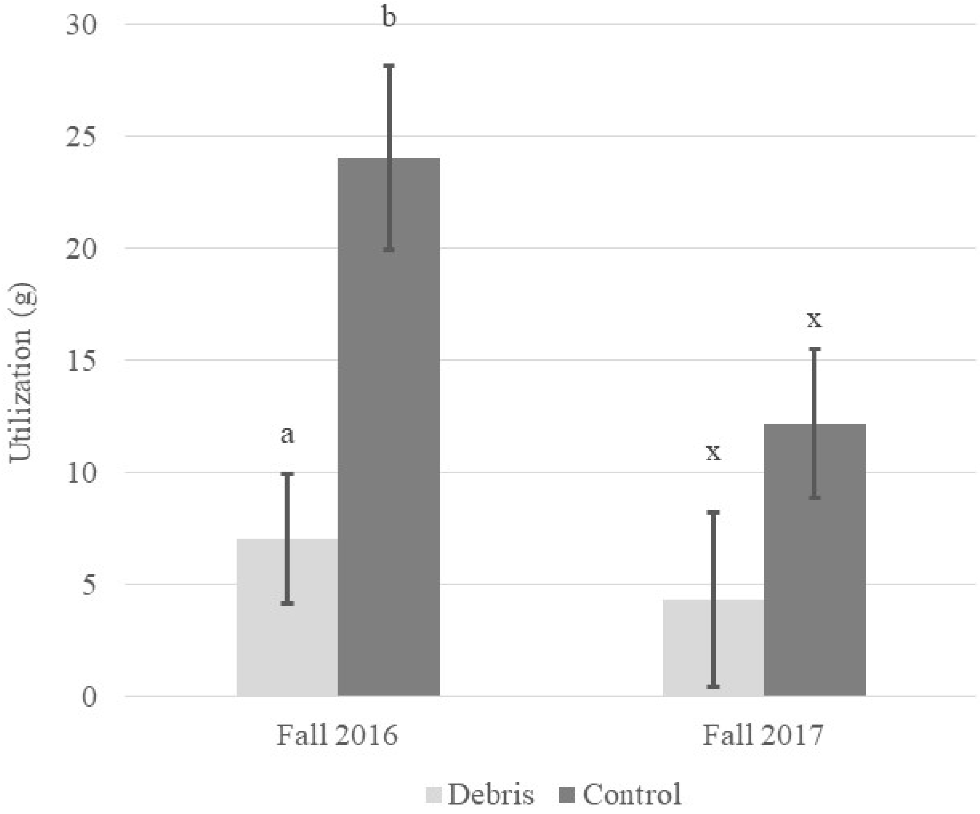

Figure 2. 15 – Mean utilization (0.5 m^2) by treatment (debris vs. control), N = 24. Significant differences ($p<0.05$) are indicated by different letters according to Tukey’s post-hoc test. Error bars represent standard errors of the mean.

There was a site effect in 2017 with Brunette 2 having more percent utilization than Brunette 1 and Echo (Figure 2. 16). There was no site effect for percent utilization in 2016. In 2016 there was a treatment effect for utilization percent (Figure 2. 17), there was no treatment effect detected in 2017.

