Grazing Management as a Climate Change Adaptation and Mitigation Strategy

by

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ABSTRACT

Land management can impact whether soils are carbon sources or sinks. Furthermore, changes to carbon dynamics across large areas have the ability to influence atmospheric greenhouse gases, and therefore future global climate. Encouraging the health and resilience of ecosystems to an altered climatic regime is key to sustaining these systems and the services they provide. Rangelands compose up to half of Earth's land base and can be highly impacted by grazing management practices. These impacts must be better researched to inform management decisions that facilitate adaptation to and mitigation of climate change in the future. I compared intensively managed (IM) (high density, short time-interval grazing) to extensively managed (EM) (low density, long time-interval, continuous grazing) grazing management practices at six separate ranch operations located in the British Columbia Interior. IM was supported as an improved management practice, with significantly higher carbon levels found in the soil and significantly lower soil compaction in the 0-10 cm depth range. Total carbon (TC) concentrations were found to be 28% greater (by proportion) under IM. Soil carbon varied significantly by depth and management, with greatest TC concentrations occurring closest to the soil surface (0-10 cm). TC concentration was found to be significantly greater under IM practices in deeper soil depths (10-30cm) when compared to EM suggesting a greater carbon sequestration potential under IM. Mean bulk density under IM was 0.557 g/cm^3 ±0.03 and was 0.699 g/cm^3 ±0.045 for EM. Intensive management may therefore be a viable strategy for climate change adaptation and mitigation if land use changes occur on a large scale. Co-benefits associated with greater soil carbon that can provide subsequent climate adaptation benefits are also discussed in detail. The ability to have science-based support for future land management is important for local food security and environmental sustainability. A vital step in achieving successful implementation of improved management practices is feedback from producers to assess feasibility and adapt practices to fit unique conditions. The final key to successful adoption of improved practices is to provide knowledge transfer to producers and the public through effective education and outreach.

keywords: climate change, adaptation, mitigation, grazing management, carbon sequestration, intensive management.

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CHAPTER 1: CLIMATE CHANGE ADAPTATION AND MITIGATION

INTRODUCTION

Elevated greenhouse gas (GHG) concentrations in the atmosphere are contributing to significant increases in climatic variability (IPCC 2014). The threat of more frequent and untimely weather events will require management strategies focused on both adapting to changes as they occur, as well as mitigation of the causal mechanisms. Climate change adaptation and mitigation strategies are often complementary (IPCC 2014) and can be tackled simultaneously. The focus of adaptation efforts is generally geared towards the establishment and maintenance of resilient ecosystems able to withstand altered environmental conditions. This resilience is achieved through healthy and diverse interactions between soils, plants and animals, and their environment. Mitigation efforts on the other hand, are focused on the reduction of atmospheric greenhouse gases such as methane and carbon dioxide, by either increasing the capture and storage of these GHG's or decreasing emissions (or both). When intentional improvements are made to ecosystem health for adaptation efforts, it can indirectly contribute to mitigation efforts via the improved storage of GHG's in stable forms that result. Similarly, mitigation efforts that aim to improve land management to store more carbon in the soil can have co-benefits that make ecosystems more adaptable and resilient to climatic change (Lal 2004).

Carbon dioxide (CO_2) is the primary focus of most climate change mitigation efforts, and the basis from which all other GHGs are measured (IPCC 2014). When CO_2 within the atmosphere is harnessed by plants as they grow, it can be stored or 'sequestered' in the soil (IPCC 2007). Increasing the amount of carbon within the soil can reduce the impacts of both drought and flood events (Food and Agriculture

Organization of the United States [FAO] 2010). This is based largely on the ability of soils to better retain water when they contain more carbon-rich organic matter. Soils higher in organic carbon also tend to have greater nutrient holding capacity (FAO 2010), reducing the movement of soil nutrients away from roots where they are most beneficial to plant productivity (FAO 2010).

Plant, Soil and Animal Interactions in Grasslands

Grasslands are responsible for storing approximately 12 percent of Earth's soil organic matter (SOM) (FAO 2010) and SOM is composed of approximately 50% organic carbon (Pribyl 2010). SOM levels are controlled by the balance between total additions from plant and animal residues, minus the losses from decomposition (FAO 2010). Since grassland soils generally receive significant plant and animal contributions in conjunction with relatively low rates of decomposition, they possess the necessary components for high amounts of carbon sequestration.

Over time, grasslands have adapted to disturbances such as wildfire and herbivory, and developed strategies to cope with resource limitations such as moisture and nitrogen (Teague et al. 2013). These factors have helped encourage adaptations in grass species that concentrate resources and growth into producing extensive root networks. Because grassland ecosystems tend to exhibit high evapotranspiration to precipitation ratios it is typical for the plants that inhabit these systems to allocate a high proportion of their resources to below-ground growth (Jackson et al. 1996; Silver et al. 2010). Furthermore, the roots of most grass species are fibrous and small in diameter and contribute to soil C not only through senescence and decomposition, but also by rhizodeposition of organic material from exudation, mucilage production and 'sloughing' of living roots (Reeder et al. 2001).

Grazing animals factor heavily into the evolutionary development of grassland plants and soils, maintaining them in a sort of disturbance-based equilibrium. However, in recent years there have been significant changes from the historical disturbance regime (Teague et al. 2013), with the large wild herds that once roamed freely, constantly on the move, having been replaced by livestock that are confined by the boundaries we impose upon them. In many cases, this altered the frequency and intensity of grazing events, as well as season of use and manipulation of cattle distribution across the landscape may have altered the plant-soil-animal dynamic and disrupted the equilibrium that once existed.

Maintaining or restoring balance in these ecosystems through effective grazing management strategies may be key to climate change adaptation and mitigation (Teague et al. 2013). The strategies implemented should be based on a scientific understanding of livestock behaviour, and impacts.

Livestock Behaviour and Impacts

Cattle are selective in what plants they will eat, as some plants are more palatable than others, and cows will generally use certain parts of the landscape more than others based on factors such as topography/elevation and proximity to water (Teague et al. 2013). Furthermore, when confined to the same area for a prolonged period, cattle will generally re-graze their preferred forage plants and leave less desirable ones untouched (Teague et al. 2013; Gerrish 2004). Without adequate recovery time, repeated defoliation can cause plants to deplete their carbohydrate reserves trying to regrow leaves for photosynthesis. Over time, this can result in reductions of desired forage species while encouraging the proliferation and success of less palatable plant species. To maintain plant biodiversity, and reduce negative impacts of localized over-use by cattle to sustain ecosystems that are more resilient to climatic changes, it is important that grazing management strategies encourage even cattle distribution and forage utilization.

Grazing Management

Grazing management can take many different forms, and is often tailored to the unique environmental conditions and limitations of a region. Grazing management practices can be viewed as a continuum ranging from extensive to intensive (**Figure 1**). Extensive management may be referred to as 'traditional' grazing management or 'conventional' grazing, and is characterized by a relatively large land area per animal and lower inputs of labour and/or capital (**Figure 1**). In contrast, intensive management, (MiG, short-duration grazing, multi-paddock grazing, etc.), is characterized by a smaller land area per animal (higher stocking rates) and greater inputs of labour and/or capital. In the case of this study, 'intensive management' is a label typically assigned to methods that follow a particular historical trend for the interior of BC. Specifically, this form of grazing management may often be considered 'continuous grazing' or 'rotational grazing'.

Continuous grazing in the BC Interior generally means cattle are put out onto rangeland and left to graze throughout the growing season based on their own movements and preferences. Rotational grazing systems are similar in that cattle may be kept in large areas (via fencing or herding), but the difference between continuous and rotational is that cows are moved after a time interval (generally a month or two). Other traditional practices considered in this study include the practice of haying (with or without the aid of irrigation) followed by grazing in the fall when cattle return from the range. Ultimately, it must be noted that no two ranches practice grazing management exactly the same, regardless of the name designated. Because grazing management exists along a continuum or gradient, the designation of extensive versus intensive is a relative distinction. Furthermore, the way in which each form of management is enacted will depend on the individual rancher and the various conditions (social, economic and environmental) that influence their decisions.

Sites with the potential for high forage productivity resulting from better soils and greater moisture due to topography, climate, irrigation, etc. have traditionally been used for hay production. These same areas are often ideal for conversion to intensive management practices. One difference between these two options is that for hay production to be sustainable over time, it requires the addition of fertilizers, since nutrients are being removed every time hay is cut and taken off-site. The intensive use of fertilizer has been shown to accelerate mineralization of SOM, subsequently reducing soil carbon. A claim of intensive management is the reduction or elimination of the need for chemical fertilizers by keeping more nutrients on-site compared to traditional extensive management practices. Another difference is that IM generally promotes zero-till practices, which can help reduce the decomposition and loss of carbon and other soil nutrients.

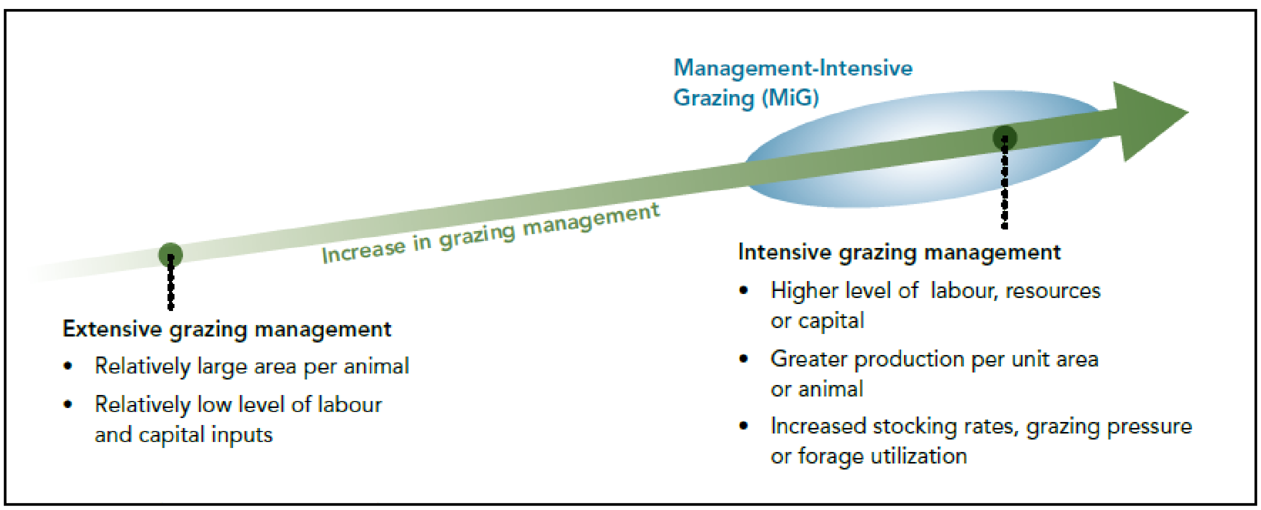

Figure 1. Grazing management continuum (from CAI 2013).

According to Holechek et al. (2000), the method of "short-duration grazing" (or rapid-rotation, holistic resource management, intensive grazing management, MiG, etc.) was conceived by Alan Savory in Zimbabwe in the 1960's. The 'Savory Method' was then brought into the U.S. by S. Goodloe in 1969 (Holechek et al. 2000). Since then, there have been many refinements/adjustments to the method and many claims as to the various benefits of this type of grazing. More recently, Jim Gerrish has written a book on what he refers to as Management-intensive Grazing (Gerrish 2004). In his book on MiG, Gerrish (2004) makes several claims regarding the optimized social, environmental and economic benefits of this form of grazing management. Many of these claims are supported by Gerrish's own research, though some results may be context-specific (applying to the particular conditions existing in the studies). Benefits attributed to intensive management practices by Gerrish (2004) include greater plant productivity, increased biodiversity, erosion control, moisture retention, and healthy soil development; all of which can improve the adaptability of a ranch to changing climatic conditions.

Direct environmental benefits to soil health as a result of IM practices are supported for various reasons. The first being that the amount of plant material harvested is not enough to significantly affect (reduce) root productivity, while maintaining the photosynthetic tissues required for effective plant regrowth. Furthermore, residual plant material is 'mulched' into the soil and mixed together with nutrient-rich cattle waste by hoof action. Smaller paddock size is also said to improve cattle distribution and result in more even grazing throughout pastures (Barnes et al. 2008).

Although improved grazing management practices have been widely recognized as a strategy for increasing rates of carbon sequestration, there is still controversy regarding what constitutes 'improved grazing management' from a carbon storage perspective (Schuman et al. 1999; Conant et al. 2001; Conant et al. 2003; Gerrish 2004; Ingram et al. 2008; Ziter and MacDougall 2013; Christensen 2012). The goal of this research is to evaluate management methods that may assist in sequestering C or enhancing soil sustainability and thereby support climate change adaptation and mitigation.

Ecological Restoration

Intensive management practices have been proposed as a means of restoring the productivity and function of grassland ecosystems (Environmental Protection Agency; Conant et al. 2003; Gerrish 2004; University of Missouri 2006; Christensen 2012). Also, because intensive management practices may be a tool for increasing soil carbon, there is the potential for this to be implemented as an ecological restoration strategy. In areas where soils have degraded because of disturbance or the loss of a 'grazer-induced equilibrium' (Wang et al. 2014), intensive management may be a tool to restore grazer impacts and the organic rich topsoil layers that resulted in the past. Allan Savory (Savory and Butterfield 1998), Jim Gerrish (Gerrish 2004) and other supporters of holistic and/or intensive management (Conant et al. 2003; Conant et al. 2001) strongly support this form of grazing as a means of restoring degraded lands, specifically in ecosystems that evolved alongside large numbers of grazing animals which may no longer be found on the landscape.

However, there are criticisms to this approach (Briske et al. 2008; Holechek et al. 2000; http://www.monbiot.com/) suggesting that scientific evidence to support the benefits of IM is lacking. Holechek et al. (2000) attempts to disprove many of the claims made by Allan Savory in support of intensive management; specifically, his claims about hoof action, forage production, plant succession and range condition, harvest efficiency and livestock distribution, livestock productivity, and financial returns. Holecheck (2000) states that the Savory's claims regarding benefits to each of these variables lack proper scientific evidence, and instead supports a conservative stocking rate as "the surest grazing approach to improving rangeland condition".

A study by Wang et al. (2014) also suggests a conservative (light to moderate) stocking rate, in addition to "even cattle distribution and periodic deferment or removal of grazing to allow plant and soil recovery". However, these strategies form some of the founding principles of a successful intensive management regime. This highlights the difficulty that sometimes exists in discerning one individual's definition of IM from another. Quite often it seems, effective grazing management is based on similar principals, yet produces different results depending on the land manager, and conditions unique to each ranch. Henderson et al. (2004) provide a reminder that ecosystems undoubtedly vary by region in their evolutionary response to historical grazing impacts. Because of this, it is nearly impossible to state that one particular grazing method is the most effective for restoring health and productivity of soils.

This controversy surrounding the efficacy of IM as a means of improving ecosystem health and resilience to climate change forms the basis of my research. My focus lies in determining whether soil carbon storage is greater under IM when compared to conventional practices. To accomplish this, I focus on localized examples from within the British Columbia Interior region.

The need for climate adaptation and mitigation strategies in the Interior of British Columbia is of great importance to the resilience of the ranching industry to environmental changes. This region has already experienced a temperature increase of 1.5-2°C over the past hundred years (IPCC 2014), and projected temperature increase over the next 100 years range from 5-7°C (IPCC 2014 pp.12).

Ranching is one of the first industries brought to B.C. by European settlers, and continues to be an important part of the history, culture and economics of this province (Harrower et al. 2012). To preserve this important industry in the face of a changing climate, science-based evidence is needed to inform management decisions that encourage climate change adaptation and mitigation. My research aims to do this in CHAPTER 2: SOIL CARBON IN RESPONSE TO GRAZING MANAGEMENT, by testing whether IM pastures contain more carbon than EM pastures, and promoting the many benefits of increased carbon sequestration. Based on the results of my research, I then discuss the implications my results have on future grazing management decisions and the importance of education and outreach to knowledge transfer in CHAPTER 3: IMPLICATIONS, PERSPECTIVES AND CONCLUSIONS.

CHAPTER 2: SOIL CARBON IN RESPONSE TO GRAZING MANAGEMENT

INTRODUCTION

The global climate is changing as a result of human activities and this change threatens the sustainability of our species (IPCC 2014; Follett et al. 2001). To combat this, we must reduce atmospheric greenhouse gas (GHG) concentrations and improve our adaptability to an uncertain climatic future. Cumulative carbon dioxide (CO_2) levels have been identified by the IPCC (2014) as the key determinant of future global temperature increase. IPCC predictions include an expected increase in frequency of severe and often untimely weather events such as flooding and drought (IPCC 2014). Actions to reduce atmospheric CO_2 levels must be taken to help reduce the intensity and severity of future climatic changes (IPCC 2014).

Carbon is dynamic, and continually cycling between the earth's surface and the atmosphere (Janzen 2015; Lehmann and Kleber 2015). In addition to fossil fuel consumption releasing GHG's, historical land and soil mismanagement has led to the flow of up to two thirds (30-40 t/ha) of soil organic carbon (SOC) from cultivated soils back into the atmosphere (Lal 2004). By increasing rates of plant productivity (growth) and/or slowing the return of stored carbon (C) into the atmosphere, rates of carbon sequestration can be increased (IPCC 2007). Plants are able to capture CO_2 from the air and produce living tissue which ties up the carbon for a period of time (Follett et al. 2001; Schuman et al. 2002). As plants undergo their own cycles of growing and senescing, old plant material assumes the form of carbon-rich organic matter (OM) (Follett et al. 2001).

In this study, we focus on carbon sequestration that results from increasing the amount and residence time of carbon stored below ground. When it comes to climate change mitigation strategies, carbon sequestration through improved land management is viewed as one of the most economically viable approaches, and can be accompanied by several co-benefits such as increased plant productivity, soil water holding capacity and nutrient cycling, as well as decreased erosion (Paustian et al. 1997; FAO 2010; Silver et al. 2010; Follett et al. 2001; Briske 2011). By increasing the amount of carbon sequestered, the resilience and adaptability of ecosystems can be improved, and thus continue to sustain livelihoods that depend on those ecosystems (Tennigkeit and Wilkes 2008).

The IPCC (2007) has outlined several actions that can be made to help mitigate and adapt to climate change (mitigation and adaptation occurring simultaneously and interacting); one of these actions being improved land management (Smith et al. 2007). According to the IPCC (2007), "enhancing removals" of carbon from the atmosphere through improved management is recognized as one of three climate change mitigation strategies within the agricultural sector (the others are 'reducing' and 'avoiding' emissions) (Smith et al. 2007). Furthermore, a meta-analysis by Conant et al. (2001) found 74% of studies showed increased carbon (C) concentrations from improved management. Rangelands are inherently grazed, and encompass a variety of biomes types that cover up to half of the global land area (Lund 2007); because of this, even a small change in soil carbon across these ecosystems would equate to a large impact on global GHG budgets.

The need for more research on the impacts that changing land management have on carbon sequestration has been identified by the Food and Agriculture Organization of the United Nations ([FAO] 2010) and others (Conant et al. 2003); specifically making reference to differences between intensive and extensive grazing management. Existing studies tend to focus on the presence/absence of grazing, or grazing intensity (stocking rate) rather than the intensity of management. The results presented are often contradictory, indicating that grazing either increases, decreases, or has no significant impact on soil carbon (Zhou et al. 2016; Wang et al. 2014; Briske 2011; Reeder and Schuman 2002; Holechek et al. 2000). Unfortunately, many of these discrepancies are due not only to differences in local environmental and climatic conditions, but variation in sampling methodologies (Reeder and Schuman 2002) and definitions of management practices. In our study, soil sampling and analysis is accompanied by indirect methods proposed as a means of inferring soil carbon; these are based on remote sensing (Tennigkeit and Wilkes 2008) and plant community (Breulmann et al. 2012). By testing these methods we can hopefully provide support for a standard method of soil carbon estimation that reduces sampling and analysis costs as well as soil disturbance. This has the potential to improve the consistency and feasibility of carbon measurement and monitoring (Tennigkeit and Wilkes 2008)

Using traditional soil sampling methods, plant community composition and remote sensing via multispectral radiometry, I researched soil carbon at six cattle ranching operations in the Central Interior of BC; specifically focusing on the comparison between intensively managed (IM) and extensively managed (EM) pastures and how this impacts climate change adaptation and mitigation. IM – often referred to as management-intensive grazing (MiG) – is the frequent, planned movement of cattle between relatively small pastures or paddocks, and may be accompanied by inputs such as irrigation, soil amendments, and seed, to increase vegetation productivity (Conant et al. 2003; Gerrish 2004). The presence of a relatively high number of livestock in a small area for a short period of time (under IM) is believed to more evenly distribute grazing impacts and nutrients from animal waste (Conant et al. 2003; Gerrish 2004). Increased productivity and compensatory growth of forage crops are additional benefits said to result from IM, which can directly influence the amount of plant-derived C additions to the soil (Conant et al. 2003; Gerrish 2004). Traditional extensively managed pastures are generally much larger in size and cattle are rotated to new pastures less often. While it is feasible that the same number of cattle may be used in both management systems, there is a clear difference in the timing and intensity of grazing between IM and EM grazing.