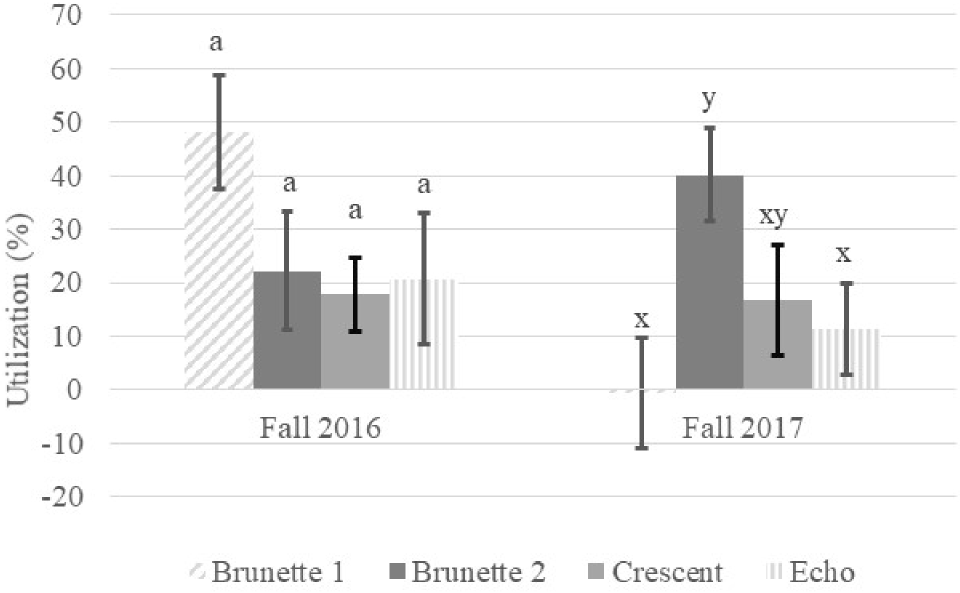

Figure 2. 16 – Mean utilization percentage (0.5 m^2) at four sites (Brunette1, Brunette2, Echo, Crescent) with treatments grouped, N = 12. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

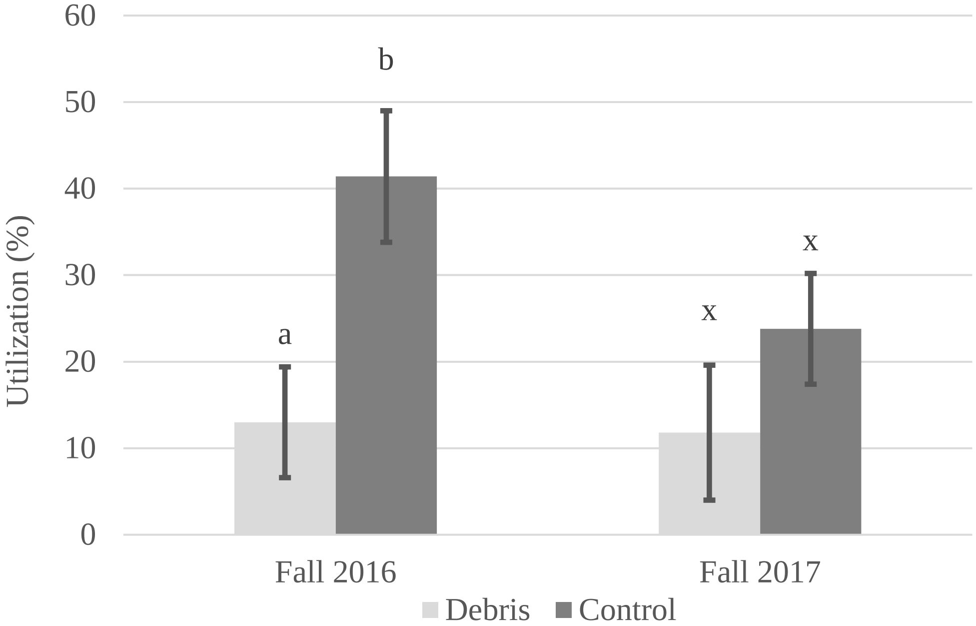

Figure 2. 17 – Mean utilization percentage (0.5 m^2) by treatment (debris vs. control), N = 24. Significant differences ($p<0.05$) are indicated by different letters according to Tukey's post-hoc test. Error bars represent standard errors of the mean.

DISCUSSION

The results from this study demonstrate that debris barriers were effective at increasing vegetative cover and reducing trampling and utilization. Vegetative cover plays a major role in the health and function of riparian areas and water quality (Belsky et al. 1999). Riparian vegetation can trap sediments and filter pollutants before they are deposited or released into streams (Svejcar 1997). Clary and Kinney (2002) noted that a vigorous herbaceous plant community results in stream and riparian areas having more resistance to erosion and bank shearing. Others such as Belsky et al. (1999) and Warren et al. (1986) determined that grazing decreases vegetative cover and reduces the long-term productivity of plants. Lower runoff volumes were found by Tufekcioglu et al. (2013) in areas where vegetative cover was the highest as a result of decreased soil compaction by livestock and Belsky et al. (1999) concluded that the volume of overland flow increases as livestock compact the soil and reduce the vegetative cover. The findings of my study that conclude vegetative cover was higher in the debris treatments are encouraging because it suggests that woody debris barriers may be an effective management tool for both riparian health and function, water quality and the hydrology of watersheds.

Trampling was one of the main variables being considered, and so the reduction in trampling in relation to the presence of debris barriers is important. Trampling has been shown to reduce infiltration and increase sediments especially in wet soils leading to many of the negative effects to riparian function and water quality when livestock are present (Warren et al. 1986). Dunne et al. (2011) concluded that trampling reduced plant cover and biomass leading to increased soil loss. Soil physical properties are affected by trampling and are magnified in riparian areas due to moist soil conditions leading to more compaction (Belsky et al. 1999; Greenwood and McKenzie 2001). Greenwood and McKenzie. (2001) also associated the same compaction caused by trampling to reduced infiltration that increases overland flow and erosion and altered the timing of flows that increase the probability of spring floods and later season drought. In a grazing simulation study, Doborro et al. (2013) noted that at low stocking levels trampling may not be enough to affect soil compaction. Trampling was reduced by debris barriers, which is a good indication that they are serving a positive function. When stocking rates and utilization of newly harvested cutblocks is difficult to predict, the use of debris barriers can provide some protection to the riparian area and stream over the short term while the cutblock has time to regrow and create the kind of barrier to livestock that was present prior to harvesting. Trampling also does physical damage to vegetation that reduces their cover and biomass and has been known to disrupt root growth and cause shifts in the plant community. Short graminoid species are favoured over tall ones and forbs and shrubs are reduced in abundance (Fleischner 1994; Dobarro et al. 2013).

Debris barriers were effective at reducing utilization in 2016 and trended in that direction in 2017. A study by Johnson et al. (2016) that used GPS collars to track livestock use in riparian buffers noted that high levels of use were expected in logged areas because of higher production of herbaceous plants and easy access to water. In the same study they also recognized the use of roads for movement not just by humans but livestock and wildlife which leads to more use of streams within cutblocks. Gillen et al. (1984) discovered that utilization was 7.5 times higher in riparian areas than in the adjacent uplands. A large proportion of available forage in the Montane Spruce biogeoclimatic zone largely comes from roadsides and cutblocks (Wikeem et al. 1993), therefore the protection of riparian ecosystems within these cutblocks is particularly important.

Percent utilization was also affected by the treatment in 2016 with much less percent use within the barrier treatments when compared to the control. When the averages of the control versus barriers is considered for the Brunette 1 site, the control was over-grazed at over 70% utilization, a level that exceeds acceptable use levels for B.C.. The percent utilization in the barrier treatments was well within acceptable levels at only 21%, this goes to show that even at high levels of use the barriers were successful at reducing percent utilization to acceptable levels. At a site level Brunette 1 was just below 50% use in 2016, if the practice of using debris barriers was used along the entire length of the stream these levels should drop well below this. The other sites in 2016 also showed positive difference between percent use levels between the control and barrier treatments but did not have the same use pressure as Brunette 1. With a change in how the livestock were herded within their rotation, Brunette 1 saw virtually no use in 2017. Use at the Brunette 2 site in 2017 was the highest but there was very little difference between the control and barrier treatment. This could be a result of the barriers not reaching the desired height of 0.75 m due to the topography and available obstacles, especially on the downstream barrier replicate where it was virtually flat. Both Crescent and Echo saw reduced use within the barrier treatments in 2017. It appears the barrier treatments are effective at reducing percent use and can be used to keep use at levels that are not considered overgrazed. The ability of debris barriers to reduce utilization, trampling and increase cover all support that this tool can help minimize cattle impacts on small streams.

The remainder of the variables sampled (species richness, bare soil, litter, biomass, and manure) did not show significant treatment results, except for site x treatment interaction for species richness. Mean species richness at the Echo site was lower in the control treatment. Species richness at the other three sites did not respond to the treatment. Literature on this topic is conflicting, Fleischner (1994) concluded that a reduction in species richness was an ecological cost of grazing and it took a decade after livestock removal for species richness to increase back to normal levels. Koerner et al. (2018) in a global study found that grazing dominant species led to an increase of less dominant species by making resources more available to them resulting in increased species richness. Belsky et al. (1999) found an increase in annual species and invasive plants can result from livestock grazing. This was also confirmed by Kauffman et al. (1984) and Doborro et al. (2013) who both found increases in species richness were most commonly weedy exotics and upland species that were benefiting from disturbance and drier conditions that get created from livestock trampling. As this was only a two-year study, it was unlikely that there would be discernable differences in species richness due to the addition of logging debris barriers and additional work would be necessary to track this over a longer period with barriers present.