Objectives

My primary objective was to test whether there were differences in soil carbon between IM and EM pastures. Ideally, this information can then be used to provide recommendations for local cattle producers to help improve the social, environmental and economic sustainability of ranching in BC. To achieve this, I quantified soil carbon levels at six ranch operations and related it to historical grazing practices and other factors that may influence soil carbon content. My secondary objective was to determine the efficacy of other variables (Normalized Difference Vegetation Index (NDVI), moisture content and species diversity) for inferring soil carbon levels. Previous studies have found strong relationships between these influential factors and soil carbon levels and developed models for predicting soil carbon without disturbing the soils to obtain a sample (Kunkel et al. 2011). However, there is the need for a greater understanding of how level of management intensity plays into the equation.

I hypothesized that TC, measured as the percentage of elemental carbon would be greater under intensive management practices when compared to extensive management practices. Intensive management is predicted to be a management tool that can lead to optimal carbon sequestration in BC ranch lands. This hypothesis is based primarily on the potential increase of subterranean carbon storage via improvements in plant productivity and avoidance of overgrazing and soil disturbance (Conant et al. 2001; Harrower et al. 2012). Furthermore, I expected that indirect methods of predicting soil carbon (NDVI, moisture content and species diversity) will exhibit a significant relationship with soil carbon, but the extent of this influence may vary depending on management.

METHODS

I determined the amount of soil carbon by collecting soil samples from differentially managed pastures (IM and EM) and then compared TC between management types. I also related soil carbon values with plant community data and NDVI to determine whether these methods could be used as a surrogate for direct measurement of soil C.

Grazing Management

There is often difficulty discerning between what constitutes 'intensive management' compared with 'extensive management'. For the purposes of this study, we will relate these to the principles of Frequency, Intensity and Opportunity (FIO principles). However, it is important to keep in mind that these are generalizations and it ultimately comes down to the discretion of the individual rancher who makes the management decisions. Furthermore, although references are made to an 'individual plant', the intention is to consider this effect at a pasture level, which consists of many individuals.

Frequency refers to the number of times an individual plant is subject to defoliation in a given period of time, and is therefore directly related to the duration an area is used for. Under IM practices, cattle are meant to be moved from one pasture to the next after a very short period of time, only giving livestock one quick chance to remove tissue from a plant before being moved to the next paddock. Conversely, under EM practices cattle have access to an individual plant for a longer period of time, and can therefore return to the same plant to repeatedly graze it before being moved on to the next pasture.

Intensity refers to the amount of plant material removed from an individual plant, and is therefore directly related to the number of livestock present in an area for a given period of time (stocking rate). Generally, ranchers abiding by the principles of IM will aim to remove only 1/3 of the above ground plant material per grazing event, and no more than ½. Under IM practices, the number of cattle per unit area is generally very high, yet the period of time is very short. If livestock are moved from one pasture to the next quickly, this can still equate to a moderate or conservative stocking rate. Conversely, under EM practices, stocking rates may be much lower, but due to the prolonged use of these areas, can still equate to higher stocking rates than IM pastures. Although many IM ranchers also aim to remove only 1/3 to 1/2 of the aboveground biomass, there is less opportunity to control this when cattle are making their own decisions regarding where they graze and what plants they prefer.

Opportunity for regrowth refers to the amount of time an individual plant is given to rest and after defoliation, and is heavily influenced by season of use, since re-growth won't occur unless temperature and moisture conditions permit. Under IM practices, the planned rotation of grazing is intended to allow adequate rest and recovery of plants. Under this type of management the rancher has better control over where the cattle graze, and can judge whether or not an area is ready to be grazed again. Furthermore, one of the intents of grazing lightly (1/3 of the plant biomass per event) is that plants remain in their most productive (vegetative) state, and will recover quickly. Conversely, under EM practices, grazing may not occur again until the following year, but opportunity for regrowth will depend largely on the season of use. In many cases, grazing in the late fall will have little effect on regrowth, since plants have already began dormancy and will regrow the following spring. In general, it is recommended that an area not be grazed at the same time of year over many consecutive years to avoid impacting critical parts of a plants growth cycle repeatedly.

Study Sites

Six cattle ranch operations were examined in this study; all lie within the southern half of British Columbia's interior region. Five of the ranch operations were located in the Cariboo-Chilcotin, with the closest urban centre being Williams Lake (**Figure 2**) and the remaining ranch -Ranch 6- was closest to Kamloops (**Figure 2**) in the Thompson-Nicola region. Ranch 2 was added to the sampling regime in 2014 and therefore was not sampled in 2013. All ranches implemented both IM and EM on their properties for comparison. Cattle were moved from one IM paddock to the next 2-7 times per week depending on size and number of cattle in the herd. EM pastures were grazed over longer time frames (week to months), were larger in size, and in some cases were also hayed 1-3 times per year.

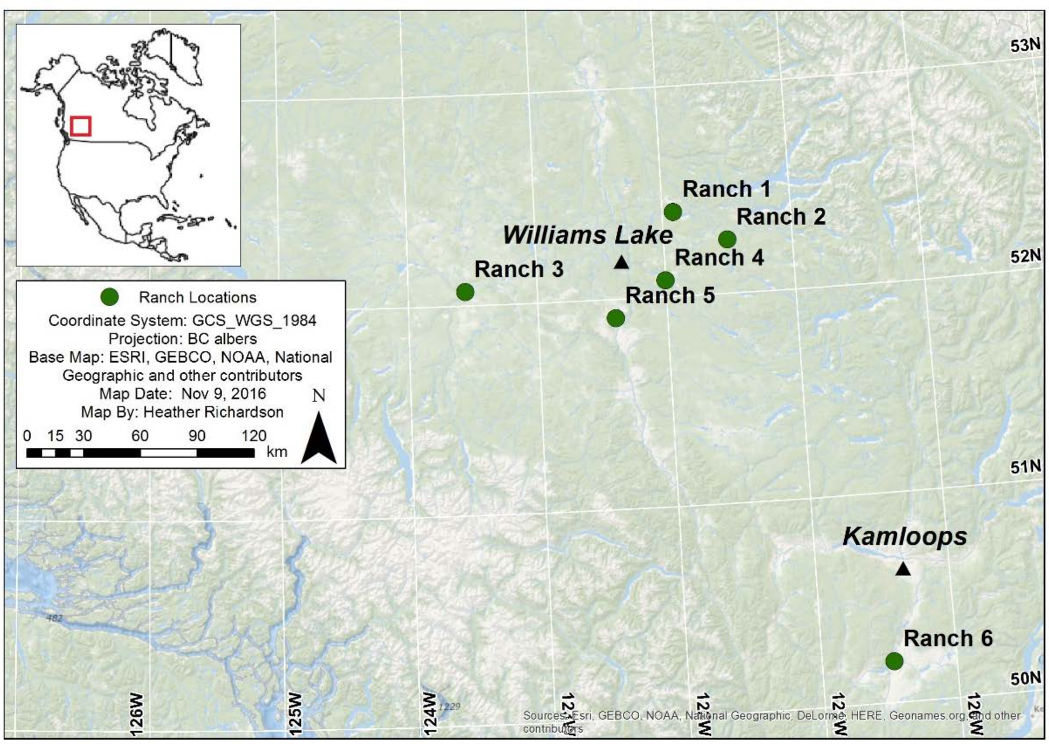

Figure 2. Locations of six study sites (ranches) within the BC Interior.

In the description of each ranch, I use the Biogeoclimatic Ecosystem Classification (BEC) system, which is used in British Columbia to group ecologically similar site based on climate, soils and vegetation (Pojar et al. 1987). This system is a valuable resource for both scientific research as well as informing land and resource management activities. More detailed information regarding transect site characteristics and plant community % cover data can be found in Appendix A.

RANCH 1

Ranch 1 (**Figure 1**) was in the Sub-Boreal Spruce (SBSmh) BEC zone, with the land cleared of trees for hayfields and grazing land. The mean annual precipitation (MAP) was approximately 613.5 mm (**Table 1**). The ranch was not irrigated. The ranch covered an area of approximately 260 hectares containing a mixture of grazing land and hayfields, as well as a mixed land-use system of harvestable timber and forage known as silvopasture. The dominant plant species were Kentucky bluegrass (*Poa pratensis*), orchardgrass (*Dactylis glomerata*), reed canary grass (*Phalaris arundinacea*) and alfalfa (*Medicago sativa*). Intensive management practices began at this ranch in 2008 and a total of 60 cow/calf pairs were stocked in 2014. IM paddocks (pastures subdivided with electric fencing) were approximately 1 acre (0.4 ha) in size and would feed 60 cow/calf pairs for 1-2 days. EM pastures were not subdivided and received continuous use for 1-3 months by bulls, horses and/or weaning calves.

Table 1. Study site information. Weather data based on 1981-2010 Canadian climate normals from Environment Canada (http://climate.weather.gc.ca/climate_normals/index_e.html).

Ranch	Latitude	Longitude	BEC	Area (ha)	# of cattle (cow+calf)	MAP (mm)	MAT (°C)	Year IM began	Dominant forage species
1	52°32'14.3"N	121°55'49.6"W	SBSmh	260	60	613.5	4.8	2008	*Poa pratensis, Dactylis glomerata, Phalaris arundinacea, Medicago sativa*
2	52°21'11.2"N	121°25'39.1"W	SBSdw	740	120	613.5	4.8	2001	*Poa pratensis, Phleum pratense, Dactylis glomerata, Phalaris arundinacea, Trifolium ssp.*
3	52°05'38.7"N	123°38'38.5"W	IDFxm	2020	340 + 100 heifers	366.9	3.2	2012	*Poa pratensis, Phleum pretense, Trifolium ssp.*
4	52°02'43.3"N	121°54'22.9"W	IDFxm	400	250	450.7	4.5	2009	*Poa pratensis, Phleum pratense, Phalaris arundinacea, Medicago sativa*
5	51°54'48.4"N	122°19'12.3"W	BGxw	730	50 + 90 steers	450.7	4.5	2010	*Poa pratensis, Dactylis glomerata, Bromus inermis, Medicago sativa*
6	50°15'18.1"N	120°27'12.0"W	BGxw	6000	750	321.1	7.8	1990	*Poa pratensis, Dactylis glomerata Elymus repens, Pseudoroegneria spicata*

RANCH 2

Ranch 2 (**Figure 2**) was located within the Sub-Boreal Spruce (SBSdw) BEC zone and was historically cleared of trees to make way for hayfields and pastures. The MAP was 613.5 mm (**Table 1**), and the ranch was not irrigated. The ranch was a mixture of grazing land and hayfields, and had been practicing IM since roughly 2001. Dominant plant species were Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*), orchardgrass (*Dactylis glomerata*), reed canary grass (*Phalaris arundinacea*) and clover (*Trifolium* ssp.). The ranch covered an area of about 740 hectares in total (half of which is forested) and was stocked with approximately 120 cow/calf pairs in 2016. IM paddocks were approximately 1-2 acres (0.4 - 0.8 ha) in size and would feed 120 cow/calf pairs for 1-2 days. EM pastures were not subdivided and received continuous use for 1-3 months by bulls or weaning calves.

RANCH 3

This ranch (**Figure 2**) lies within the Interior Douglas Fir (IDFxm) BEC zone and had a MAP of 366.9 mm (**Table 1**). The ranch had a mixture of irrigated hayfields and grazing land with IM beginning in 2012. The ranch consisted of approximately 2020 hectares of deeded land consisting of low-lying meadows and drier rangeland on the hillslopes. This ranch also leased about 200 hectares of crown rangeland. Dominant plant species were Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*) and clover (*Trifolium* ssp.). In 2014 the herd consisted of approximately 340 cow/calf pairs and 100 replacement heifers. IM paddocks were approximately 1-2 acres (0.4 - 0.8 ha) in size and would feed 100 heifers for 1-2 days. EM pastures were not subdivided and received continuous use for 1-3 months by bulls, horses and/or weaning calves in addition to being hayed occasionally.

RANCH 4

This ranch (**Figure 2**) was in the Interior Douglas Fir (IDFxm) BEC zone and had a MAP of 450.7 mm (**Table 1**). The ranch was primarily flood-irrigated using a network of ditches, and areas not receiving irrigation were composed of dryland adapted plant species. The ranch was approximately 400 hectares in size, with range composed of a mixture of open meadows and forest. Dominant plant species were Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*), reed canary grass (*Phalaris arundinacea*) and alfalfa (*Medicago sativa*). At the time of the study, this ranch did not operate hayfields, only cattle grazing, and had been practicing IM since 2009. In 2014, the herd consisted of approximately 250 cow/calf pairs. IM paddocks varied from roughly 1-5 acres (0.4 – 2.0 ha) in size and would feed 50 cow/calf pairs for 1-5 days. EM pastures were not subdivided and received continuous use for 1-3 months by bulls or weaning calves.

RANCH 5

This ranch (**Figure 2**) lies within the Bunchgrass (BGxw) BEC zone and had a MAP of 450.7 mm (**Table 1**). The ranch was approximately 730 hectares which includes pivot-irrigated hayfields and grazing land as well as arid rangelands. Dominant plant species under the irrigated pivots were Kentucky bluegrass (*Poa pratensis),* orchardgrass (*Dactylis glomerata*), smooth brome (*Bromus inermis*) and alfalfa (*Medicago sativa*). At this ranch, they had been practicing IM since 2010. In 2013, the ranch was operating about 90 steers and 50 cow/calf pairs. IM paddocks were approximately 1-2 acres (0.4 - 0.8 ha) in size and would feed 50 cow/calf pairs for 1-2 days. EM pastures were not subdivided and received continuous use for 1-3 months by bulls or weaning calves in addition to being hayed 1-2 times during the growing season.

RANCH 6

This ranch (**Figure 2**) was in the Bunchgrass (BGxw) BEC zone and had a MAP of 321.1 mm (**Table 1**). The ranch contained a mixture of irrigated meadows in the valley bottom, with native plant communities stretching up the drier hillslopes. Dominant plant species of the low-lying meadows were Kentucky bluegrass (*Poa pratensis*), orchardgrass (*Dactylis glomerata*) and quackgrass (*Elymus repens*), while the arid upland areas were dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*). At this ranch, they practiced a form of intensive management referred to as both "planned grazing" and "holistic management" since roughly 1990. The ranch consisted of approximately 6000 hectares of deeded pastureland and semi-arid upland range. In 2014 the herd consisted of approximately 750 cow/calf equivalents. IM paddocks were approximately 1-5 acres (0.4 – 2.0 ha) in size and would feed 150 heifers for 1-5 days. EM pastures were not subdivided and received more continuous use for 1-3 months by bulls or weaning calves. Some EM pastures were also grazed by the entire herd (750 head) for 1-2 weeks.

The ranch sites chosen for this study were selected specifically because they represented sites within the BC Interior that are currently managed both intensively and extensively. Amongst these ranches there was diversity in seasonal moisture regimes and other climatic variables. Specifically, conditions tended to be much drier during the growing season in the sites that lied south or west of Williams Lake (Ranches 3, 4, 5 and 6), whereas east of Williams Lake (Ranches 1 and 2) received more moisture. Although ranch sites exhibited a variety of conditions, standardized methodologies were used for developing strict soil sampling protocols which were replicated at each of the study ranches so that comparisons between management systems could be made within ranch sites as well as across ranch sites.

Soil Sampling

Sampling was conducted during the growing season, between the months of July and September. Accounting for the spatial variability inherent in soils of the British Columbian interior, sampling occurred at multiple sites within the region. At each ranch, a minimum of 3 sampling transects were replicated for each management type (IM and EM). There was generally one transect per pasture unless further stratification was required due to differences in vegetation community, topography, productivity, etc. within a pasture. Sampling occurred in the same areas for two consecutive years (2013 and 2014) to better account for temporal variability in measurements caused by annual differences in environmental conditions. Although soil cores from sampling transects were the primary source of data used in this study, they were complemented with soil pit sampling in 2014 to better characterize soil parameters according to the Canadian system of soil classification (National Research Council of Canada [NRC] 1998).

A minimum of five 30 cm deep soil cores were taken from each 50 meter transect. The start point and orientation of each transect was randomly located within a pasture in 2013 and then replicated in the same general area - not overlapping- in 2014. Core sampling for soil carbon and bulk density were separated into 10 cm intervals to a depth of 30 cm (Breulmann et al. 2012). Soil carbon samples were taken from the sidewall of cores excavated with an earth auger.

In 2014, soil pits were excavated to a depth of 50 cm in one IM and one EM pasture at each of the six ranches using hand tools. Field sheets based on those found in Soils Illustrated (Watson 2009) were used to identify soil horizons, texture, coarse fragment content and secondary carbonates (see blank field sheet in Appendix B) and photographs were taken with a ruler for scaling purposes. Soil samples were then collected in 5 cm intervals from 0 cm to 50 cm and later analyzed for carbon content. This facilitated observation at a finer scale than soil core samples (10 cm intervals) and to deeper soil layers (compared to 30 cm max. depth).

Soil Analysis

Carbon and bulk density values for individual soil cores from each transect were measured and then pooled by depth so that each transect possessed a single value for each depth interval. Samples from both years were not pooled but regarded as separate samples. This allowed us to account for annual variability inherent in soil carbon dynamics. Not all variables were collected during both years; NDVI, plant species richness/diversity and soil bulk density were only measured once in either the 2013 or 2014 field season.

Total Carbon % (TC)

Soil carbon samples were air-dried, sieved and stored in Ziploc plastic bags. Sieving was performed using a "Laboratory test sieve" (ASTME 11) Endecotts Ltd., London, England with an aperture of 355 μm (mesh #45). Samples were then analyzed using an automated elemental analyzer (EA) (CE-440 Elemental Analyzer, Exeter Analytical Inc., North Chelmsford, MA) for total % carbon content. Subsamples were weighed to the nearest thousandth of a milligram between 10-20 mg and were handled with sterilized metal utensils to avoid contact with oils from human skin or other soil samples.

Bulk Density

Bulk density (BD) samples were collected once during this two-year study. Samples were taken from a minimum of two soil cores per transect and separated by depth interval (0-10 cm, 10-20 cm and 20-30 cm). Samples were weighed prior to drying and then transferred into paper bags. The bags were then placed in a drying oven at 70°C for a minimum of four days (96 hours). This method was based on the 'compromise' between the air dry method and the damaging effects of 105°C method as described by the Canadian Society of Soil Science (2008, p.68). To correct for the presence of rocks, samples were weighed when dry and sieved to remove coarse fragments ≥2 mm in diameter (Canadian Society of Soil Science 2008, p.54). The sieved soil was then weighed and this mass was subtracted from the unsieved soil dry mass to determine the mass of rock in each sample. The volume of rock was then determined from the mass using a standard rock density of 2.7 g/cm^3. The adjusted bulk density was then calculated by dividing the sieved, dry soil mass by the soil core volume -with rock volume subtracted and reported in g/cm^3 (Conant et al. 2003).

Moisture content percentages were calculated from bulk density samples by subtracting the dried soil mass from the wet soil mass, and dividing that number by the dry soil mass.