Bare soil was significant at the site level but not as a result of the treatment or site by treatment interaction. This could be a result of not having control of livestock stocking density. Being a natural environment with many other factors at play it is possible that the grazing pressure on these sites was not high enough to show significant differences between the control and debris treatments. Many other studies including Belsky et al. (1999) and

Jones and Carter (2016) have concluded that livestock use increases bare ground due to the consumption of vegetation and trampling and areas excluded from grazing had significantly less bare soil than grazed areas. The high amount of bare soil at the Brunette 1 site in 2017 is most certainly a factor of the carry-over from 2016 when this site saw much higher signs of grazing including trampling than the other three sites (Figure 2. 10) and the recovery of bare soil was unlikely to occur in just one year. Plant community shifts with this higher level of use are not in favour of forage for livestock or hydrological processes as often bare soil creates sites for shallow rooted, annual plants and weedy species (Dobson 1973; Dobarro et al. 2013)

Litter was not impacted by treatment but was affected by site in both 2016 and 2017. It is possible that the timing of sampling affected the results for litter. As sampling in fall 2016 and 2017 took place in late September and early October it was a time of year when some of the first frosts following the growing season occurred. Some plants following frost die, if that was the case they were noted as litter rather than percent cover of those individual species. This may have played a role in how much litter was seen from site to site in the fall. Brunette 1 was the first site sampled in 2016 and may have had less litter recorded that year due to no/fewer frost events at the time of sampling, although all other indications such as cover, bare soil, biomass and trampling showed much higher use of this site which would have also resulted in less litter. By the time the last site was sampled it likely experienced more frost events which may have led to more vegetative species being classified as litter rather than percent cover of those species. Belsky et al. (1999) while studying livestock grazing effects on soils and influences on stream and riparian ecosystems found that grazing the aboveground biomass leads to a reduction in litter and an increase in bare ground. Fleischner (1994) has also linked the reduction in litter to delayed plant phenology which could have a negative effect on plant communities converting to more upland and annual or weedy species.

Biomass was not impacted by treatment but was different at the site level. Riparian areas tend to be more productive through the grazing season due to an increased level of soil moisture when compared to the adjacent uplands (Svejcar 1997; Rawluk et al. 2014). Even though riparian ecosystems occupy a small proportion of the overall landscape, they offer a disproportionate amount of the available biomass. Riparian areas should not be treated as sacrifice areas as they were in the early years of grazing management in the West (Kauffman and Krueger 1984). Fleischner (1994) and Callaghan et al. (2018) among others have all linked a decrease in biomass with livestock grazing. Scrimgeour et al. (2003) observed that excluding livestock led to a positive response in riparian vegetation biomass as well as instream vegetation biomass and bank stability. Although there were not significant results at the treatment level for biomass it is intrinsically linked to cover and litter and if debris barriers can provide some level of protection to the functioning of small streams by creating more stable, vegetated banks and can assist in reduced sloughing of the soils, it can lead to a reduction of sediment deposited into streams (Scrimgeour and Kendall 2003)

Manure did not differ by treatment, or site by treatment interaction. Others have shown that deposition of faeces and urine within the riparian area or directly into the stream channel can have a significant effects on aquatic life and downstream water quality (Derlet et al. 2010). During convective thunderstorms that are common in the summer or during sudden rapid snow melt in the spring, manure from the uplands can be transported by overland flow to surface water sources including small streams (Bohn and Buckhouse 1985). Meays et al. (2006) studied the survival and transport of *Escherichia coli* and concluded that fecal pats survive longer under forested situations than in the open. This is important to note as this study was conducted after timber harvest occurred and no riparian reserve zones were maintained allowing fecal pats to be exposed to solar radiation that greatly affects the survival of *E. coli*. Maintaining a line of defense with good vegetative cover and litter helps to trap and filter sediments and pathogens that are present in livestock and wildlife faeces (Correll 2005). As Miner et al. (1992) discussed, the discouragement of animals away from the stream can allow for greater filtration during times of overland flow. One of the main functions of debris barriers is to deflect the use of animals away from the stream channel which would help to achieve this benefit. As percent cover of manure at all sites over both sampling periods was very low, this suggests that either stocking density was too low, time spent in the pastures was too short or the barriers were effective at deflecting use out of the riparian area.