Carbon Stocks and Sequestration Rates

TC stocks ($t\ C\ ha^{-1}$) were calculated by multiplying soil bulk density by % carbon values (Donovan 2013). This allowed for spatial scaling of results and facilitated comparisons with similar studies (Conant et al. 2001; Conant et al. 2003). However, as highlighted by Henderson et al. (2004), the accuracy of any comparisons between carbon stocks is sacrificed when significant differences in bulk density exist. Furthermore, assessing carbon stocks diminished our dataset by half, since bulk density samples were only collected during one field season, and it would not have been appropriate to combine bulk density from one year with carbon values from another to calculate stocks. For these reasons, focus remains on the comparison of % carbon concentration (TC) rather than carbon stocks, since these values were independent of any density differences by soil depth or grazing management (Henderson et al. 2004). The same applies for carbon sequestration rate (t C ha^{-1} yr^{-1}) which was calculated by dividing the difference in carbon stocks between IM and EM type by the number of years since pastures were converted to intensive management (Conant et al. 2003).

Multispectral Radiometry (MSR)

In 2014, soil carbon sampling was accompanied by measurements of spectral reflectance using a DLC Multispectral Radiometer (MSR16R, CROPSCAN Inc.) -or MSR. Prior to any mechanical disturbance, every soil core location was measured with an MSR reading as well as an estimate of relative plant species cover (%). All operational specifications were followed according to the MSR User's Manual and MSR Reflectance data from readings were converted into Normalized Difference Vegetation Index (NDVI) values using the following equation:

$$\boldsymbol{NDVI = \frac{NIR - RED}{NIR + RED}}$$

Where NIR are reflectance values for wavelengths within the near infrared spectrum and RED are the reflectance values for wavelengths within the red light spectrum (Pers. Comm. Del Nantt). Or:

$$\boldsymbol{NDVI = \frac{\%RFL\,830 - \%RFL\,650}{\%RFL\,830 + \%RFL\,650}}$$

Where %RFL are the output reflectance values from the MSR for wavelength bands of 650 and 830 nm (pers. comm. Del Nantt, Cropscan, Inc.).

Vegetation Sampling

For each transect, soil sampling was accompanied by visual estimates of plant species relative percent cover (the sum of which equals 100%) at a landscape-level, as well as within a 50 cm by 50 cm quadrat where each soil core was later excavated. species diversity was calculated using the landscape-level cover estimates (to account for a larger diversity of species) and based on the Shannon Diversity Index, which accounts not only for the number of species present (species richness), but also the relative proportion of each species to one another (Shannon and Weaver 1949).

Statistical Analysis

The statistical software package 'R' was used to conduct analysis of variance (ANOVA) as well as regression analyses. The significance threshold was set at α=0.05. Initial trends in the data were observed using mean data calculated for each depth (0-10, 10-20 and 20-30 cm) by transect. When values were available for both 2013 and 2014, the mean was not taken, and data between years viewed separately.

TC data (the primary response variable examined) was initially separated by ranch site, transect and depth interval during sampling, but later grouped together for the purposes of analyses. Samples from individual soil cores were averaged to produce one value per depth, per transect, and transects were grouped together by management across all ranches to test for significant differences.

For the ANOVA tests, average values by depth for each transect were used to avoid pseudoreplication (if each core was considered a true replicate). The data often required a log transformation to meet the assumption of a normal distribution and the default log function (natural logarithm) was implemented in 'R' software. 2-way ANOVA was used to evaluate the effects of depth and management on total carbon as well as organic carbon. Because depth can have such a significant impact on both BD and carbon content, data were also separated by depth prior to individual ANOVA within each interval. This allowed for better isolation of the depths in which the treatment (management) had an effect.

Regression analysis was also used to determine the relationship between carbon and NDVI, moisture and species diversity; specifically whether these variables are effective at predicting carbon levels. Since soil carbon values were separated by depth, only values belonging to the top 10 cm depth interval were used for comparison with NDVI, as this depth was the most consistently measured (samples from deeper layers weren't always obtainable) and most likely to show a relationship with remotely sensed surface measurements.

To compare TC between sampling years (2013 and 2014) Welch 2 sample t-tests were conducted. However, differences between 2013 and 2014 were expected to be miniscule in relation to the differences in carbon between depth intervals or management type. To account for this, data were separated by depth and management to ensure that these influential variables would not mask any observable differences between sampling years. When necessary, data were also transformed using the 'log' function in R (natural logarithm) to better fit a normal distribution.

Soil pit data were averaged across all ranches based on management type (EM or IM) by depth. A paired t-test was then conducted to see whether there was a significant difference in carbon by management type. Justification for pairing this t-test is based on spatial correlation in terms of soil depth.

RESULTS

Soil Carbon

There were no significant differences detected in TC between sampling years or by ranch site. P-values for paired comparison t-tests (separated by depth and management) between 2013 and 2014 were all above the α=0.05 threshold and ANOVA of soil carbon by ranch location showed no significant difference between ranches.

There was a significant difference in TC by depth (**Table 2**). The difference between TC by management was also significant. No significant interactions were detected between depth and management for TC (**Table 2**).

Table 2. Summary table for 2-way ANOVA examining the relationship between total carbon and the factors 'depth' and 'management'. df is degrees of freedom, SS is sum of squares, MS is the mean squared, F is F-statistic and p is P-value. Bold values are significant ($p < 0.05$).

		Total Carbon			
	df	SS	MS	F	p
Depth	2	28.741	14.370	69.145	**<0.001**
Management	1	3.877	3.877	18.656	**<0.001**
Depth x Management	2	0.416	0.208	1.001	0.369
Residuals	206	42.813	0.208		

Further analyses were conducted after data were separated by depth interval (**Appendix A**). Significant differences in TC by management were only observed in deeper soil layers (10-20 cm and 20-30 cm), with higher carbon values in IM pastures according to post-hoc Tukey HSD testing. Actual mean values for TC by management and depth can be found in **Table 4**.

Table 3. Mean values for TC concentration by depth and management. Significant differences between TC by management for a depth interval are identified with an asterisk. n=45 for each IM depth interval and n=35 for each EM depth interval. n values represent sample size for each mean value calculated.

	Mean TC Concentration			
Depth Interval	**-IM-**	n	**-EM-**	n
0-10 cm	**4.545 %**	45	**3.955 %**	35
*10-20 cm	**2.945 %**	45	**1.950 %**	35
*20-30 cm	**1.967 %**	45	**1.410 %**	35

There was a strong inverse relationship observed in carbon by depth, with carbon levels highest near the soil surface (0-10 cm) and decreasing into deeper layers (**Figure 3**). This trend was observed for both management types compared (IM and EM).

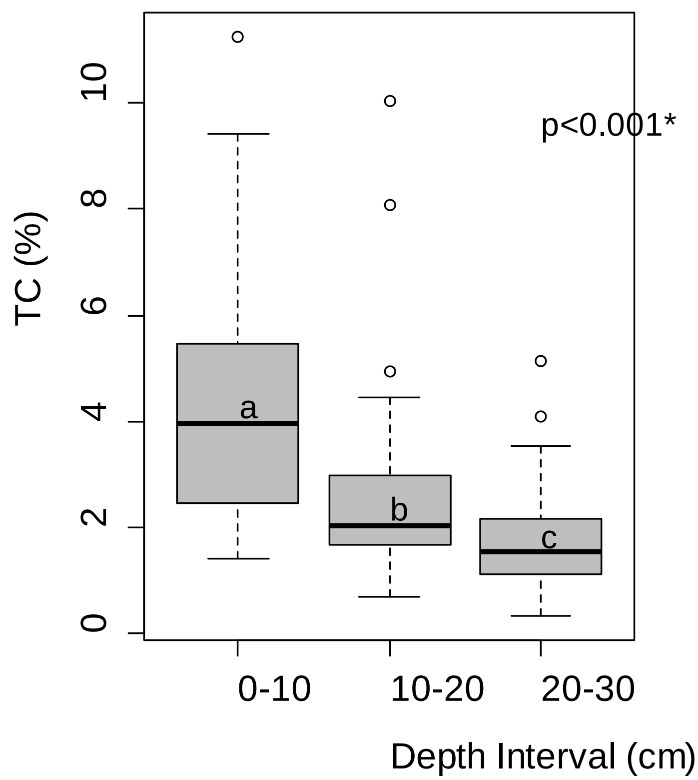

Figure 3. TC percent concentration by depth interval. p-values represent statistical significance based on ANOVA. Lettering distinguishes significantly different means based on the results of Tukey HSD tests. Error bars illustrate sample variability by showing the largest and smallest observations less than 1.5 times the interquartile range from upper and lower quartiles.

A significant difference was found between management types for TC (**Figure 4**). This single factor ANOVA coincides with our previous results from two factor ANOVA by depth and management.

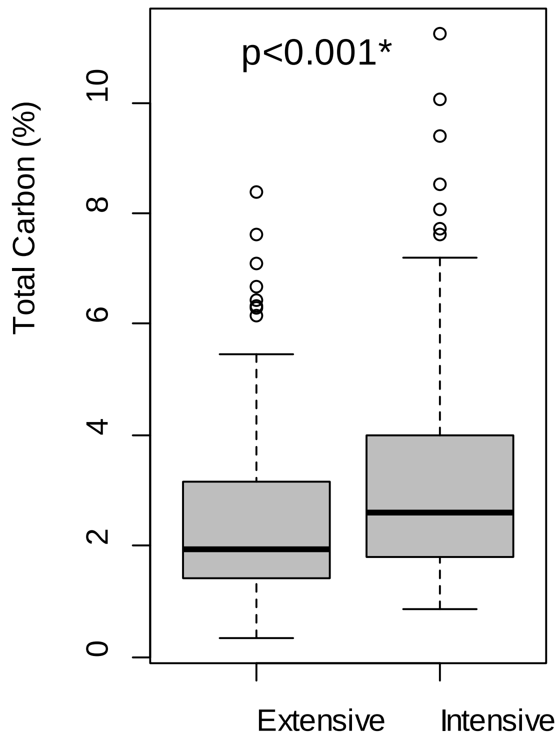

Figure 4. TC percent concentration by management, which included all depths at all study sites. p-values represent statistical significance based on ANOVA. Error bars illustrate sample variability by showing the largest and smallest observations less than 1.5 times the interquartile range from upper and lower quartiles.

Soil pit TC was significantly different between management types ($p=0.001$) as well as depth interval ($p<0.001$) and neither variable showed evidence of interactions by ranch site. There were no significant differences between ranch sites when combined in two factor ANOVA's with either management ($p=0.532$) or depth ($p=0.442$).

When data from all ranches were grouped and the factors of depth and management considered, a significant difference was detected from paired t-testing (t = 4.8923, df = 9, p-value <0.001). Based on the figure below, intensively managed pastures exhibited a pattern of greater total carbon when compared to extensively managed ones (**Figure 5**). The difference between curves decreases and eventually disappears when depths of 50 cm below the soil surface is attained (**Figure 5**).

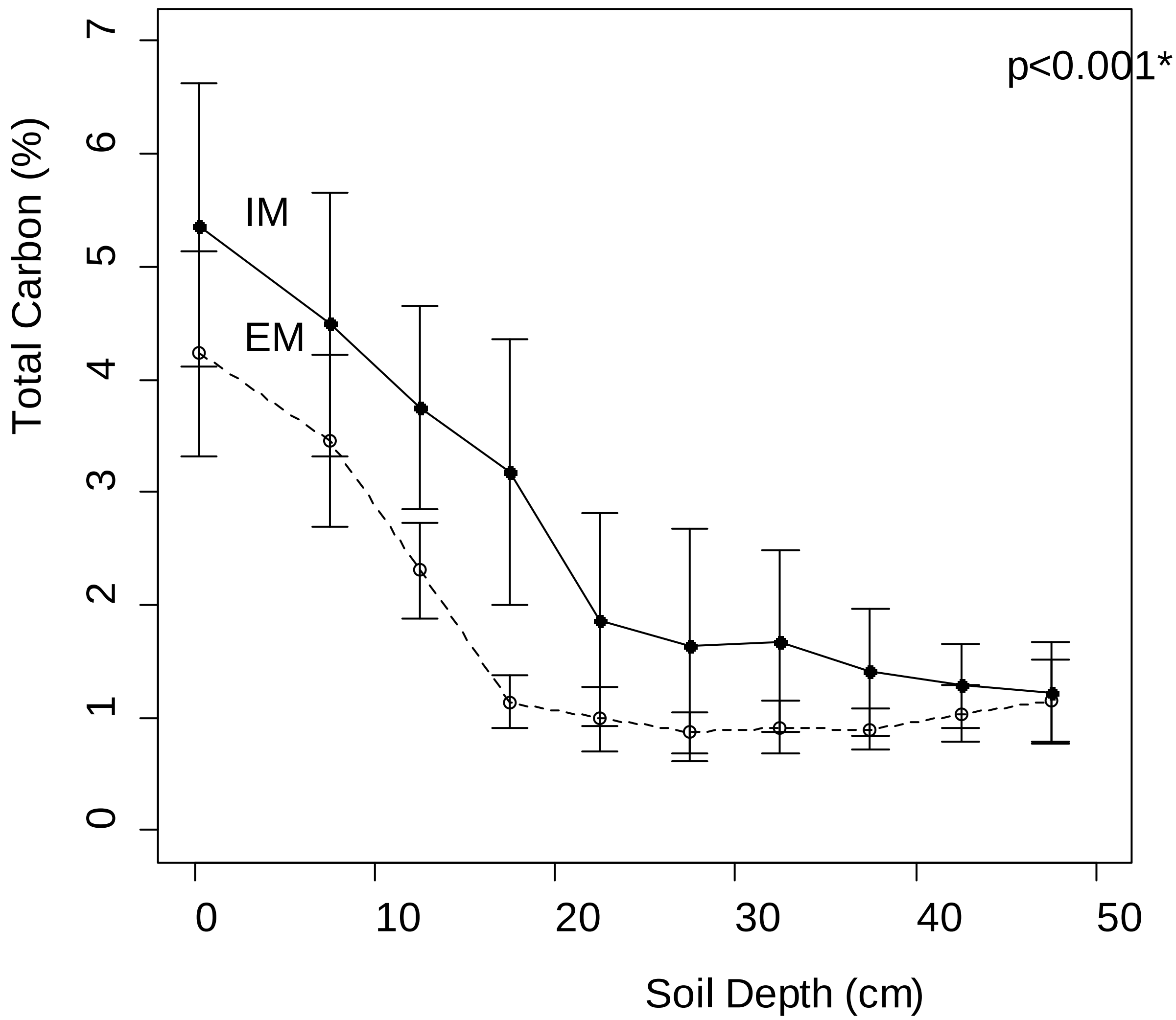

Figure 5. Mean total carbon by depth and management across all study sites. Results of Welch 2-sample t-test displayed indicates a significant difference (p<0.001)

between data by management type (Intensive -IM- and Extensive -EM-). Error bars represent standard error (SE) values.

Soil Bulk Density (BD)

Significant variation was detected in BD by depth (**Figure 6**; **Table 5**). Post-hoc Tukey HSD testing supported that the BD of 0-10 cm was significantly less than 10-20 cm, which was significantly less than 20-30 cm ($p<0.001$).

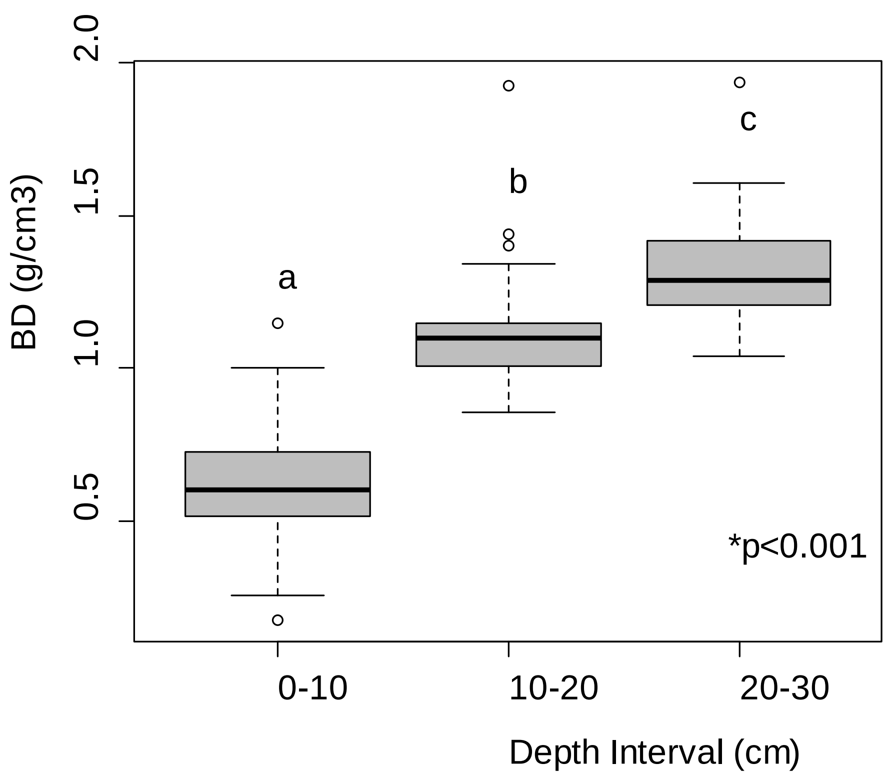

Figure 6. Soil bulk density (BD) by depth interval (0-10 cm, 10-20 cm, 20-30 cm). P-values represent statistical significance based on ANOVA. Bars sharing the same letters are not significantly different (Tukey's HSD). Error bars illustrate sample variability by showing the largest and smallest observations less than 1.5 times the interquartile range from upper and lower quartiles.

Soil BD also varied by management (**Table 5**). Post-hoc Tukey testing showed that BD of EM pastures was greater than that of IM pastures.

Table 4. 2-way ANOVA summary table for Bulk Density by depth and management. df is degrees of freedom, SS is sum of squares, MS is the mean squared, F is F-statistic and p is P-value. Bold values are significant ($p < 0.05$).

	Bulk Density				
	df	SS	MS	F	p
Depth	2	9.454	4.727	134.507	**<0.001**
Management	1	0.208	0.208	5.921	**0.017**
Depth x Management	2	0.071	0.035	1.007	0.369
Residuals	101	3.549	0.035		

Although the 2-way ANOVA for BD by depth and management showed no significant interaction between the two factors (p=0.369) it was expected that a difference may be detected if data were manually separated by depth prior to analysis by management type. After this initial separation, they were subject to ANOVA with management as the only factor, a significant difference was detected for the 0-10 cm depth interval, with mean BD for IM at 0.557 g/cm^3 ±0.03 and mean BD for EM at 0.699 g/cm^3 ±0.045. The top 10 cm of soil are most likely to be impacted by soil compaction resulting from varied management practices, and in this case, post-hoc Tukey HSD results supported that EM pastures were more compact in the 0-10 cm soil depth interval. Deeper soil layers (10-20 cm and 20-30 cm) were statistically similar (**Table 6**). Actual mean values for BD by depth and management can be seen in **Table 7**.

Table 5. Summary of 3 individual ANOVA's for bulk density by management type with data separated by depth interval (0-10, 10-20, 20-30). df is degrees of freedom, SS is sum of squares, MS is the mean squared, F is F-statistic and p is P-value. Bold values are significant ($p < 0.05$).

BULK DENSITY

	Depth	**df**	**SS**	**MS**	**F**	**p**
	0-10	1	0.211	0.211	5.836	**0.020**
Residuals		40	1.446	0.036		
	10-20	1	0.039	0.039	1.753	0.195
Residuals		33	0.727	0.022		
	20-30	1	0.002	0.002	0.169	0.684
Residuals		28	0.474	0.017		

Table 6. Mean values for Bulk Density (g/cm^3) by depth and management. Significant differences between BD by management are identified with an asterisk. n values represent sample size for each mean value calculated.

	Mean Bulk Density (g/cm^3)			
Depth Interval	**-IM-**	n	**-EM-**	n
*0-10 cm	**0.557**	23	**0.699**	19
10-20 cm	**1.077**	19	**1.164**	16
20-30 cm	**1.310**	17	**1.324**	13

Carbon Stocks

There was no significant relationship detected between TC stocks and depth, but there was a difference by management (Appendix C). There was also a significant interaction between depth and management (Appendix C). Post-hoc Tukey HSD testing revealed that TC stocks for the 20-30 cm depth interval tended to be greater under intensive management than extensive management ($p=0.071$). No significant relationships between SOC and either depth or management were detected. TC stocks averaged 6.63 t/ha (30.7%) greater under IM compared with EM. Mean TC stocks for IM pastures (**Table 8**).