This study looked at the effectiveness of using woody debris barriers in protecting small, headwater streams in the Montane Spruce biogeoclimatic zone in B.C., Canada. This practice could be used across other forested rangeland types where streams are left without the protection of a riparian buffer. Requirements to retain riparian buffers differ within Canada and around the world and the lack of protection for smaller stream types is often motivated by the value of timber that comes from these areas (Kuglerova et al. 2017). Natural events such as fire and disease do not stop at the riparian margins and many studies show that an increase in light to a stream can increase primary production and be a benefit to fish and other aquatic invertebrates and plants. Studies have also found that a small increase in temperature resulting from the removal of a riparian zone is quickly negated when the water flows to an area with shade and downstream inputs of cold groundwater (Newton & Ice 2016). Larger streams in most jurisdictions where stream temperature is more relevant usually have a requirement to maintain riparian buffers that help to maintain those temperatures for the aquatic ecosystem. The practice of using debris barriers should be suitable for different stream types providing that the source of debris can span the channel and function to restrict movement while not posing a threat over time when they settle into the stream. This will be most effective for lower gradient headwater, riffle pool or meandering stream types on forested rangelands. They could also help to protect step-pool streams, but the protection of these types is often provided by boulders and steeper gradients. Uses of the land, the type of forest and stream along with the legal requirements to either require a riparian buffer or not will dictate whether this tool can help to minimize the cumulative effects of livestock grazing and timber harvesting on the land base.

STUDY LIMITATIONS

Plant variables such as species richness, bare soil and litter did not show treatment effects but did show site effects and site x treatment interactions. This demonstrates the variability among sites and the difficulty in controlling a study in a natural environment on extensive rangelands. It is difficult to select sites with the same attributes and to know how much use a site will get from livestock considering the size of the pastures. Higher targeted use in a smaller riparian pasture may give better insight into the effectiveness of debris barriers.

Personal communication with the range agreement holder’s cow boss indicated a change in cowboys from the 2016 to the 2017 grazing seasons for the pasture where the Brunette 1 site was located. This is most likely a contributing factor in the results found in 2016 where there was higher bare ground, manure and trampling and lower litter. All these factors indicate higher cattle pressure at the site in 2016. Although herding livestock was not a consideration in this study, it is a beneficial livestock management tool that may have contributed to the difference in use levels at Brunette 1 from 2016 to 2017.

Brunette 1 had significantly more tramples, bare soil and manure and less litter in 2016. These are all signs of higher livestock pressure at this site. Results did not show significantly higher utilization at this site in 2016. Brunette 1 also showed a significant result for bare soil in 2017. This is likely in part to the time it takes for revegetation to occur following heavy trampling and was a carry-over from the higher number of tramples that were counted in 2016.

CONCLUSION

Although the barriers do not provide full exclusion, they do show to be effective at increasing vegetative cover while minimizing trampling and utilization. These can be to the benefit of water quality and hydrologic function of riparian areas. Logging debris barriers are a tool that can be used to minimize the cumulative effects of timber harvesting and livestock grazing where small headwater streams have been harvested up to their edge. Proper range management takes knowledge, experience and observation along with tools such as fencing, water developments, mineral and salt supplements and herding of livestock to be effective. Range management needs to be adaptive where managers make changes to when, where and how much livestock graze based on climate, weather, natural disturbances and other factors that occur allowing them to make changes month to month and year to year.

Many of the response variables that were selected in this study did not show significant results. Logging debris barriers are not all created equal, they can take on different forms and structures based on the materials at the site being used, topography of the site and the presence of obstacles. Although the target was for the barriers to be a minimum of 0.75 m off the ground it proved to be impossible to achieve this height across all debris treatments and sites. Utilization occurred within the barrier treatment as designed, they were not meant to provide full exclusion. Although it was not measured, observations at all the sites showed that the linear movement of livestock up and down stream channels was eliminated. These results are positive and should lead to better riparian health, hydrologic function and water quality on sites if debris barriers are used where livestock graze and timber has been harvested to the edge of small streams.

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CHAPTER 3. MANAGEMENT IMPLICATIONS AND FUTURE DIRECTION

INTRODUCTION

This study has shown that using coarse woody debris barriers is effective at minimizing livestock use and the effects livestock can have within riparian areas adjacent to small streams following timber harvest. Although the barriers do not provide full exclusion, they do show to be effective at increasing vegetative cover while minimizing trampling and utilization. These can be to the benefit of water quality and hydrologic function of riparian areas. Providing that legislation continues to allow harvesting of riparian timber up to the edge of small streams, coarse woody debris barriers should be considered as a tool to reduce the effects of livestock grazing following timber harvesting. With other important values at risk it would be proactive for timber licensees to consider maintaining riparian reserve zones or increasing basal area retention within the riparian zone. In most cases, this leads to healthier, higher functioning streams (Tschaplinski 2010). In addition to restricting livestock access and use where insufficient riparian vegetation was maintained, woody debris barriers could ‘bridge the gap’ and provide a level of structure and habitat in the short to medium term until the forest canopy has grown to the point where it can provide the natural component of coarse woody debris back to the system decades later (Correll 2005; Tschaplinski 2010).