Table 7. Summary table of mean data by management for TC, BD and TC Stocks. Sample size (n) for TC Stocks are equal to those for bulk density means found in Table 7.

	IM			EM		
Depth Interval	TC (%)	BD (g/cm^3)	TC Stocks (t/ha)	TC (%)	BD (g/cm3)	TC Stocks (t/ha)
0-10 cm	4.54	0.56	24.35	3.95	0.70	25.97
10-20 cm	2.94	1.10	32.16	1.95	1.16	21.61
20-30 cm	1.97	1.31	28.02	1.41	1.32	17.06
Mean	**3.15**	**0.99**	**28.18**	**2.44**	**1.06**	**21.55**

The estimated difference in carbon sequestration rate by management (and weighted by number of years practicing IM) across all six study sites was approximately 6.3 t C ha^{-1} yr^{-1} (TC) and 3.8 t C ha^{-1} yr^{-1} (SOC) (**Table 9**).

Table 8. TC sequestration potential across all six study sites under IM practices. Sequestration potential was calculated by dividing the difference between carbon stocks for each management type by the number of years under new management practices (IM). Mean values for all three soil depth intervals were added together to produce values in this table.

Ranch #	**t TC ha^{-1} yr^{-1}**
1	5.901
2	2.918
3	6.492
4	2.667
5	6.821
6	0.196
Mean	4.166

Soil Carbon and NDVI

NDVI explained 42% of the variation of logTC and 30% of the variation in logSOC under intensive management practices (**Figure 7**; **Figure 8**); whereas NDVI only explained 7% and 8% of the variation in logTC and logSOC, respectively, in extensively managed pastures (not shown).

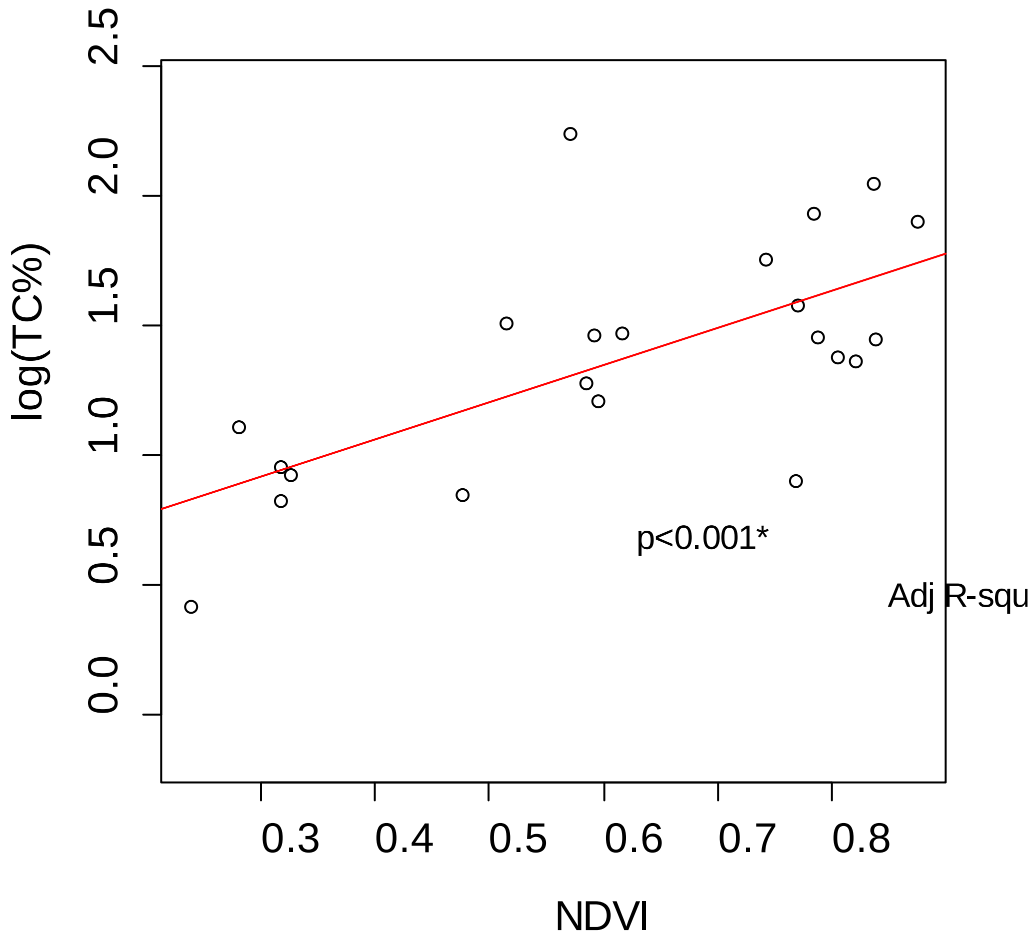

Figure 7. Regression for the natural logarithm of total carbon % for the 0-10 cm depth interval as a function of NDVI under intensive management.

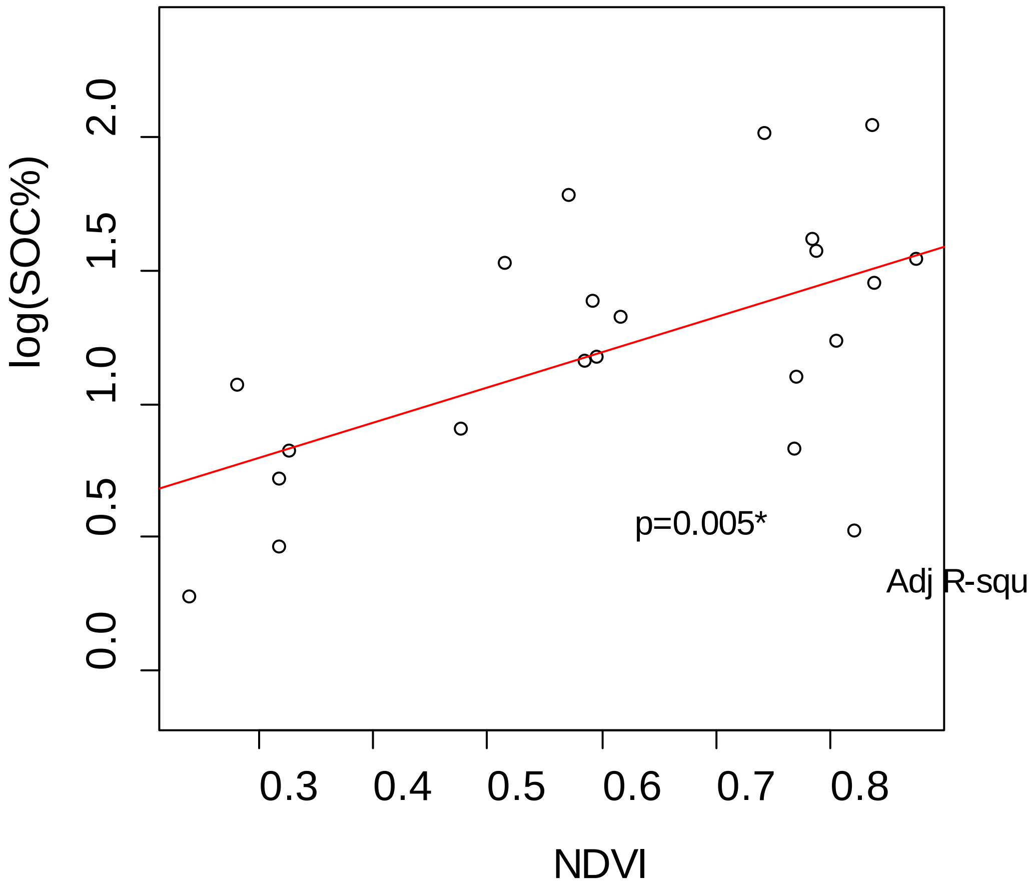

Figure 8. Regression for the natural logarithm of organic carbon % for the 0-10 cm depth interval as a function of NDVI under intensive management.

Carbon and Moisture Content

Under intensive management, moisture content (logMC) explained 15% of the variation in logTC (**Figure 12**), but there was no relationship between logMC and logSOC (p=0.1498). Under Extensive Management, logMC explained 26% of the variation in logTC and 17% of the variation in logSOC (**Figure 14**; **Figure 15**).

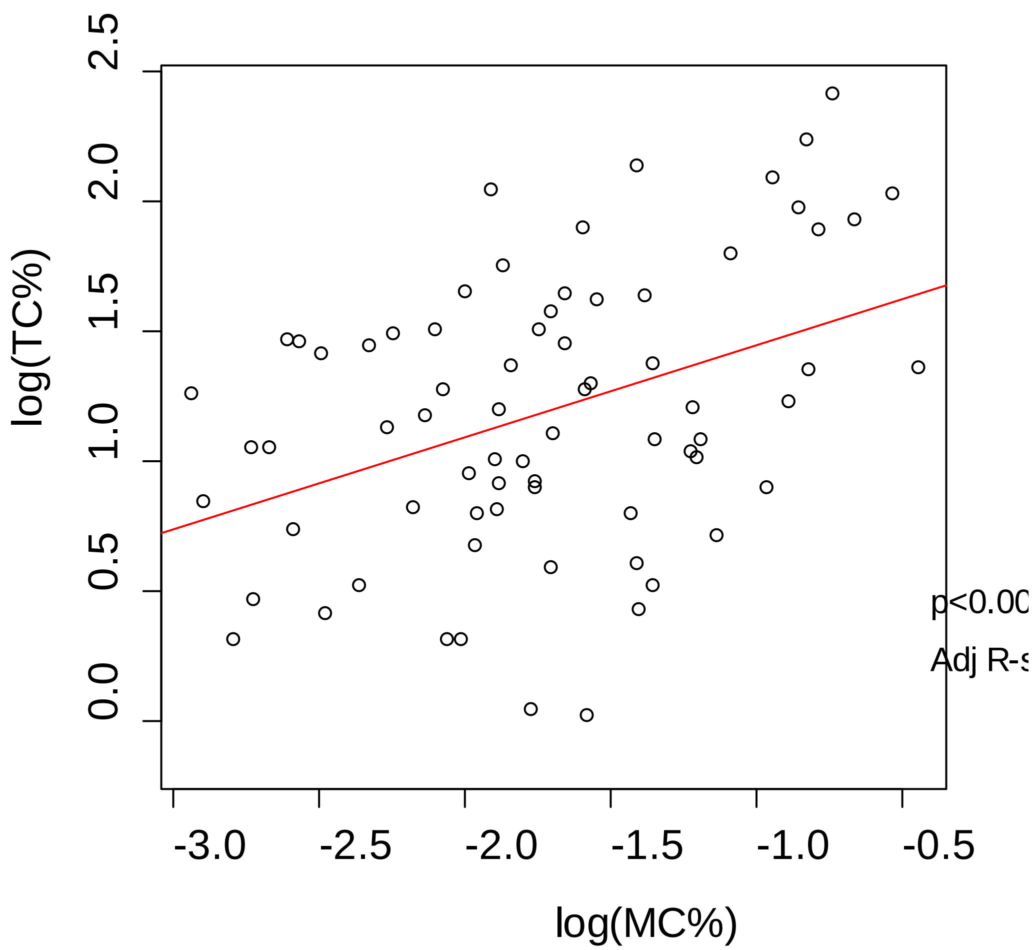

Figure 9. Regression for the natural logarithm of moisture content % as a predictor of total carbon % under intensive management.

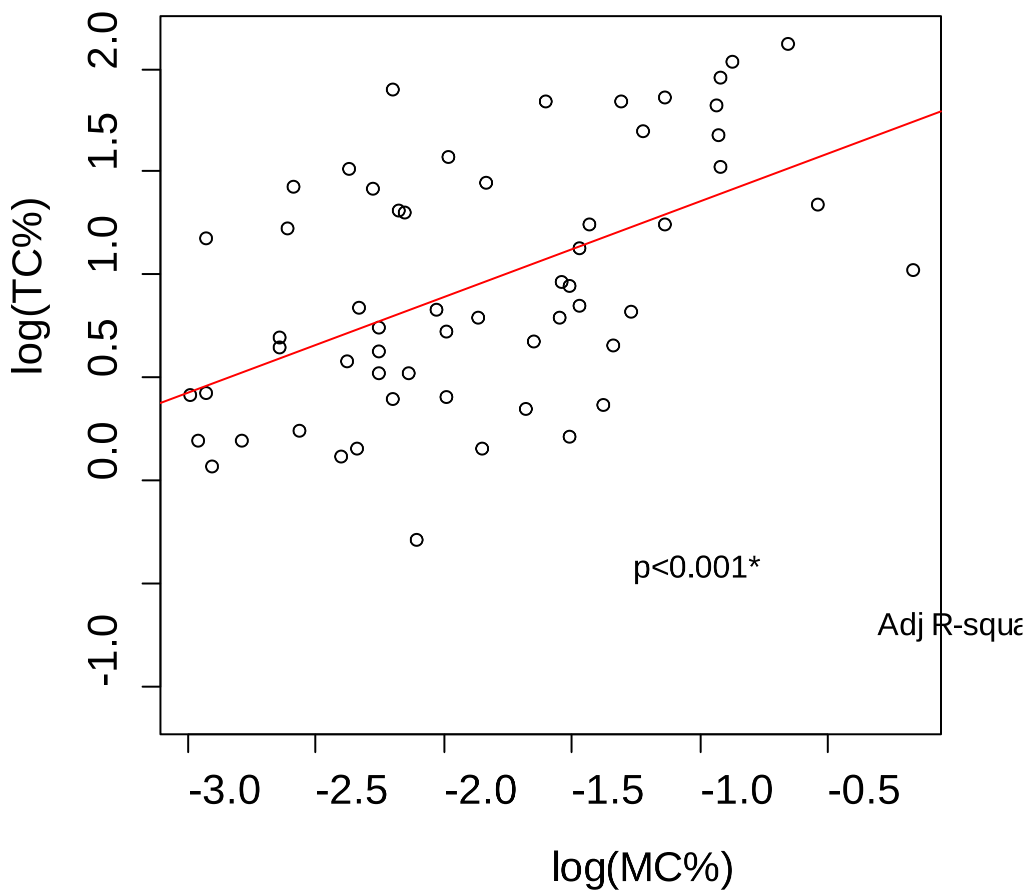

Figure 10. Regression for the natural logarithm of moisture content % across all depths as a predictor of total carbon % under extensive management.

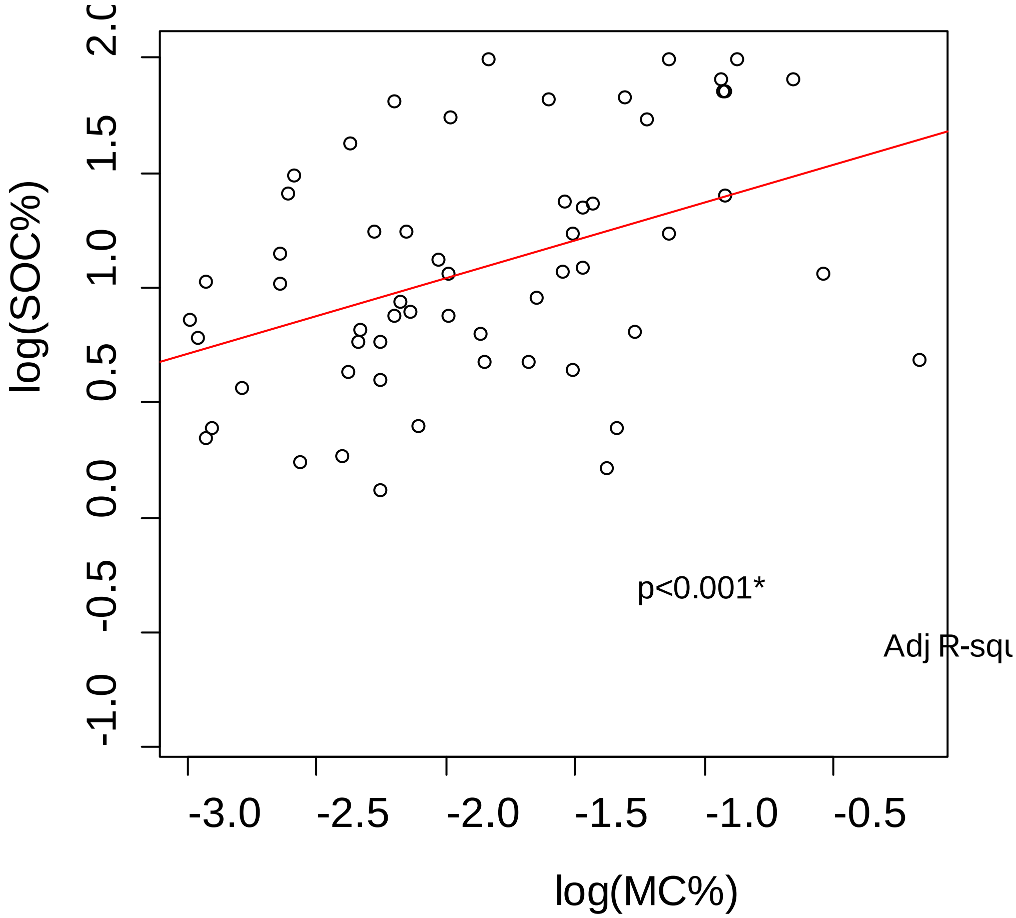

Figure 11. Regression for the natural logarithm of moisture content % across all depths as a predictor of organic carbon % under extensive management.

Species Diversity

Based on regression analyses, species diversity was not an effective predictor of soil carbon under either form of management examined in this study.

DISCUSSION

Soil Carbon (%)

Soil carbon did not vary significantly between 2013 and 2014, or by ranch location. This supported the grouping of data from both years and from all 6 study sites to increase the power of statistical results and reduce any impacts resulting from annual variations in soil carbon due to environmental conditions. It is possible that the reason for differences in soil properties by management type could be the result of preferential selection by ranchers. Perhaps the more productive pastures on a ranch are those first selected for conversion to IM over less productive ones (remaining under EM). This would mean that the reason for greater SC and productivity in IM pastures is not due entirely to management type, but rather was selected initially due to these inherent qualities. However, many ranchers indicated a desire to improve upon their lower productivity sites by bringing in more intensive management practices. Thus there is the potential for a pasture selection bias in both directions.

Similar to previous soil studies, our results indicated in that TC(%) concentrations were greatest at the soil surface and decreased with depth (Conant et al. 2001; Conant et al. 2003; Ziter and MacDougall 2014). Intensively managed pastures were found to have significantly higher TC(%) compared with extensively managed pastures. On average, across all depths IM pastures had 30.7 6.63 t/ha (30.7%) % greater TC by proportion than EM pastures. This difference refers to the percentage increase in carbon that may be attained through shifting management practices, as a means of comparison with similar studies, and does not refer to the actual percent elemental carbon concentrations found in the soils.

The results of Conant et al. (2003) were similar, as they found average SOC to be 22% greater in intensively managed pastures. However, it should be noted that this percentage is based on their results for SOC stocks, and ours are % carbon values. While our results for carbon stocks can be compared with other studies, the comparisons we make based on % carbon are more robust, as they are free from the influence of variable bulk density measurements used in the calculation of carbon stocks.

Contrary to our results, Ward et al. (2016) found intensive management to be associated with lower soil carbon levels than extensive management. Upon further examination however, it is evident that their definition of 'intensive management' was quite different from our own. The IM pastures in our study were generally managed in a holistic way, forgoing the use of chemical fertilizers in exchange for more natural forms of fertilization through animal waste and the associated nutrient cycling provided by hoof action/mulching of residual plant material. Furthermore, the use of heavy machinery to harvest forage also tended to be replaced with simply allowing animals to harvest forage crops. Other IM characteristics employed by cattle producers in our study included no till land use, efforts to improve species biodiversity, and irrigation to improve plant productivity. In contrast, Ward et al. (2016) considered intensive management to be much the opposite; use of chemical fertilizers, cutting grass with haying equipment, tilling, ploughing and seeding with only a few, fast-growing forage species. Thus, the results of Ward et al. (2016) appeared at first glance to be different because of their definition of intensive management, yet actually showed similar trends when the management actions were compared with our own rather than using designated title for each management. A significant challenge faced when interpreting existing literature can often be lack of consistency in defining terms, methodology used, and units of measurement being reported.

Sampling carbon from various soil depths allowed us to observe relative differences in carbon within the soil profile and make inferences about carbon sequestration. Decomposition tends to be reduced in deeper soil layers since there are fewer essential resources for decomposers, resulting in less biological activity and subsequent release of CO^2 back into the atmosphere (Chabbi et al. 2009; Silver et al. 2010). Since TC % was found to be significantly greater in IM pastures for the 10-20 cm and 20-30 cm depth intervals, improved levels of sequestration under IM were therefore supported.

Because there was no significant interaction detected between depth and management, we can consider their effects to be additive. The greatest carbon values can be expected under intensive management, in the most shallow depth layer (0-10 cm) and the lowest carbon values can be expected under extensive management in the deepest soil layer (20-30 cm).

Soil pit data further supported the hypothesis of greater carbon under IM, though the differences between management gradually disappeared around 50 cm. Soil pits ultimately provided more detailed understanding of soil carbon change with depth compared with soil cores, since samples were taken in 5 cm increments to a depth of 50 cm. Conversely, replication was much more thorough for soil cores; each study site having a minimum of 3 transects per management, with at least 5 representative cores per transect. This compared with only one soil pit per management type at each ranch location. This limitation was primarily because excavation of soil pits was highly invasive as well as labour-intensive. However, when carbon results from pits across all ranches were combined and compared by management type, the results quite clearly indicated a trend of greater carbon under intensive management.

Other characterization of soil properties was largely observational, though still directly related to comparison of soil carbon. In all cases, differences in soil properties were visibly apparent upon excavation (**Figure 12**; **Figure 13**).

Figure 12. Soil profile (left) extracted from a pit (right) in an intensively managed pasture at Ranch 6.

Figure 13. Soil profile (left) extracted from a pit (right) in an extensively managed pasture at Ranch 6.

Other parameters were also used to better characterize differences in soils. For instance, soil texture was measured, as well as the presence/absence of inorganic (secondary) carbonates using a mild hydrochloric acid solution. These factors were not measured for soil cores however, and were not included in statistical analyses.

Bulk Density

Similar to previous studies (Ingram et al. 2008), and as one would expect, we found bulk density increased with soil depth. Comparing between management revealed, however, that soils in the 0-10 cm depth interval were more compact in extensively managed pastures than IM ones. Soil compaction equates to less pore space, which is an important factor influencing soil health, since it facilitates the flow of water and nutrients through the soil, and provides conditions for healthy growth of both soil fauna and plant roots (Wolf and Snyder 2003). Since evidence from this study suggests an association between IM practices and decreased surface soil compaction, this form of management may be a means of improving water infiltration and promoting healthy soil development alongside microorganisms and plant roots.

Carbon Stocks

Pastures under intensive management had significantly greater TC stocks when compared to extensively managed pastures. TC stocks averaged 6.63 t/ha (30.8%) greater under IM compared with EM and this relationship was found to be statistically significant

Calculation of carbon stocks facilitated comparison of our results with those of similar studies, but the potential for varying bulk densities to influence carbon stock values should not be overlooked. Our results were similar to those of Conant et al. (2003) who found total SOC to be 8.4 t/ha (22%) greater in IM pastures compared with extensively managed areas.

The estimated annual total carbon sequestration rate resulting from improved management across all six study sites was approximately 4.2 t C ha^{-1} yr^{-1}. Conant et al. (2003) found the average 'treatment duration-weighted' estimate for rate of carbon sequestration to be 0.41 t C ha^{-1} yr^{-1} (SOC) under IM, with the highest rates observed being 2.9 and 2.7 t C ha^{-1} yr^{-1}. Our estimated rates of carbon sequestration increase are generally higher than those reported in similar studies (Wang et al. 2014; Ingram et al. 2008; Tennigkeit and Wilkes 2008; Lal 2004; Conant et al. 2003; Schumann et al. 2001). We attribute this largely to the way in which carbon sequestration potential was calculated. Most of the IM pastures sampled had been converted from IM relatively recently (<10 years). As supported by previous studies (Conant et al. 2003; Schumann et al. 2002; Conant et al 2001), the highest rates of carbon sequestration are associated with more recent shifts to IM practices, prior to the rate of increase leveling out, and eventually stagnating.

It should also be noted that the research of Conant et al. (2003) reported carbon stocks (and annual sequestration potential) based on carbon data to a depth of 50 cm, while this study assessed only the top 30 cm layer of soil. Based on this, our results might be expected to be lower than those of Conant et al. (2003). The fact that our calculated carbon stocks were higher despite having assessed only shallower soil layers is likely due to the contrast between IM and EM pastures observed at our study sites. Annual precipitation at our sites was roughly half that of the study sites in Conant et al. (2003), and irrigation was likely not used. At our study sites however, irrigation was often (but not always) used in IM pastures and sometimes not used in EM pastures, and a noticeable contrast between plant species composition and productivity levels between pastures under different management was often observed. This is also believed to have influenced the great difference in soil carbon levels observed between management types.

The potential for increasing carbon sequestration is greatest in pastures with lower initial carbon (FAO 2010; Jones and Donnelly 2004; Conant et al. 2003). This is because pastures that already sequester larger amounts of carbon require greater effort for a potentially smaller increase. Since this study has found a trend of significantly lower carbon levels in extensively managed pastures (compared to intensively managed ones) it is suggested that the greatest increase in carbon sequestration may be obtained by converting these pastures to more intensive management practices. Additionally, continuing intensive management in already converted pastures may continue to increase soil carbon until a plateau is reached, and then simply maintain higher levels of soil carbon.

Predictive Methods

The results of regression analyses comparing carbon with some of our predictive variables suggest that remote sensing could be used in the future to infer soil carbon levels in IM pastures.

NDVI

Similar to previous studies, our results showed a significant relationship between NDVI and soil carbon (Kunkel at el. 2011; Richardson et al. 2017). Kunkel et al. 2011 found NDVI to be the strongest positively correlated indicator of soil carbon, explaining 54% of the variation (based on R^2), while our results showed that NDVI explained 42% of variation in TC under intensive management. The results of Richardson et al. (2017) were based on models with NDVI as the main predictor variable, and explained 70-77% of the variation in soil carbon data. Our results were not effective predictors of soil carbon under extensive management, highlighting the importance of considering other influential factors in making predictions. Since EM pastures were much larger and grazed over longer time periods, these pastures had the potential for greater heterogeneity in NDVI due to grazing selectivity as well as differences in productivity and/or plant community. This heterogeneity in EM pastures may have caused increased variation (and coefficient of variation) in NDVI, making a relationship with carbon values more difficult to detect. Other factors such as aspect and elevation/moisture can influence soil carbon at a significant level. Kunkel et al. (2011) found North-facing slopes had up to five times greater soil carbon than South-facing ones, and carbon at the top of their observed elevation/moisture gradient was as much as ten times greater than at the bottom.

NDVI has the ability to infer plant productivity, which has been shown to be linked with soil carbon (Kunkel et al. 2011). Additional studies should be conducted to refine the link between NDVI and soil carbon before it is used for predictive purposes. Studies should make reference to influencing factors such as time of year in relation to the growing season and any prior defoliation events during the growing season.

Moisture Content

Significant relationships were detected between MC and TC. Moisture is generally the limiting resource for plant growth in arid environments (Ingram et al. 2008). In these areas, greater moisture has been linked with increased plant productivity and subsequently, soil carbon (Lal 2004). Although the relationships observed from our data are not enough to predict soil carbon levels from moisture content alone, these methods could be improved through controlled, manipulated studies that isolate the effect of soil moisture on carbon levels.

Species Diversity

Our study failed to find a significant relationship between species diversity and soil carbon, but other studies found support for a positive relationship (Lal 2004). It is possible that we could not detect differences in plant diversity because our study lacked controlled manipulations. The focus of our research was on the effects of management on soil carbon, and it was difficult to detect differences based on plant species due to the other dependent variables.

Climate Change Adaptation and Mitigation

The ability of ranchers to adapt to, and mitigate the effects of climate variability in the future is important for local food security and environmental sustainability. Improvements in soil carbon storage result in reductions in the volume of greenhouse gases (primarily CO_2) in the atmosphere (Lal 2004). As a result, carbon crediting programs can be developed to help encourage practices that sequester carbon in the soil (Lal 2004). Adaptation to climatic changes can come in the form of improved ability to cope with drought conditions as well as high precipitation events by increasing the moisture retention, stability and structure of soils. This is largely due to increased organic material in the soil, as well as improved plant cover and rooting (Lal 2004).

A rangeland's resilience to climate change is very difficult to place a monetary value on, which can be problematic since funding agencies and agricultural producers must often make decisions based cost-benefit analysis using dollar values. Furthermore, when it comes to climate change mitigation strategies, it is important to ensure that gains in soil carbon -resulting from changes in management- are not accompanied by increases in other GHG's such as methane (FAO 2010).

Limitations

Site-specific Conditions

Although several variables were compared between intensively managed pastures and extensively managed ones, it was difficult to isolate the effect of management alone on soil carbon. Significant natural variability exists between sampling transects and ranches alike. However, ranchers practicing IM placed utmost importance upon the improvement of soil health in pastures managed intensively and have observed noticeable improvements in plant productivity and soil moisture retention after switching from more traditional, extensive methods to intensive ones. Furthermore, strategies proposed that can be implemented to sequester more carbon in agricultural soils, which are also encouraged under the principles of IM include but are not limited to: reduction or elimination of ploughing, reduced erosion, increased irrigation (in moderation), increased organic inputs (decreased chemical ones) and improved biodiversity (Lal 2004).

The amount of time each ranch has been practicing IM is variable, as are the methods in which this form of management is implemented. Each ranch is unique in the resources that are available to it, as well as the land management goals that influence decision-making. Furthermore, soil and climate conditions vary geographically. Because of this uniqueness and inherent variability, it is important to note that there cannot be one single "right" way of doing things. However, from a broad perspective that encompasses the BC Interior, the results of this study indicate that more intensive management of grazing animals can contribute to higher levels of carbon than conventional, or extensive methods.

Labile Carbon

Labile carbon can be a sensitive indicator to changes in management (Weil et al. 2003; Breulmann et al. 2012) and provide detectable changes in the readily available or 'active' carbon fractions that are consumed by soil microbes. However, this carbon is less indicative of long term storage for the purpose of climate change mitigation. Future research could include labile carbon as a response variable to improve detection of changes resulting from management management.

CONCLUSION

Rangelands possess great potential for belowground storage of carbon. Tennigkeit and Wilkes (2008) estimated that improved rangeland management has the biophysical potential to sequester 1.3 - 2Gt CO_2 eq worldwide to 2030 (UNFCCC). Since atmospheric carbon dioxide is the most abundant greenhouse gas, capturing and storing it in the soil may help mitigate climate change. In other words, our rangelands offer promise and hope; but it requires improving the way we manage them. Improving the management of these ecosystems is a win-win scenario, as it can result in subsequent benefits to productivity, biodiversity, invasive species and erosion control (Paustian et al. 1997; FAO 2010; Silver et al. 2010) which are also assets when it comes to climatic change adaptation (IPCC 2014).

The main purpose of this research was to test whether the adoption of intensive management practices might be used as a tool to mitigate climate change through soil carbon sequestration and adapt to climate change by creating more resilient ecosystems alongside domestic grazing animals. Our research provided evidence supporting these hypotheses, as soil carbon was found to be significantly greater under intensive management practices. In particular, the higher levels of carbon found in deeper and more stable soil layers mean it could be more effectively sequestered (Chabbi et al. 2009). Finally, because pastures with lower initial carbon are known to have the greatest potential for improved carbon sequestration, adoption of more intensive management practices in extensively managed pastures can produce significant results. This information can serve as a valuable asset to BC's ranch managers trying to improve carbon sequestration and other ecosystem services associated with healthier soils.

This study also tested whether remote sensing methods or vegetation community could be used to infer soil carbon levels for more feasible widespread application of soil carbon estimates. Our findings showed a notable relationship between TC and NDVI, though more precise work can be pursued in the future to improve predictions based on this method.

Future Research

In addition to improving methods of soil carbon prediction with remote sensing and plant community composition, manipulated grazing trials should be undertaken to control for all variables other than the treatment to isolate the effects of grazing management alone. Furthermore, these trials should include specific examination of IM on drylands in the BC interior, since they compose much of the grazed lands. It is not likely feasible to irrigate or even fence these expansive areas in the way that IM pastures tend to be equipped with. However, if the results coincide with those from this study (comparing the effects of grazing management on soil carbon), and feasible methods for implementation can be recommended, the implications would be monumental. For one thing, much of these arid landscapes possess significant potential for large increases in soil carbon due to historical land degradation or simply moisture limitations to plant productivity (though additional water inputs may be required) and second, the areas are vast, which further adds to the potential effects towards climate change mitigation through carbon sequestration.

When planning and research are used to inform better management decisions, grazing can result in improvements to ecosystem services such as biodiversity, soil moisture retention, carbon sequestration and forage production (Conant et al. 2001; Conant et al. 2003; FAO 2010; Harrower et al. 2012; Ziter and MacDougall 2013). These benefits of good grazing management ought not to be ignored, and should be supported and implemented when suitable conditions exist. In the face of a changing climate, improvements to these ecosystem services would equate to greater adaptability for BC ranches.

Outreach and Education

A main component of the research was outreach to the community. Information and feedback was provided to local ranchers about different grazing management practices and the benefits that may result from improving the way we manage our lands. Throughout the life of this research project, education and outreach have played a significant role. There have been several poster presentations, informational workshops and tri-fold brochures have been distributed. This will be discussed in greater detail in chapter 3 – public perceptions and outreach.

CHAPTER 3: IMPLICATIONS, PERSPECTIVES AND CONCLUSIONS

INTRODUCTION

Sustainable land management practices should be informed by research and backed by scientific results. However, the capacity of decision makers to implement subsequent changes will influence overall feasibility of improved practices. In the case of grazing management, ranchers themselves are able to offer first-hand information from their own experiences (trial-and-error) and are in-touch with the land they manage. Ranchers observe the land responding to input variables and environmental factors year to year, season to season and often day to day, and can therefore provide operational insight and practical anecdotal knowledge to others in a similar situation.

With this in mind, and in parallel to my field experimental test of range management practices on soil carbon sequestration (Chapter 2), I conducted face-to-face rancher interviews, ran interactive producer workshops and presented my results to the local cattle producer community through multiple channels. Workshops served as a means of reaching out to local interest groups, providing them with information and receiving their feedback. The result of my research, interviews and feedback from the community was incorporated into multiple newsletter articles (Appendix D), an online website (https://grazingmgtandclimatechange.wordpress.com/research/management-intensive-grazing/), as well as an informational brochure (Appendix E) to communicate results and facilitate knowledge transfer. This research provides the first step for future feasibility studies involving intensive management practices in the BC Interior.

Rancher Interviews

Many agricultural feasibility studies focus on survey methodologies (Liu et al. 2014; Sorice et al. 2012) or semi-structured interviews (Vasquez-Leon et al. 2003; Wilmer and Fernández-Giménez 2015), and sometimes a combination of the two (Kennedy and Brunson 2007). In this study, it was important to develop a good relationship with the voluntary participants, understand historical land management practices, as well as their observations and views regarding their newly-adopted grazing management practices. This was best achieved through in-person, semi-structured interviews, where a list of the same questions was repeated at all six ranches. Although the repetition of questions was much like a survey, responses were not based on selecting from a pre-formulated list of responses. This allowed ranchers to go into as much depth with their answers as they felt comfortable with. Both historical information and opinion-based information was obtained from these responses.

A list of the interview questions repeated at all six ranch sites (described in Chapter 2) and can be found in Appendix H. The questions were subject to a human ethics review and acceptance (Appendix F). Consent to participate was also obtained prior to interviews (Appendix G). Conversations were recorded using a digital audio recording device. What follows is a summary of the rancher responses that ensures anonymity of all participants involved:

Ranch History

Five of the six ranch properties possessed hayfields that had traditionally been ploughed, seeded and fertilized in some form or another, and fields were irrigated where lack of precipitation significantly limited crop production (4 out of 6 ranches). After transitioning from more traditional practices to intensive management

(Management-intensive Grazing or holistic management) ploughing, seeding and/or fertilization has either been reduced drastically or discontinued entirely. Irrigation is still used at the more arid ranch locations.

Although four of the six ranches continue to produce hay, it typically remains on-site and is not sold. The general consensus of ranchers is that hay should be valued not just for cattle feed, but for the nutrients and organic material it can return to the land, or for remediating areas identified to have poorer soil quality.

Intensive management practices have been implemented anywhere from 3 to almost 30 years depending on the ranch and the individual pastures, while a few pastures at each ranch continue to be managed more traditionally (extensively) by comparison.

All ranchers interviewed are very actively involved and progressive when it comes to working to find more sustainable ways of managing the land. One rancher stated that “agriculture needs to be a knowledge-based industry” and this involves a lot of research, self-learning (through books and online sources), and attending/teaching workshops to continuously improve their ranching techniques. All six ranches have participated in one or more of the following initiatives: Healthy Steppes (in partnership with TRU and Jim Gerrish), Ranching for Profit, Executive Link, and multiple workshops that accompanied this ranching study.

Landscape Change

All of the ranchers interviewed consistently observed an increase in plant productivity and biodiversity, soil moisture retention (erosion control/drought resistance) and health. Furthermore, all ranchers have observed a decrease in bare ground, leading to better interception of water by plants, decreasing erosion and runoff. As one rancher clearly stated: “water quality has benefitted” (all of the other ranchers are in accordance with this).

Management Impacts on the Soil

Interviews at all five ranches showed consensus on the observation that better management has led to significant improvements in the biological activity of soils. Specifically, observations such as “thicker soils”, and a greater presence of invertebrates (worms, dung beetles, etc.); in general, that “more life can be found in the soil”. In many cases, ranchers believe that soil biological activity has benefitted from the lack of chemical fertilizer use, as well as antibiotics/parasite drugs such as IVOMEC®. One rancher also indicated that soils are noticeably more porous (even over the timespan of a single year), and the pigtails for portable electric fencing have become easier to drive into the soil.

Some ranchers also noticed a decrease in soil erosion and more (thicker) cover of grasses and forbs (clover, alfalfa, etc.). In terms of perceptions regarding carbon sequestration, responses were slightly more variable. It was indicated that since productivity appears to have increased, one would *expect* carbon storage to follow suit, though they would like me to provide scientific evidence of this. It was also suggested that carbon sequestration may not be increasing at all, due to compensatory effects through increased decomposition rates occurring under the current management practices.

Management Impacts on Ecosystem Services

In general, most of the surrounding ranches continue to practice extensive grazing practices such as continuous grazing or rotational grazing, where cattle have free range over large pastures for at least one month at a time. Quite often crown range is utilized starting in the spring, and then cattle are brought back to the ranch to graze hayfields in the fall. Although these practices can be thought to deteriorate the land, it's not in their best interests to continuously degrade the land. Despite this, it was commented that ranchers who look after their land well (improving it rather than just perpetuating it) are still quite rare in the BC Interior.

Social, Environmental and Economic Impacts

Many of the ranchers refer to their current grazing practices as a form of holistic management, and as one rancher put it, this in itself means managing for all three aspects (social, environmental and economic).

All of the ranchers agreed that the public interest in grass-fed, hormone and antibiotic-free (aka: 'healthy') food sources is on the rise, and this can sometimes be accompanied by a greater concern for environmental impacts of food production. For this reason, the intensive management methods used by ranchers interviewed can be expected to be more beneficial socially, as they tend to address these concerns. It was also mentioned that the social benefits go beyond just providing healthier food sources, to include helping the people around you, in your community and through other interactions. One example of this is the practice of increasing the amount of cattle that are finished in the summer, spring, etc. in order to provide more consistent supply to buyers, instead of all at once in the fall.