Currently, timber companies in B.C. must include measures in operational plans to mitigate the removal of natural range barriers, including the removal of timber adjacent to streams. The General Appraisal System determines stumpage rates and allows for forest licensees to have stumpage fees adjusted to install woody debris barriers. It has been determined that the most opportune and cost-effective time to install barriers is at the time of harvest when equipment and material are on site. Rangeland fencing is traditionally used to manage distribution of livestock and most commonly used to contain livestock within pasture and tenure boundaries. It would be cost prohibitive and impractical to exclude livestock from all riparian areas with barbed wire fencing. The installation costs of installing debris barriers are significantly lower and do not require maintenance and would favour wildlife. Fencing in riparian areas requires higher visibility or adjustments in standard construction specifications. Debris windrows have also been shown to increase biodiversity and habitat for small mammals (Sullivan et al. 2011). Debris windrows could serve a dual purpose in some situations by providing small mammal habitat and restricting livestock access to small streams when exclusion is the goal. The protection of small streams in cutblocks is only a temporary requirement while tree regeneration is occurring. After approximately 20 years the trees start to outcompete forage species (Clark and Mclean 1980) and livestock will begin to source forage in newer cutblocks within the area as there tends to be a constant rotation of harvesting over time in forested rangelands. This provides more reason to not construct permanent structures to exclude livestock from riparian areas.

MANAGEMENT CONSIDERATIONS

The implications of harvesting all the timber adjacent to small streams leaves range agreement holders in a situation where they may be unable to meet their legislative requirements. Current regulations state that an agreement holder must not carry out a range practice if it would result in a material adverse affect on the ability of the riparian area to; withstand normal peak flow events without accelerated soil loss, channel movement or bank movement, filter runoff, store and safely release water, and conserve wildlife habitat values in the area (Range Planning and Practices Regulation, 2020). If damage to the environment occurs, a range agreement holder must retrieve their livestock and prevent further damage. Proactive and collaborative planning of forest operations that maintains riparian reserve zones, uses woody debris barriers, or a combination of the two would be a cost-effective way to avoid alternative mitigation actions that are required in forest stewardship and range use planning.

As part of the Ministry of Forests, Lands, Natural Resource Operations and Rural Development in B.C., the Forest and Range Evaluation Program (FREP) “collects and communicates the best available natural resource monitoring information to inform decision making, improve resource management outcomes and provide evidence of government's commitment to environmental sustainability" (Forest and Range Evaluation Program, 2019). Between 2005 and 2008 this monitoring program sampled 1441 streams across the province. In some cases, S4 streams within cutblocks did receive the protection of a reserve zone even though it was not a legislated requirement. Small, fish bearing streams were found to be in proper functioning condition (PFC) when more than 90% of the merchantable stems were retained within 10 m of the edge of the stream. Some of the sample sites only received buffers of 5 m on small streams and these results showed that they were in much better condition than streams where harvesting occurred up to the edge of the stream and that any retention of trees is better than none (Tschaplinski 2010). The more riparian vegetation that is retained helps with bank stability and the maintenance of stream temperature that can be critical for the survival of aquatic invertebrates and fish (Fleischner 1994). When reserves are removed and debris barriers put in place, they do not assist in maintaining stream temperatures. Retention of non-merchantable trees and understory vegetation with the incorporation of woody debris barriers should be the minimum target for managing small streams in cutblocks.

Forestry related disturbances were the major contributing factors to the deteriorating health of small streams following harvesting and included fine sediment inputs from roads, low levels of tree retention and windthrow. Trampling by livestock was most notably a concern within the southern interior of B.C. (Tschaplinski 2010). Maintaining riparian reserve zones helps mitigate many of the negative outcomes that result from forestry and range related activities.