All ranchers interviewed indicated that their current management practices are more sustainable economically now than in the years prior to management changes. In particular, most ranchers have followed the simple formula of decreasing inputs while maintaining or increasing productivity. As one rancher put it, "this system is less capital-intensive, more management-intensive". For example, inputs such as machinery and fuel for haying, fertilizer, seed, etc. have all been significantly reduced if not eliminated at most ranches, though more actual time is spent actively managing cattle.

One rancher indicated that beliefs with respect to their relationship with the land play an important role in the recent change towards intensive management, though economics are still the driving factor.

There was also mention that improved practices have led to a noticeable decrease in the presence of invasive species, with the abundance of some having decreased by up to 90% in places. Other observed or expected environmental benefits are discussed in greater detail farther along.

Existing Methods and Literature

Jim Gerrish visited most of the ranches, and the majority of the ranchers have read at least one of his books (Gerrish 2010, 2004). Many of the basic principles outlined in Jim's book on Management-intensive Grazing are being implemented at the ranches, as well influences from other known proponents of intensive management styles including Alan Savory and Kathy Voth. However it was stated by the ranchers that many practices work well in theory, but need to be "tailored to the local conditions" of each ranch.

Basic principles discussed by Gerrish such as leaving generous amounts of residual plant matter (1/2 to 1/3 in most cases), distributing waste and even grazing through concentrated use, electric fencing methods, encouraging plant diversity (use plants adapted to environment), and using cattle to harvest hay rather than machinery, are implemented by the ranchers interviewed to varying degrees.

Most, if not all of the ranches have significantly reduced how long they need to feed cattle hay over the winter by following another one of Gerrish's principles of letting cattle graze 'stockpiled' forage that is still standing. In general, feeding hay has been reduced by approximately 2 months to 4 months or less in which cattle must be fed hay. Furthermore, this hay is typically fed by 'bale grazing' rather than being spread out in a pasture. In this way, the residual hay, manure etc. can significantly improve conditions for plant growth where these bales have been placed.

Another tactic suggested by Gerrish and mentioned by several ranchers, is that if possible, it's beneficial to bring in more animals in the spring, summer and fall, when plant growth is high and reduce numbers in the winter. This takes advantage of surplus growth, while reducing the amount of feed required when resources are scarcer. Additionally, it was mentioned that it's okay if cows lose some weight in winter, that's normal. They do not need to be kept fat year-round, and this practice can be wasteful.

Strategies for Healthy Plants, Soil and Animals

Two very common strategies being used are to leave generous amounts of residual plant matter, and to ensure adequate plant recovery. The first strategy generally depends on only grazing the top 1/3 (and in some cases top 1/2) of plants. In general, it seems as though the top 1/3 is both highly palatable to livestock, and the remaining vegetation (residual) can be worked into the ground by hooves. This 'mulch cover' is credited with promoting both water retention and biological (microbial) activity. Furthermore, this method is a means of keeping plants in their vegetative stage (stage 2) which is believed to be the stage of maximum plant growth and productivity. The second strategy of ensuring adequate plant recovery recognizes that plant health is better off when they aren't re-grazed before having a chance to recover.

In general, the ranchers all agree that they avoid doing anything that would harm or deteriorate the land, and focus on building soils, improving biodiversity, using less stored feed, increasing moisture retention and nutrient cycling, etc.

Climate Change Adaptation

Several benefits of intensive management improving a rancher's ability to cope in a changing climate were communicated during rancher interviews. All six ranches believe that this type of management is a practical tool for controlling the spread and vigour of invasive plant species, since cattle are concentrated in an area and will graze all plants equally (rather than avoiding less palatable species, which are often the invasive ones).

All six ranchers believe that the benefits to soil health including increased organic matter help the soil hold onto moisture longer, "like a sponge". One rancher stated that they would "cope better than their neighbours in a drought year", and this sentiment was shared by the other ranchers in this study. One rancher stated that "the 1st main benefit of increased carbon storage is climate change mitigation while the 2nd is complementary retention of water".

Improvements to plant (and sometimes animal) biodiversity are also supported by all ranchers in this study. Biodiversity is widely accepted in the academic communityto help maintain healthy, productive ecosystems during climatic changes, because while some species may not be able to cope with the change, the diverse community is likely to possess some that will.

The flexibility of electric fencing, and actively managing cattle on a daily basis was also identified to be an adaptation strategy, since a rancher is able to adapt his or her practices based on conditions which vary from one year to the next (weather patterns, pest outbreaks, economic variables, etc.).

Additional Insight Provided by Ranchers

- It's important to adapt your practices to ones that make logical sense. For example, if you calve later in the year, you don't have to feed high value hay in winter.
- Beef production should take a "value chain approach" not just a "production chain approach". Every person needs to make money in this system, though in the more traditional system, all profits seem to go to the retailer now, and very little goes to the producer unless you can market the value of your product, or even get it to retail on your own.
- Holistic management depends on an understanding that everything is connected and changing one thing affects other things.
- Biological decomposition occurs at the soil surface and chemical decomposition (oxidation) occurs with standing litter.
- A lot of government subsidies are currently directed at things that don't address the 'root of problems' (subsidies for fuel, pesticides, etc. rather than improved methods).
- A rancher needs to "fit the enterprise to the land, not the land to the enterprise". In other words, it's important that we understand the capabilities of the land, and adapt our practices to reflect these capabilities, rather than

imposing our own preconceived notions of what we want our business to look like.

Education and Outreach

There is often a disconnect between those who conduct research and those who can most benefit from the scientific findings of that research. For this reason, a strong emphasis was placed on bridging this gap through various forms of education and outreach. Information from rancher interviews and preliminary scientific findings were presented at several public workshops, seminars and field-tours. These events not only engaged the public and the ranching community, but allowed them to provide valuable feedback, furthering the research process.

One workshop in particular (held September 8, 2015) provided significant feedback from a very diverse group of ranchers, interested individuals, government employees and NGO representatives. In total, 25 individuals attended the workshop, 60% of which were ranchers and 40% were not (most of these were government employees). Of the ranchers in attendance, about 50% currently practiced IM on their ranches, while the other half did not.

The workshop began at the Thompson Rivers University (TRU) Williams Lake campus where we conducted the indoor portion of the workshop. Initially, I provided the group with background information on the principles of IM. Later we divided into 3 smaller groups, each of which tackled a set of questions based on one of three categories; Economics, Ecosystem Services and Climate Change. This was followed by a short group discussion and a catered lunch. Afterwards, the group reconvened at a nearby ranch in 150 Mile House (Clint and Karen Thompson's, *San José Cattle Co.*) to participate in a field tour. During the tour, I demonstrated the sampling procedures used in my research comparing soil carbon levels between IM and EM, including a transect line for soil carbon sampling, and a soil pit which I used to identify different soil horizons and properties important to the study of soil health.

The primary objectives of the workshop were as follows:

i. Determine which principles of grazing management are practical and effective in our region, and which require modification (based on different climates and conditions)

ii. Tie all of this together from a climate change adaptation and mitigation perspective, and

iii. Develop the framework for a document guiding effective and sustainable ranch management in the BC interior.

Objectives: Principles of effective grazing management

Those present indicated that the main reasons IM ranchers had made the switch were as follows: 1) to be profitable; 2) greater productivity on same land-base; 3) improved forage quality and growth; and 4) long-term sustainability, including reduced dependency on mechanical equipment and fuel. Ultimately, the ranchers concluded that regardless of the name placed on a particular management style, the mission statement for a successful ranching operation should be *"to be profitable and sustainable, with healthy plants, animals and soil while maintaining a rancher's passion and personal well-being for their lifestyle*."

Ultimately, the need for education was in the forefront throughout the workshop. Not only for the ranching community, but also for those who can and should be supporting local ranchers who put in the extra effort to raise animals in an ethical and sustainable way. Furthermore, it was highlighted that being a successful rancher ought to be a continual learning process. Like any other industry, things are constantly changing and new technologies and information is being made available. It is therefore important to continue the pursuit of knowledge and try new things rather than simply always doing things in the same traditional ways. This continued learning is why most of the ranchers and non-ranchers took time out of their day to attend this workshop and learn more about the potential benefits of intensive livestock management.

While IM was widely believed to help increase soil carbon, offering the potential for ranchers to participate in carbon trading/crediting programs, water management was identified as a key limitation to achieving this. These concerns focused mostly on BC's vast and arid rangelands, where water is limited both for plants and cattle. In many of these areas, irrigation could boost plant productivity and water provisioning would be needed for cattle to thrive, requiring infrastructure that does not currently exist. The costs and benefits of these developments in a given situation would ultimately have to be weighed. However, many workshop attendees indicated that developing irrigation, and intensively managing cattle could create a feedback loop wherein initial soil carbon increases could improve moisture retention in the future. It was also suggested that water loss might be reduced by incorporating trees and shrubs to form 'windrows', reducing evaporation and transpiration that results from exposure to sun and wind.

Another principle of IM which was identified to have some inherent limitations was based on matching herd size to the level of plant productivity. In other words, increasing herd size during peak plant productivity, and reducing herd size when forage becomes scarcer. This herd number flexibility was identified to sound effective in theory, but may be difficult to implement effectively in the Central Interior.

Yet another perceived limitation to IM in the BC interior was the high input of labour. Although several other input costs (haying equipment, fertilizer, etc.) may be reduced by implementing this form of management, it is also important to consider the cost of labour involved in the day-to-day operations of managing cattle intensively. Ultimately, intensive management can be a full-time job, and potentially the sole source of income for a rancher. However, the point was also raised that by working closely with the cattle on a daily basis, there is the opportunity for much greater control over the impacts of cattle grazing on plant health (leaving residual growth, allowing plant recovery time, etc.). Furthermore, it is an effective means to monitor animal behaviour and health quite closely.

Objectives: Climate change adaptation and mitigation

From a climate change perspective, several strategies were discussed that may increase a rancher's ability to adapt and be more resilient to changes. Many of these strategies are linked to IM practices, including bale grazing to increase organic matter on less productive sites (increasing nutrients and moisture retention), managing invasive species using high stocking densities (mob grazing), stockpiling forage to reduce the amount of hay fed during winter months, and increasing biodiversity of plants and animals.

Objectives: guiding sustainable ranching in BC

To continue encouraging sustainable, science-based land management, it was suggested that events such as this continue to occur within the community, with additional focus directed towards educating the younger generation of future ranchers. Based on the results of this workshop, and the findings of this study, I produced an informational brochure and made it available at local events and businesses. Now that the brochure is complete, there is still the need to continue research on the impacts of grazing management on soil carbon (as this relates to climate change adaptation and mitigation). To obtain more definitive results, the next step for this research project is to initiate controlled grazing trials that will help isolate the effects of grazing management on soil carbon. However in order to achieve this, we are looking for ranchers who would be interested in collaborating with us. This will require commitment on both sides, as we would be asking ranchers to alter the way they might normally graze their land.

DISCUSSION

Ranchers identified noticeable changes in vegetation cover, productivity and biodiversity as well as improved soil health and moisture retention. Resulting reduction and/or control of erosion on sloped sites is important for maintaining soil carbon stocks (Lal 2004). Furthermore, inputs that are shown to decrease soil carbon such as tillage and repeated removal of biomass without any replacement (Lal 2004) have been reduced or eliminated. Other inputs that have the potential to hinder soil health and biodiversity include the use of chemical fertilizers, pesticides and antibiotics (Lal 2004) have also been reduced or discontinued. The decreased use of farm machinery also offers increased independence of ranchers from the oil and gas market which can be unpredictable.

Several ranchers indicated that a side-benefit of intensive management is that a rancher tends to see his herd regularly (often daily) and can therefore monitor the health of his animals more effectively. In addition to this, it was indicated that if a pasture is accidentally overgrazed (which is bound to happen occasionally), the area impacted is comparatively much smaller under intensive management. In other words, perhaps only an area of 1 or 2 acres will be negatively impacted by an overgrazing event, instead of a much larger pasture.

Limitations

While the study of working ranches and first-hand accounts of perceived changes is representative of conditions on the ground, it provides limitations through lack of control and manipulation. In this study, it was difficult to isolate the effect of management alone due to the influence of several other variables on soil properties (primarily carbon). Because of this, future research should focus on more long term, controlled manipulation plots to better isolate the treatment effect (management intensity) from other influential variables and natural variation in soil properties across the landscape. Local ranchers have already shown interest in becoming involved in such studies. Long term monitoring studies (greater than 2 years) would help provide more definitive results for the effect of grazing management on soil carbon levels, reducing the influence of annual variations in soil carbon due to climate and other factors.

CONCLUSION

In Chapter 1 we discussed the pressing issue of climate change and the need for adaptation and mitigation strategies if we hope to sustain ourselves into an uncertain future. Then, in Chapter 2 we focused specifically on whether improved grazing management could be one of these strategies. In particular, the ability to increase soil carbon through intensive management, sequestering atmospheric CO^2 and improving other ecosystem services (e.g., moisture retention and biodiversity) and ultimately, resilience to climatic changes. Finally, in this chapter we used feedback from the ranching community to determine the feasibility of implementing improved grazing management in the BC Interior, and discussed the importance of education and outreach to communicate scientific results and encourage ranching as a knowledge-based industry.

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User's Manual:

Multispectral Radiometer (MSR) User's Manual. Cropscan, Inc. Copyright 1992-2001. 1932 Viola Heights Lane NE Rochester, MN 55906.

APPENDIX A – Transect site descriptions and plant community

Date	Ranch	Pasture	Slope (°)	Aspect	Elevation (m)	Lat	Long	Bearing (°)	Curvature	Bare ground/rock (%)	Litter	Kentucky bluegrass	Timothy	Orchardgrass	Reed canarygrass	Redtop	Quackgrass	BBWG	Brome ssp.	Rough fescue	Fescue ssp.	Foxtail barley
2014-09-10	4	TH02	1	W	660	52.0363	-121.914	90		1	10	15			5	10	10					
2014-09-10	4	TH04	2	W	663	52.0406	-121.915	105		0	10	30	25		40	20	10	5				
2014-09-10	4	TH06	0	E	678	52.0457	-121.91	305		0	15	40			20		30					
2014-08-22	4	TH08	0		607	52.0347	-121.892	80	flat				85		10	1	2		5			
2014-08-22	4	TH09	0		705	52.0358	-121.884	80	flat				35		40	5						
2014-09-10	4	TH12	0		717	52.0486	-121.9	55	convex	5	7.5	50							5			
2014-09-10	4	TH13	0		765	52.0459	-121.691	350		5	10	60			10							10
2014-09-10	4	TH14	5	NW	761	52.0517	-121.892	72		5	12.5	50			5				1			
2014-08-19	1	ZI01	0		688	52.5038	-121.861	230	flat	0	20	15	5	40					15			
2014-08-19	1	ZI02	0		669	52.5103	-121.874	145	flat	0	0	1	2		90	10						
2014-08-19	1	ZI03	3	NE	661	52.5086	-121.876	190	flat	0	10	2	5	50	1	5			5			
2014-08-19	1	ZI04	1	N	683	52.5368	-121.93	185	flat	5	10	45		35	5	2	10					
2014-08-19	1	ZI05	0		684	52.5369	-121.932	347	flat	1	0	30	5	15		1						
2014-08-19	1	ZI06	2	NNE	672	52.534	-121.93	118	flat	0	0	35	5	35	5	5			5			
2014-08-26	5	HU01	1	E	551	51.9239	-122.292	45	flat	15	10	8										
2014-08-26	5	HU02	0		586	51.9212	-121.302	203	flat	1	5											
2014-08-26	5	HU04	1	ENE	550	51.9146	-122.306	180	flat	15	25	10		30					20			
2014-08-26	5	HU05	0		550	51.9068	-122.314	217	flat	30	20	2		25			5		10			
2014-08-26	5	HU07	0		556	51.9084	-122.317	80	flat	5	25	30		25			5		35			
2014-08-26	5	HU08	5	E	556	51.9084	-122.317	0	flat	15	20	25		2								
2014-08-26	5	HU09	2	E	551	51.9005	-122.321	85	flat	10	15	10		15			1		2			
2014-08-28	3	BA02	0		803	52.1048	-123.659	228	flat	0	0	5	50		30							
2014-08-28	3	BA03	0		749	52.1084	-123.666	150	flat	0	0			5			5		65			
2014-08-28	3	BA04	0		807	52.0942	-123.649	215	flat	0	25	30	40				10					
2014-08-28	3	BA05	0		805	52.0944	-123.653	264	flat	0	15	30	35				25		3			
2014-08-28	3	BA07	0		807	52.0884	-123.639	230	flat	5	10		45			5						
2014-08-28	3	BA08	0		810	52.095	-123.646		flat	0	5	75	5				4		1			
2014-08-28	3	BA09	0		809	52.1018	-123.651	249	flat	0	0	5	40	2			1		2			
2014-08-13	6	GU01	0		657	50.2649	-120.447	145	flat	0	0		20	30	5	1	20		30			
2014-08-13	6	GU02	0		642	50.2678	-120.449	95	flat	10	0	35		20			25		10			
2014-08-13	6	GU03	0		627	50.2577	-120.449	275	flat	0	0				10		75					
2014-08-14	6	GU04	0	ESE	667	50.2729	-120.411	195	flat	30	15							50		15		
2014-08-14	6	GU05	6	NE	706	50.2552	-120.428	327	flat	50	15							30		1		
2014-08-14	6	GU06	2	SSE	733	50.2513	-120.436	347	flat	60	5						2	20				
2014-08-13	6	GU07	0		638	50.2626	-120.448	283	flat	1	5	25	2	20			55					
2014-08-20	2	KR01	0		820	52.3587	-121.432		flat	0	3	30	40	10								
2014-08-20	2	KR02	0		838	52.3525	-121.43	213	flat	0	10	15	55	5								
2014-08-20	2	KR03	0					95	flat	0	5	70	20		5	1			15	1		
2014-08-20	2	KR04	0		836	52.3487	-121.431	225	flat	0	15	10	5	10		5					25	
2014-08-20	2	KR05	6	ENE	825	52.3557	-121.423	50	flat	0	10	20	30	1	15	5	5				3	
2014-08-20	2	KR06	0		823	52.349	-121.422	100	flat	0	2	10	5	15	2	5						

Sandberg's bluegrass	Squirreltail	Junegrass	Needle and thread	Crested wheatgrass	Spangle top	Yarrow	Dandelion	Cinquefoil	Yellow salsify	Silverweed	Alfalfa	Clover	Buttercup	Pussytoes	Strawberry	Mustard	Plantain	Sedge	Rush	Mint	Aster	Horsetail
						2	1		5		50	1										
							2					10						20				
							2		5		15	5										
												1							1			
												3						20	10			
						5			40	1				3								
	10					20			20	1		1					1		1		5	
		10				3			10	1	2			10					5		1	
							20				20	5										
							1										1			1		1
						1	30				12	5			1							
							1				1	5	1				1					
						1	35					20	2				10					
							2					20			1		1					
			45	1					1		1			3								
				90													2					
											10											
				20							1					1						
				2							2						1					
											45											
							1				60											
							5				1	11						5	2			
							5				15	15										
							15	1				10							1			
							8	1			1	8										
								1				10			1			30	10			
							5	1				20					1					
							30				30	4					1					
							1			1	1	1	1			1		1	3			
									1		5	1				1						
										1	1	1						10	5			1
		10				1			1		1			1								
1		5		1		1								1								
		3		15		1			1					1								
							1		1		2	1										
							8					20	1									
							15					25										
						1	5				1	2	1									
						1	3					8	1		25							
						3	3	8				5			10							
						1	2					5	1		20							

Daisy	Hawkweed	Field chickweed	Curly dock	Burdock	Knapweed	Rattlebox	Cow parsnip	Shepherds purse	Parsnipflower buckwheat	Field peppergrass	Pasture sage	Rabbitbrush	Desert parsley	Thistle	Cactus	Primrose	Black medic	Bedstraw	Lamb's quarters	Locoweed	Purple peavine	Thimbleberry	Old man's whiskers	Common groundsel
1											2													
			1																					
														3										
											2													
											5							5		5				
						1										1				1			1	
																		1						
2																		1						
1				1																				
1		1					1	1																
1				1			20															1		
											15				1									
																			1					
																					1			
								1																
																					5			
																								1
2					1						1	1												
3										1	1	10												
2									1	1	5	4	1		1									
														1			1				1			
														2										
1	5																							
1														2										
2	40													1				1						

Night flowering catchfly	Giant wild rye	Unknown	Willow	Aspen	Lodgepole pine	Rose
				20		
			1			
					1	
		1				
					1	
					1	
		1				
	1					
1						
		5			5	
					1	
					2 3	

APPENDIX B – Soil pit data sheets

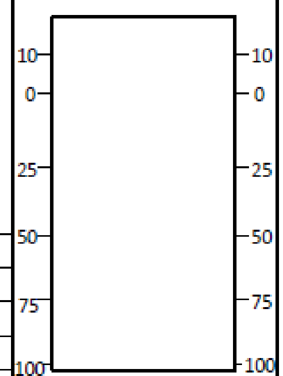
Surveyor(s): ______________ Ranch: ______________________________ GPS Coordinates of soil pit: ___________________________________

Date: _______________________ Weather: _______________________ Other notes: ____

1	2	3		4		5							6	7								8	9				10
HORIZON DESIG	HORIZON DEPTH cm	HORIZON THICKNESS cm		HORIZ BOUND		COARSE FRAGMENT DESCRIPT.							SOIL TEXTURE	STRUCTURE								MST	CONSIST.				Soil Sample Numbers
							Gravel <7.5cm		Cobbles 7.5-25cm		Stones >25cm		<2mm	PRIMARY				SECONDARY									
		MIN	MAX	Dist	Form	% By Vol	%	Type	%	Type	%	Type		GRADE	CLASS	KIND	MOD.	GRADE	CLASS	KIND	MOD.	DMW	Dry	Moist	Wet	Plastic	

1	11						12							13							
HORIZON DESIG	COLOUR 1			COLOUR 2			MOTTLES							ROOTS 1				ROOTS 2			
	Aspect	MATRIX HUE VALUE/ CHROMA	MUNSELL COLOUR NAME	Aspect	MATRIX HUE VALUE/ CHROMA	MUNSELL COLOUR NAME	AB	SI	CO	Aspect	COLOUR		BOUND DIST	AB	SIZE	ORI	DIST	AB	SIZE	ORI	DIST
							FCM	FMC	FDP		MOTTLE HUE VALUE/ CHROMA	MUNSELL MOTTLE COLOUR NAME	SCD	VFPA	VFMC	VHOR	IN EX MX	VFPA	VFMC	VHOR	IN EX MX

1	14			15							16	17			18	19							20	21							
	pH			PORES							HOR POR	CLAY FILMS			EFF.	SECONDARY CARBONATE DESCRIPTION							SAL	CONCRETIONS, NODULES AND CASTS							
HORIZON DESIG	pH Value	Reaction	Method	Ab	Size	Ori	Dist	Cont	Mor	Type		Freq	Thi	Loc	Deg	Cont	Ab	Size	Shape		Consist			Kind	Ab	Size	Loc	Shape	Aspect	COLOUR	
																			Str	Spo	Moist	Dry								HUE VALUE/ CHROMA	MUNSELL COLOUR NAME
				VFPA	VFMC	VHOR	IN EX MX	CO DC	SDC	VIT	SMH	FCM CS	TN MTK TK VTK	0 to 8	VW W M S	0 to 9	FCM	FMC	VHR	ROI			WMS	1 to 11	FCM	FMC	123	SOIP			

1	22			23							24	25		26
HORIZON DESIG	CEMENT			ORGANIC MATERIAL DESCRIPTION							COMMENTS	SOIL TEMP		SOIL PROFILE
	Agent	Degree	Extent	Material Composition	Woody Material				Pyro Index	von Post	Parent Material 1: Parent Material 2: Landform: Humus Form: Gleying Depth: Rooting Depth: Water Table: Soil Order: Great Group: Sub Group:	Depth cm	°C	
				Kind	Kind	Decom	Hard	Vol						
				1	2	N S M H	S SH H VH	0 1 2 3 4						

APPENDIX C – Statistical analyses

Summary of three 1-way ANOVA's for TC by management when each depth range was analyzed separately. df is degrees of freedom, SS is sum of squares, MS is the mean squared, F is F-statistic and p is P-value. Bold values are significant ($p < 0.05$)

			TOTAL CARBON			
	Depth	df	SS	MS	F	p
	0-10	1	0.475	0.475	1.888	0.174
Residuals		75	18.871	0.252		
	10-20	1	2.299	2.299	12.777	**>0.001**
Residuals		68	12.238	0.180		
	20-30	1	0.152	0.152	8.174	**0.006**
Residuals		63	11.705	0.186		

Total carbon sequestration potential across all six study sites under IM practices. Sequestration potential was calculated by dividing the difference between carbon stocks of IM and EM pastures by the number of years since new management was adopted. Mean values for all three soil depth intervals were added together to produce the values in this table

	TC Stocks				
	df	SS	MS	F	p
Depth	2	0.702	0.351	1.772	**0.175**
Management	1	1.538	1.538	7.764	**0.006**
Depth x Management	2	1.236	0.618	3.120	0.048
Residuals	101	20.013	0.198		

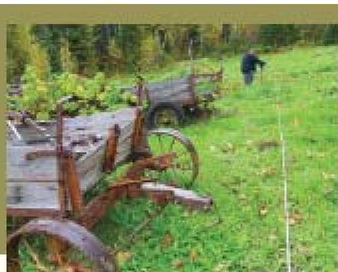
APPENDIX D – Newsletter articles

ARTICLE

Grassland Research

Can Carbon Trading Improve the Economic

SUSTAINABILITY OF RANCHING?



During fieldwork last fall, Lorena Tillotson and I had the privilege of working at several ranches throughout the Cariboo-Chilcotin and Thompson-Nicola regions of B.C. We were studying how grazing influences soil carbon pools in grasslands.If we could show that certain grazing management programs enhance soil carbon storage, then perhaps this could be used by ranchers to improve the health of their range and even to provide funding through carbon offsets.

Story by Dan Demestuk, MSc candidate Thompson Rivers University, Kamloops, B.C.

Photos above: Dan Demestuk taking soil samples

Management-intensive Grazing and Soil Carbon in BC

The ranchers we visited were very welcoming, inviting us into their homes, offering comfortable places to sleep as well as delicious home-cooked meals. The ranches themselves were selected for two important reasons. First, they currently exhibit a form of grazing management known as 'Management-intensive Grazing' (MiG) (AKA: intensive-grazing management, short-duration grazing, holistic management) – which ties into my Masters research project at Thompson Rivers University. Second, the ranchers are highly involved in their community and in programs geared towards improving the social, environmental and economic aspects of ranching. To illustrate this point, the ranchers **attended "Ranching for Profit"** workshops, leading them to **make significant changes to improve the profitability of** their operations.

Most of the participating ranches are involved in the 'healthy steps' beef marketing program, in which healthy, grass-fed beef is marketed from the ranches to local communities for consumption. They displayed a high level of motivation and education for incentive programs to improve biodiversity, ecosystem health, etc on their ranches.

Some of the incentive programs include funding sources to help develop off-channel watering for cattle (to eliminate any negative impacts on riparian ecosystems) or to conduct biodiversity assessments. While these types of incentives are known to exist, they depend on drive and initiative from ranchers to seek them out and put them into action.

> Increasing carbon storage in ranch lands can contribute to climate change mitigation efforts.

Ranching is one of B.C.'s **first industries, and is an** important part of the province's history and culture, not to mention economy. This industry has suffered hardships and decline in recent years, and according to a report produced by the BC Ranching Task Force (RTF) in

2009, the major contributors include droughts, economic recession, high Canadian dollar values, growing feed and energy prices, Bovine Spongiform Encephalopathy (BSE) and country of origin labelling in the U.S. This has threatened not only the financial side of ranching, but the many, often overlooked, environmental benefits ranching can have. For example, biodiversity, erosion control and carbon sequestration are all ecosystem services that have been shown to increase under certain grazing management regimes.

Carbon sequestration occurs in soils when carbon dioxide (a major greenhouse gas) from the atmosphere is harnessed by plants and then stored in layers of soil. Because carbon sequestration relates directly to the reduction of atmospheric greenhouse gases, increasing carbon storage in ranch lands can contribute to climate change mitigation efforts. If this can be quantified, it has the potential to be recognized and rewarded through carbon crediting programs resulting in economic incentives/rewards for the ranchers involved.

My research is based on the study of carbon storage in soils as it relates to ranching; specifically on the study of Management-intensive Grazing compared to other more traditional ranching methods. MiG tends to rely on frequent (often daily), planned movement of cattle between relatively small pastures, and the use of inputs such as irrigation, soil amendments, seed, etc. to increase vegetation productivity. The presence of a relatively high number of livestock in a small area for a short period of time is believed to evenly distribute grazing impacts and allow greater plant recovery time prior to re-grazing.

I am testing whether MiG is more effective at storing soil carbon than other more traditional methods. I will use this information to provide information to ranchers to improve the social, environmental and economic sustainability of ranching in B.C. To achieve this, I measure soil carbon levels at ranches to compare with historical grazing practices and other factors that may influence soil carbon content. I can determine the amount of carbon found in soil by drilling holes and collecting soil samples from different pastures.

I work closely with five ranches in the Southern Interior of British Columbia; each has some pastures that are intensively managed and some that are traditionally grazed. I took soil samples last summer and plan to take more this summer. The samples I took last summer have not yet been analyzed, but I have observed three consistent themes between the ranches currently practicing.

1. All ranchers are trying to improve the health of their land, not just maintain it. They have a very clear understanding that this depends on contributions and interactions between three key 'players' – soil, plants and animals. For example, healthy soils are needed to produce healthy vegetation, which in turn produces healthy livestock. The cycle continues as livestock then contributes nutrients back into creating healthy soils and plants.
2. The ranchers have noticed an improvement in their operations' abilities to earn profit. Some even suggest that without the transition to Management-intensive Grazing their operation would not be economically sustainable.
3. Most of the ranchers participate in the production of grass-fed beef for local markets, providing the consumer a different option to beef preference, which can increase overall beef marketing.

The Management-intensive Grazing system is a tool for ranchers. There still remains a question whether it is beneficial or not. Ultimately, scientific evidence is needed. This is where my research will work towards filling the knowledge gap to help inform land management options.

ARTICLE

In the Field: MANAGEMENT-INTENSIVE GRAZING

Submitted by Dan Denesiuk, MSc Candidate in Environmental Sciences at Thompson Rivers University. Photos by Dr. Lauchlan Fraser, TRU

On September 8th, I hosted a day-long workshop on Management-intensive Grazing (MiG) for the Central Interior region of B.C. The day began at the Thompson Rivers University (TRU) Williams Lake campus where we conducted the indoor portion of the workshop.

Initially, I provided the group with background information on the principles of MiG. Later, we divided into three smaller groups, each of which tackled a set of questions based on one of three categories; Economics, Ecosystem Services and Climate Change. This was followed by a short group discussion and a delicious catered lunch. Afterwards, the group reconvened at a nearby ranch in 150 Mile House (Clint and Karen Thompson's, San Jose Cattle Co.) to participate in a field tour. During the tour, I demonstrated the sampling procedures used in my Master's research (comparing soil carbon levels between intensively managed pastures and conventional ones https://grazingmgtandclimatechange.wordpress.com/research/management-intensive-grazing/).

The group also learned the basics of portable electric fencing from Clint Thompson, who uses these resources on a daily basis as well as supplying electric fencing equipment to many ranchers in the area. The day finished off with a soil pit which I used to identify different soil horizons and properties important to the study of soil health.

The workshop received an excellent turnout of 25 individuals. A short questionnaire was handed out at the beginning of the workshop. Based on this questionnaire, it was determined that about 60% of those in attendance were ranchers and 40% were not (many of these being from the Ministry of Forests and Range). Of the ranchers in attendance, about 50% currently practice MiG on their ranches, while the other half do not.

The three primary objectives of the workshop were to:

1. Determine which principles of grazing management are practical and effective in our region, and which require modification (based on different climates and conditions),
2. Tie all of this together from a climate change adaptation and mitigation perspective, and
3. Develop the framework for a document guiding effective and sustainable ranch management in the B.C. interior.

One of the main topics discussed included carbon marketing as an incentive for ranchers to actively try to increase the amount of soil carbon in their pastures through improved management practices. MiG was widely believed to help accomplish this, though limitations were identified; primarily water management.

The concern regarding water management was raised for both supporting plant growth (irrigation, etc.), and for consumption by cattle. This hit home especially due to the drier than usual conditions experienced in the Cariboo region this past growing season. However, MiG was also proposed as one of the means in which ranchers can improve moisture retention in their pastures if it can increase organic matter in the soil. Another solution proposed to help reduce water loss from forage crops was the incorporation of trees and shrubs to reduce evaporation and transpiration from exposure to sun and wind.

Another limitation presented regarding MiG was the high input of labour. Although several other input costs (haying equipment, fertilizer, etc.) may be reduced by implementing this form of management, it is also important to consider the cost of labour involved in the day-to-day operations of managing cattle intensively. However, the point was also raised that by working closely with the cattle on a daily basis, there is the opportunity for much greater control over the impacts of cattle grazing on plant health (leaving residual growth, allowing plant recovery time, etc.). Furthermore, it is an effective means to monitor animal behaviour and health quite closely.

Another principle of MiG which was identified to have some inherent limitations was based on matching herd size to the level of plant productivity. In other words, increasing herd size during peak plant productivity, and reducing herd size when forage becomes scarcer. This herd number flexibility sounds effective in theory, but may be difficult to implement effectively in some parts of the Central Interior.

From a climate change perspective, several strategies were discussed that may increase a rancher's ability to adapt and be more resilient to changes. Many of these strategies are linked to MiG practices, including bale grazing to increase organic matter on less productive sites (increasing nutrients and moisture retention), managing invasive species via high stocking densities, stockpiling forage to reduce the amount of hay fed during winter months, and increasing biodiversity of plants and animals.

Ultimately, the need for outreach and education was in the forefront throughout the workshop; not only for the ranching community, but also for those who can (and should) be supporting local ranchers who put in the extra effort to raise animals in an ethical and sustainable way. Furthermore, it was highlighted that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1. *Using an eyedropper with 10% HCl solution to observe effervescence (indicating a reaction between the HCl and secondary carbonates in the soil.)*
2. *Collecting soil carbon samples from cores drilled in the soil.*
3. *The indoor portion of the MiG workshop, held at the TRU Williams Lake campus.*
4. *Demonstrating the use of a multispectral radiometer (MSR) for inferring plant productivity and possibly soil carbon.*
5. *Demonstrating sampling procedures for obtaining soil moisture content, percent plant cover, bulk density and soil carbon.*
6. *Clint Thompson showing the ease in which he can create effective boundaries for cattle, and check the amount of electricity flowing through his fencing.*

being a successful rancher ought to be a continual learning process. Like any other industry, things are constantly changing and new technologies and information is being made available all the time. Therefore, it is important to continue the pursuit of knowledge and try new things rather than always doing things in the same traditional ways.

The workshop itself, and the informational brochure(s) that will be produced based on it, will be one of many tools available for informing and educating the public as well as ranchers. However, it was suggested that events such as this continue to occur within the community, and focus should also be directed towards educating the younger generations.

When asked "What potential barriers are there preventing ranchers from adopting MiG?" the group provided the following list: **water, man-power, fencing** (electric fencing is unfamiliar to many), **paradigms** (resistance to change) **and time** (MiG requires commitment to cattle movement on a regular basis).

Those present indicated that the main reasons why MiG ranchers have made the switch? Were as follows: **economics** (to be profitable), better use of the land base (**greater productivity** on same land-base), **improved quality and growth of forage, long-term sustainability and reduced dependency on mechanical equipment and fuel.**

Ultimately, the ranchers concluded that regardless of the name placed on a particular management style, the guiding principles for a successful ranching operation should be the following: **be profitable and sustainable**, with **healthy plants, animals and soil** while **maintaining** a rancher's **passion and personal well-being** in this lifestyle.


3


4


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NEXT STEPS:

Now that the workshop is complete, the next steps in the process are to a) **create informational brochures for the public** (one for producers and one for the consumer) and b) **to continue research on the impacts of grazing management on soil carbon** (as this relates to climate change adaptation and mitigation). To obtain more definitive results, we hope this research project can expand with the initiation of controlled grazing trials. Trials such as this will help isolate the effects of grazing management on soil carbon. However in order to achieve this, we are looking for ranchers who would be interested in collaborating with us. This will require commitment on both sides, as we would be asking ranchers to alter the way they might normally graze their land.

If you would like to find out more about my research or MiG in general, feel free to visit the project website at: **https://grazingmgtandclimatechange.wordpress.com/research/management-intensive-grazing/** or contact myself by email at: **daniel-denesiuk@tru.ca**


6

Carbon Sequestration and CLIMATE CHANGE

By Dan Denesiuk

Grasslands possess great potential for below ground storage (sequestration) of carbon. Since atmospheric carbon dioxide (CO2) from the burning of fossil fuels is our most abundant greenhouse gas, capturing and storing it in the soil may help mitigate climate change. In other words, our grasslands offer promise and hope; and it simply requires improving the way we manage grasslands. Improving the health of these ecosystems is a win-win scenario, as it can result in subsequent benefits to productivity, biodiversity, invasive species and erosion control; which are also assets when it comes to adapting to climatic changes.

The catch here is that we need to be able to define what it means to improve our land management, and communicate this to land managers. To do this we need scientific research that provides evidence for and supports better management practices, and this needs to be applicable at a local scale to suit the often unique conditions that exist in different geographical areas.

Various soil profiles from pits that were excavated in the 2014 field season. Soil horizons are variable and change with depth, as does the amount of carbon held within these layers.

Research

Thompson Rivers University (TRU) is currently undertaking research to test whether the adoption of intensive management practices can be used as a tool to improve soil carbon sequestration in grazing lands. Literature suggests that intensive management, or 'Management-intensive Grazing' (MiG) can do just this, though research hasn't been done at a local scale in the Interior of BC, and the feasibility of MiG varies with our landscape and climatic conditions.

One can view grazing management as a continuum, spanning from 'extensive' to 'intensive' practices. To put this into context, the more intensive a management style is, the more planning, resources and effort goes into managing. On the other hand, extensive management requires comparably little in the way of the aforementioned inputs.

Two examples of intensively managed pastures before grazing (left) and after grazing (right). Notice that residual plant material left behind is 'mulched' into the ground and cattle waste is evenly distributed and available for nutrient cycling. Also note the use of portable electric fencing to contain cattle and allow for fast and effective boundary control.

A fence line contrast between extensively managed (left) and intensively managed pastures (right). Notice the abundant residual plant material left after the recent MiG grazing.

Education and Outreach

A main component of the research being conducted by TRU is to reach out to the community and provide information and feedback about different grazing management practices and the benefits that may result from improving the way we manage our lands. Throughout the life of this research project, there have been several poster presentations, informational workshops and tri-fold brochures have been distributed.

Demonstrating soil sampling methods as part of a grazing management workshop put on by TRU in the fall of 2015.

Results

What we've found so far is evidence that supports MiG as an improved management practice which can help increase carbon levels found in the soil. This is based on the comparison between intensively (MiG) and extensively (traditionally) managed pastures at several different ranch locations throughout the BC Interior. The amount of time each ranch has been practicing MiG is variable, as are the methods in which this form of management is implemented. Each ranch is unique in the resources that are available to it, as well as the land management goals that influence decision-making. Furthermore, soil and climate conditions vary geographically. Because of this uniqueness and inherent variability, it's important to note that there can't be one single "right" way of doing things. However, from a broad perspective that encompasses the BC Interior, the results of this study thus far indicate that MiG pastures exhibit significantly higher levels of carbon compared with traditionally or conventionally managed ones (Figure 1), and that carbon also varies by depth (Figure 2).

The graph illustrates the differences in total carbon between two styles of grazing management that have been observed in this study.

However, it is also important to understand that soils are three-dimensional, varying not only across the surface of the land but also with depth into the ground. One way to observe this change is by digging soil pits and separating samples into depth intervals. The diagram below (figure 2) represents the differences that were observed with depth in soil pits from pastures under different management, and it is evident that intensively managed pastures exhibit a pattern of greater total carbon when compared to extensively managed ones. However, the difference seems to decrease and eventually disappear by the time we reach depths of 50 cm below the soil surface; this is to be expected, since deeper soil layers are less likely to be influenced by relatively recent changes that have occurred in grazing management.