When timber barriers are removed on range tenure or pasture boundaries or create access to sensitive features some form of mitigation to address livestock movements are often required. Timber licensees are required to mitigate the removal of natural range barriers and the most common measure is to construct a four-strand barbed wire fence and the costs are off-set by the appraisal at a rate of $1,567 per 100 m (Interior Appraisal Manual, 2019). This is a flat rate and not based on the engineered cost. The actual costs to construct the fence can be more than that due to difficult terrain, soil conditions or region of the province. The costs of constructing a logging debris fence were amended into the B.C. Interior Appraisal Manual in 2014. The cost estimate provided in the appraisal manual for constructing the debris fence is $250 per 100 m. When this is done at the time of harvesting when debris and machinery are on site it can significantly reduce the costs in mitigating the removal of natural range barriers to streams and other sensitive features, a requirement of forest stewardship planning. The other major significance of debris barriers is that there is no long-term maintenance required when compared to that required on standard barbed wire fencing. Over the life of a fence it has been determined that the costs of maintenance often equal or exceed that of the initial cost to construct the fence. The maintenance obligation falls on the range agreement holder, this makes the use of debris barriers a practical option.

FUTURE DIRECTION

It is recommended that where range and forest licences overlap, coarse woody debris barriers are considered to help maintain the function of the stream and riparian values in cutblocks where harvest has occurred up to the stream edge. Observations have shown that barriers that are 0.75 m or greater are most effective at minimizing livestock access to the riparian area. Using the natural topography of the site along with using obstacles such as stumps, rocks and root wads help to achieve this height. The use of more debris compared to the methods of my study could be used in areas where the risks to environmental values are determined to be higher. This could be most effective when additional debris is used to close off the open ends of the X’s paralleling both sides of the stream channel providing more restriction and deflection away from the stream. Openings for both livestock and wildlife should be maintained for access to water and crossing where appropriate and should be planned at existing stream crossings if available. Species selection in the construction of debris barriers is critical as we do not want to exacerbate forest health concerns. Fir and spruce beetle are a concern in many areas of the province and these species should be avoided when constructing barriers.

A challenge of this study was the level of use could not be controlled in such extensive pastures on Crown land. Future studies should consider similar methods in setting up the experiment but using a known number of livestock for a specified period of time within a smaller riparian pasture. Higher targeted use in a controlled experiment may give a better indication of the effectiveness of debris barriers to reduce livestock access and effects to riparian values following timber harvest.

Windthrow is a known challenge when planning cutblocks and maintaining riparian vegetation and can reduce the effectiveness of riparian reserves and create forest health concerns. Large amounts of windthrow can result in re-entry to salvage merchantable timber which may not be the most cost-effective approach to harvesting. Studies have shown that windthrow did not decrease with increased buffer widths or with thinning (Ruel et al. 2001). More research and local observations of wind patterns and levels of windthrow should be considered with local topographical features and prevailing wind direction to minimize the amount of windthrow created when leaving riparian buffer strips of timber. Avoidance of streams within cutblock boundaries in the planning and layout stages of operations should continue to be considered by forest professionals as a management practice to maintain healthy stream and riparian values.

Debris barriers are not a silver bullet when it comes to the protection of small stream and riparian values. They are simply another tool that can be used in conjunction with other proven livestock management practices including herding, off-stream watering and supplements (Bailey 2004). Riparian buffers protect small stream values much more than from just livestock and more consideration should be given to leaving them intact (Tschaplinski 2010). I believe that the societal value gained from maintaining riparian values on small, headwater streams including water quality and hydrologic function are far greater than the value of the timber removed from these areas. Competing industries should strive to find a balance between economic and environmental outcomes.

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APPENDICES

Appendix A

English Name	Native/Exotic	Current Name
alder	N	Alnus sp.
American speedwell	N	Veronica beccabunga
arnica	N	Arnica sp.
arrow-leaved coltsfoot	N	Petasites frigidus var. sagittatus
arrow-leaved groundsel	N	Senecio triangularis
balsam poplar	N	Populus balsamifera
bentgrass	N	Agrostis sp.
black gooseberry	N	Ribes lacustre
black twinberry	N	Lonicera involucrata
blue wildrye	N	Elymus glaucus
bluejoint reedgrass	N	Calamagrostis canadensis
bracted lousewort	N	Pedicularis bracteosa
brome	N	Bromus sp.
bull thistle	E	Cirsium vulgare
bunchberry	N	Cornus canadensis
Canada bluegrass	E	Poa compressa
clasping twistedstalk	N	Streptopus amplexifolius
clover	N	Trifolium sp.
Columbian monkshood	N	Aconitum columbianum
common mitrewort	N	Mitella nuda
common spike-rush	N	Eleocharis palustris
crisp starwort	N	Stellaria crispa
dagger-leaf rush	N	Juncus ensifolius
dandelion	N	Taraxacum sp.
dwarf blueberry	N	Vaccinium caespitosum
dwarf red raspberry	N	Rubus pubescens
edible thistle	N	Cirsium edule
elderberry	N	Sambucus sp.
false melic	N	Schizachne purpurascens
false melic	N	Schizachne purpurascens
fescue	N	Festuca sp.
field chickweed	N	Cerastium arvense
field filago	E	Filago arvensis
fireweed	N	Chamerion angustifolium
five-leaved bramble	N	Rubus pedatus
fleabane	N	Erigeron sp.
fowl bluegrass	N	Poa palustris
fragrant white rein orchid	N	Platanthera dilatata

grass	N	Poaceae
grey sedge	N	Carex canescens
grouseberry	N	Vaccinium scoparium
hawkweed	N	Hieracium sp.
horsetail	N	Equisetum sp.
Kentucky bluegrass	E	Poa pratensis
large-leaved avens	N	Geum macrophyllum
leafy aster	N	Symphyotrichum foliaceum
lodgepole pine	N	Pinus contorta
long-stalked starwort	N	Stellaria longipes
meadow sedge	N	Carex praticola
meadow-foxtail	E	Alopecurus pratensis
mitrewort	N	Mitella sp.
mountain ash	N	Sorbus sp.
mountain hairgrass	N	Vahlodea atropurpurea
mountain sweet-cicely	N	Osmorhiza berteroi
nodding trisetum	N	Trisetum cernuum
nodding wood-reed	N	Cinna latifolia
northern bedstraw	N	Galium boreale
northern blackcurrant	N	Ribes hudsonianum
one-leaved foamflower	N	Tiarella trifoliata var. unifoliata
orchard-grass	E	Dactylis glomerata
palmate coltsfoot	N	Petasites frigidus var. palmatus
pearly everlasting	N	Anaphalis margaritacea
pinegrass	N	Calamagrostis rubescens
plantain	N	Plantago sp.
prince's pine	N	Chimaphila umbellata
purple-leaved willowherb	N	Epilobium ciliatum
pussytoes	N	Antennaria sp.
queen's cup	N	Clintonia uniflora
rattlesnake-plantain	N	Goodyera oblongifolia
red fescue	N	Festuca rubra
red raspberry	N	Rubus idaeus
reed mannagrass	N	Glyceria grandis
rose	N	Rosa sp.
sandwort	N	Arenaria sp.
saxifrage	N	Saxifraga sp.
sedge	N	Carex sp.
sheep sorrel	E	Rumex acetosella
shiny-leaved meadowsweet	N	Spiraea lucida
short-beaked agoseris	N	Agoseris glauca
sibbaldia	N	Sibbaldia procumbens
silky lupine	N	Lupinus sericeus
Sitka valerian	N	Valeriana sitchensis

slimstem reedgrass	N	Calamagrostis stricta
small bedstraw	N	Galium trifidum
small-flowered wood-rush	N	Luzula parviflora
small-winged sedge	N	Carex microptera
soft-leaved sedge	N	Carex disperma
soopolallie	N	Shepherdia canadensis
star-flowered false Solomon's-seal	N	Maianthemum stellatum
starwort	N	Stellaria sp.
stinging nettle	N	Urtica dioica
streambank butterweed	N	Packera pseudaurea
subalpine fir	N	Abies lasiocarpa
sweet-scented bedstraw	N	Galium triflorum
swollen beaked sedge	N	Carex utriculata
thimbleberry	N	Rubus parviflorus
thistle	N	Cirsium sp.
trembling aspen	N	Populus tremuloides
twinflower	N	Linnaea borealis
two-flowered rush	N	Juncus biglumis
Utah honeysuckle	N	Lonicera utahensis
violet	N	Viola sp.
water sedge	N	Carex aquatilis
western meadowrue	N	Thalictrum occidentale
white spruce	N	Picea glauca
wild bergamot	N	Monarda fistulosa
wild strawberry	N	Fragaria virginiana
willow	N	Salix sp.
willowherb	N	Epilobium sp.
wintergreen	N	Pyrola sp.
yarrow	N	Achillea millefolium

NOTES

Personal communications with:

Lisa Zabek, September 2020
Francis Njenga, October 2019
Kyra Witt, October 2019
Andrew Pantel, April 2015

SYSTAT 13 Statistics. 2009. SYSTAT Software, Inc. Chicago, IL.