Figure 1. Comparison between carbon (total carbon and organic carbon) by management type (extensive and intensive) across the 6 ranches involved in this study in 2013 and 2014.

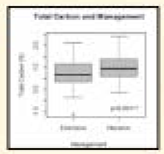
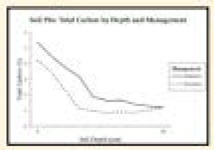


Figure 2. Mean total carbon (%) by depth and management type across from soil pits at 6 ranches in 2014.



Looking Ahead

More research is still needed on the feasibility of intensive management in more arid, natural grassland communities. The primary concerns being water and fencing over such vast areas. However, if it can be done, the implications for climate change mitigation through carbon sequestration could be monumental due to the sheer scale of soil improvement.

In the future, TRU hopes to collaborate with ranchers to develop controlled research plots with all conditions remaining the same between study plots except levels of management intensity. By manipulating only the intensity of management, the treatment effect can be better isolated, providing very powerful results.

For more information and to follow the progress of this study, please feel free to visit the project website: https://grazingmanagementandclimatechange.wordpress.com/research/management-intensive-grazing/

Can Grazing Increase Soil Carbon Sequestration?

By Scott Benton, Dan Denesiuk and William Harrower

The results from the Grassland Conservation Council and Thompson Rivers University 2013 soil carbon research project suggest that the amount of total soil carbon present can be increased through management intensive grazing practices. This finding appears to be subject to certain bio-geoclimatic conditions found in different regions of the province. Not surprisingly, not all grasslands are the same or have the same site productivity.

Pastures that were sampled in the study managed under a Management Intensive Grazing regime tended to exhibit higher levels of total soil carbon compared to "traditionally" managed ones. Further analysis is required to observe the influence of soil moisture (via irrigation and/or precipitation) on soil carbon levels, since the pastures sampled thus far have been associated directly with higher levels of soil moisture, either naturally or through irrigation. Although this suggests that soil moisture may be a significant factor in driving increased carbon storage, further analysis is required to separate the influences of grazing management and soil moisture (via irrigation and/or precipitation).

The GCC's interest in soil carbon sequestration is fourfold: increasing soil carbon increases plant and ecological health of grasslands; increasing the quality and quantity of forage for wildlife and cattle, creating potential for the sale of carbon credits; and undisturbed grasslands serve as one of the planets great carbon sinks second only to forests terrestrially for absorbing atmospheric carbon dioxide. If managing grazing can increase the amount of soil carbon captured then the rancher, society at large and the planet all benefit.

The soil carbon sequestration project results highlight many factors that influence soil carbon sequestration in grasslands. Soil composition and density, annual precipitation, grazing intensity, and topography (site aspect and elevation) are some of the key influencing factors. Pastures with higher levels of soil moisture through natural or irrigated means demonstrated higher levels of soil carbon sequestration. This suggests that the provinces interior regions with higher levels of precipitation and favorable soil and site conditions and are subject to Management Intensive Grazing practices, have higher carbon sequestration rates.

When carbon is sequestered to soil by plants, some carbon remains in a “fast” (organic) layer known as soil organic carbon and some is transformed over time to an intermediate state (slow carbon) and then into a fixed state (passive) carbon which is not readily accessible to plant communities. All forms of soil carbon degrade when exposed to the atmosphere transforming into carbon dioxide. This typically occurs through soil disturbance such as cultivation, excavation, landslides, and normal soil respiration.

The key for adding soil organic carbon in BC’s grasslands is to promote root growth. Native grass species have evolved to have significant root systems adapted to the dry conditions found in the provinces interior. Promoting root growth will increase top growth. The rate at which carbon can accumulate appears to be dependent on three factors: topography, climate (soil moisture/precipitation and temperature) and grazing intensity. Grazing intensity (frequency and amount) can be a trigger in promoting root growth providing the environmental factors are favorable. The results from this year’s soil sampling are still being analyzed to determine the levels of soil organic carbon within the total soil carbon account of the ranches sampled.

In a separate study, Heather Richardson (MSc student at Thompson Rivers University) and a team of researchers spent the last two summers travelling BC's interior grasslands (Kootenay's, Boundary, Okanagan, Thompson, Cariboo, Chilcotin, and the Peace regions). They sampled soils inside and outside fenced Range Reference Areas in each region measuring soil carbon as well as other variables that might relate to soil carbon. The results are still being processed, but initial trends suggest that the Cariboo/Chilcotin grasslands have increased soil carbon when they are grazed compared to being in a fenced exclosure. The team also found that mean annual precipitation was positively correlated with soil carbon.

The trends in the Okanagan grasslands seem to show an opposite pattern than the Cariboo/Chilcotin. Since the Cariboo/Chilcotin has more precipitation than the Okanagan, it is possible that precipitation may influence whether grazing increases or decreases soil carbon. These findings are consistent with studies in the U.S. where carbon stocks are largest toward the cooler and wetter northeast, and are smallest in the hotter and drier southwest (from Jenny 1941).

This year's project added another research element by examining the synergies between soil carbon sequestration and other ecological goods and services such as water quality and quantity. We partnered with the Ecological Services Initiative and William Harrower to do this portion of the research. Ecological services are the goods and services that provide for human health, social, cultural and economic needs. It can be forage production from natural grasslands; water filtration, storage and flood protection from an intact watershed or biodiversity abundance for producing clean air, water and food. Soil carbon sequestration is an ecosystem service providing for a stable climatic system through carbon storage, healthy plant communities and abundant forage for wildlife and cattle, clean water, increased biodiversity etc.

Both of the soil carbon sequestration and ecosystem initiatives are being developed to fit within the Province of BC's Environmental Farm Plan program to build on an existing management framework that ranchers are familiar with.

The Ecosystem Services component of this project was delivered on four of the five ranches where the carbon sequestration sampling occurred. The project entailed completing or updating an Environmental Farm Plan and Biodiversity Plan for each of the ranches, identifying an appropriate riparian zone for management improvement and completing a site assessment and resource attribute analysis. A management prescription to achieve improvement in a riparian zone was developed for each of the four ranches and a monitoring plan established.

The benefits the rancher accrues from this program are multiple: reduced disease issues associated with watering areas, reduced erosion of riparian areas, improved water quality and quality on the ranch and downstream, to name a few. This also helps maintain biodiversity on the ranch which augments the grasslands. Building carbon stores in the soil augments the riparian protection and enhancement by increasing soil moisture and storage, reducing erosion, and increasing soil microbes, plant and animal biodiversity.

The process of increasing the size of carbon stocks and how it relates to grazing management differs depending on the type of rangeland being utilized. Uncertainty of how grazing management and rangeland type influence carbon stocks is considerable, but should not impede the development of an Ecological Services program for soil carbon; there appears to be positive links between management of grazing for increased soil carbon and increased forage production.

We are proposing an adaptive management program aimed at defining specific relationships between rangeland type, grazing management, forage production, and soil carbon. This should allow an Ecological Services program to move forward despite the scientific uncertainty that exists for soil carbon today. This program would include mapping carbon stores by rangeland types, experimental trails for determining the relationship between rangeland type and grazing, land-use mapping to determine how grazing management can influence carbon stocks, development of standards to ensure consistent and internationally recognized monitoring programs, and continued refinement and incorporation of scientific and management information aimed at expanding Ecological Services programs to water and biodiversity services as well as refining the quality of existing forage production and soil carbon models.

There are many positive benefits in managing rangelands for both forage production and soil carbon, and programs designed to provide Ecological Services to ranchers promise to improve both the financial and operational viability of ranches. One of the barriers preventing this from happening is the lack of recognized monitoring and evaluation systems that provide data to confirm the broad ecological benefits ranchers provide. The proper management and good stewardship of rangelands provides not only financial savings to ranchers but potential for increased revenue provisions of many ecosystem services to society in general. The storage of carbon in rangelands is one such resource.

The development of a conceptual monitoring framework and linking it to other ecosystem services activities was part of the recommendation of the report. There is still much work to be done to finalize this work

The work on understanding how soil carbon sequestration can be enhanced through grazing management and other techniques that will carry on in the next few years under the guidance of Lauch Fraser at Thompson River University. So too, will the ecosystems services component of the program under the guidance of Dave Zehnder of the Ecosystem Service Initiative and many others who are seeking to improve the economic and environmental outcomes from activities like farming and ranching.

APPENDIX E – Informational brochure

Principles of MiG in the BC central interior

- Mimicking the effect of large herds of wild grazing ungulates
- Short duration, high-intensity grazing
- Portable electric fencing for control
- Long-term reduction in operational costs

Improving soil health

- Animals spread and mulch 'fertilizer'
- Bale grazing to amend poorer soils

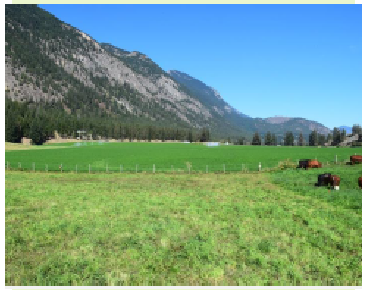
Managing for plant growth/productivity

- Leaving residual plant growth
- Allowing adequate plant recovery time
- Improving plant and animal diversity
- Promoting plant structural diversity (trees/shrubs) comes with benefits

Above: Clint Thompson checking the electrical current flowing through his portable fencing

Economics

Switching to MiG will likely require an initial investment to establish electric fencing infrastructure as well as water for cattle and irrigation.



Economic Benefits of MiG?

- Direct marketing of local, grass fed products
- Designed to improve quality and growth of forage
- Stockpiling standing forage to save on winter hay feeding
- Potential for reduced operational costs: fuel, machinery, fertilizer, etc.
- Less dependency on fossil fuels, which can have an unpredictable market

The contents of this brochure are largely based on feedback gathered during a grazing management workshop held in Williams Lake in fall 2015.

Could switching to MiG improve your resilience to climate change?

Adaptation :

- Improved soil moisture retention to reduce impacts of drought
- Greater plant and animal diversity that can increase resiliency
- A tool for invasive species control

Mitigation and Carbon Marketing:

Increasing the amount of carbon stored beneath the soil means removing it from the atmosphere, thus reducing greenhouse gases. The resulting stored carbon provides an opportunity for carbon crediting programs.

APPENDIX F – Ethics approval documents

REB Approval (COA)

From: **dkrebs@tru.ca**
Sent: May-08-14 12:31:33 PM
To: Mr. Dan Denesiuk (Primary Investigator) (ddenesiuk@hotmail.com)
Cc: Lauchlan Fraser (Co-Investigator) (lfraser@tru.ca); dkrebs@tru.ca

THOMPSON RIVERS UNIVERSITY

May 08, 2014

Mr. Dan Denesiuk
Faculty of Science\Natural Resource Science
Thompson Rivers University

File Number: 100685
Approval Date: May 08, 2014
Expiry Date: May 07, 2015

Dear Mr. Dan Denesiuk,

The Research Ethics Board has reviewed your application titled 'Quantifying Carbon Sequestration to Identify Sustainable Ranching Methods in BC'. Your application has been approved. You may begin the proposed research. This REB approval, dated May 08, 2014, is valid for one year less a day: May 07, 2015.

Throughout the duration of this REB approval, all requests for modifications, renewals and serious adverse event reports are submitted via the Research Portal. To continue your proposed research beyond May 07, 2015, you must submit a Renewal Form before May 07, 2015. If your research ends before May 07, 2015, please submit a Final Report Form to close out REB approval monitoring efforts.

If you have any questions about the REB review & approval process, please contact the Research Ethics Office via 250.852.7122. If you encounter any issues when working in the Research Portal, please contact the Research Office at 250.371.5586.

Sincerely,

Chair, Research Ethics Board

Gmail by Google

Dan Denesiuk <drdenesiuk@gmail.com>

REB Renewal/Amendment Approval

1 message

dkrebs@tru.ca <dkrebs@tru.ca> Wed, May 6, 2015 at 2:27 PM
To: "Mr. Dan Denesiuk (Primary Investigator)" <ddenesiuk@hotmail.com>
Cc: "Lauchlan Fraser (Co-Investigator)" <lfraser@tru.ca>, dkrebs@tru.ca

THOMPSON RIVERS UNIVERSITY

May 06, 2015

Mr. Dan Denesiuk
Faculty of Science\Natural Resource Science
Thompson Rivers University

File Number: 100685
Original Approval Date: June 01, 2014
Expiry Date: May 07, 2015
Renewed: May 6, 2015
Expiry Date: May 5, 2016

Dear Mr. Dan Denesiuk,

The Research Ethics Board has reviewed your renewal/amendment for the project titled'Quantifying Carbon Sequestration to Identify Sustainable Ranching Methods in BC'. Your renewal/amendment has been approved. You may begin the proposed research. This REB approval, dated June 01, 2014, is valid for one year less a day: May 05, 2016.

Throughout the duration of this REB approval, all requests for modifications, renewals and serious adverse event reports are submitted via the Research Portal. To continue your proposed research beyondMay 06, 2016, you must submit a Renewal Form before May 06, 2016. If your research ends before May 07, 2016, please submit a Final Report Form to close out REB approval monitoring efforts.

If you have any questions about the REB review & approval process,please contact the Research Ethics Office via 250.852.7122. If you encounter any issues when working in the Research Portal, please contact the Research Office at 250.371.5586.

Sincerely,

Andrew Fergus
Chair, Research Ethics Board

APPENDIX G – Consent to participate

Informed Consent to Participate in a Research Project or Experiment

Thompson Rivers University
900 McGill Road
Box 3010
Kamloops, BC
V2C 0C8
Telephone (250) 828-5000

Note: The University and those conducting this project subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of participants. This form and the information it contains is given to you for your own protection and full understanding of the procedures, risks and benefits involved in this research project or experiment.

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more details, feel free to ask at anytime. Please take the time to read this carefully and to understand any accompanying information.

I have been asked by Dan Denesiuk of the Environmental Sciences Department of Thompson Rivers University, to participate in a research project entitled: "Quantifying carbon sequestration to identify sustainable ranching methods in BC", which encompasses the following:

Project details:
The study will involve an interview, ranch tour and subsequent field-sampling. Rancher(s) will not be required to be present for the field sampling component. A question list will be used to guide rancher interviews, and will be provided to ranchers, though they will not be asked to submit any written responses. Notes will be taken based on verbal responses during the interview. The interviewee(s) may review the written responses at the end of the interview to ensure that the information is accurate (if not, it will be fixed to accurately reflect their opinions or information).

The interview (and ranch tour) should take no longer than 4 hours total, and the conversation may be recorded using a digital voice recorder. There will be two different types of information gathered during the interview. The first will be historical land management data -to be compared with the results of soil sampling and other fieldwork. The second will be opinion-based information that will be summarized and potentially included in final reports and/or publications in a way that retains anonymity of ranchers.

Interview details:
I will be asking several interview questions that are either fact-based or opinion-based. The fact-based information will primarily relate to the history of land management (ranching practices) on the various ranch properties, to be later compared with field data and results of lab analysis. Additionally, these questions will relate to any changes in the land that have been observed over time. In terms of the opinion-based questions, these will relate more to how grazing management practices are perceived to impact the land, what principles guide decision-making, etc.

The principal investigator (interviewer) will be Dan Denesiuk, who will often be accompanied by Heather Richardson or an alternate research assistant. Dan's supervisor (Dr. Lauchlan Fraser) will be involved in analysis and interpretation of any results. Together, these individuals will compose the research team.

Data and results:
Dr. Fraser and Dan Denesiuk will be the only individuals with access to the information recorded during the interview process. Upon completion of Dan's MSc thesis, Dr. Fraser will hold all the records (written and digitally recorded audio) in a locked filing cabinet for 7 years (as per TRU policy). After this time, all paper copies will be destroyed (shredded) and the digital audio files deleted.

The results obtained from this study will potentially be included in written reports/publications and conference proceedings. To retain rancher anonymity, the principal investigator (Dan Denesiuk) will either use general statements that do not implicate any rancher or ranchers in particular, or will assign them arbitrary labels (rancher 1, rancher 2…).

Additional information:

- Ranchers who choose to participate will not do so based on any monetary compensation. However, if they have voluntarily chosen to participate in the larger soil study, they will receive an honorarium of $500 for the 2014 field season.
- Copies of the results of this study, upon its completion, may be obtained by contacting Dan Denesiuk or his supervisor Dr. Fraser (contact information provided below).

Contact information:

Principal investigator: Dan Denesiuk, MSc Candidate
Phone: 250.828.0084
Email: ddenesiuk@hotmail.com

Supervisor: Dr. Lauchlan Fraser, TRU Faculty
Phone: 250.377.6135
Email: lfraser@tru.ca

My signature on this form indicates that I understand the information regarding this research project, including all procedures, and that I voluntarily agree to participate in this project.

I understand that my identity and any identifying information obtained will be kept confidential.

I understand that I may refuse to participate or withdraw my participation in this project at any time without any negative consequences.

I understand that I may ask any questions or register any complaint I might have about the project with either the chief researcher named above or with the Chair of the TRU Research Ethics Board (REB), telephone:250-828-5000, email: TRU-REB@tru.ca.

I have received a copy of this consent form.

Name: (Please Print) HUGH BAYLIFF

Address: PO BOX 5 REDSTONE BC.

Participant's signature ____________ Date SEPT 5/14

Investigator's signature ____________ Date Sept. 5/14

....

I agree to have digital audio data recorded and used for future reference material if the need exists will be destroyed by deleting all copies by May 2021.

Participant's signature ____________ Date SEPT 5/14

My signature on this form indicates that I understand the information regarding this research project, including all procedures, and that I voluntarily agree to participate in this project.

I understand that my identity and any identifying information obtained will be kept confidential.

I understand that I may refuse to participate or withdraw my participation in this project at any time without any negative consequences.

I understand that I may ask any questions or register any complaint I might have about the project with either the chief researcher named above or with the Chair of the TRU Research Ethics Board (REB), telephone:250-828-5000, email: TRU-REB@tru.ca.

I have received a copy of this consent form.

Name: (Please Print) Gerard Guichon Ranch Limited, Allison Guichon

Address: Box 10 Quilchena BC V0E 2R0

Participant's signature [signature] Date Aug 13/14

Investigator's signature Don Dav[signature] Date Aug 13/14

....

I agree to have digital audio data recorded and used for future reference material if the need exists will be destroyed by deleting all copies by May 2021.

Participant's signature [signature] Date Aug 13/14

My signature on this form indicates that I understand the information regarding this research project, including all procedures, and that I voluntarily agree to participate in this project.

I understand that my identity and any identifying information obtained will be kept confidential.

I understand that I may refuse to participate or withdraw my participation in this project at any time without any negative consequences.

I understand that I may ask any questions or register any complaint I might have about the project with either the chief researcher named above or with the Chair of the TRU Research Ethics Board (REB), telephone:250-828-5000, email: TRU-REB@tru.ca.

I have received a copy of this consent form.

Name: (Please Print) Cuyler Huffman

Address: 5734 Moon Rd. Williams Lake BC V2G 2V3

Participant's signature [signature] Date Aug. 25/14

Investigator's signature Dan Deresiuk Date Aug. 25/14

....

I agree to have digital audio data recorded and used for future reference material if the need exists will be destroyed by deleting all copies by May 2021.

Participant's signature [signature] Date Aug. 25/14

My signature on this form indicates that I understand the information regarding this research project, including all procedures, and that I voluntarily agree to participate in this project.

I understand that my identity and any identifying information obtained will be kept confidential.

I understand that I may refuse to participate or withdraw my participation in this project at any time without any negative consequences.

I understand that I may ask any questions or register any complaint I might have about the project with either the chief researcher named above or with the Chair of the TRU Research Ethics Board (REB), telephone:250-828-5000, email: TRU-REB@tru.ca.

I have received a copy of this consent form.

Name: (Please Print) Rainer Krumsiek

Address: 5647 Lincoln Road

Horsefly BC V0L 1L0

Participant's signature [signature] Date 28-5-14

Investigator's signature Dan Denesiuk Date May 28, 2014

....

I agree to have digital audio data recorded and used for future reference material if the need exists will be destroyed by deleting all copies by May 2021.

Participant's signature [signature] Date 28-5-14

My signature on this form indicates that I understand the information regarding this research project, including all procedures, and that I voluntarily agree to participate in this project.

I understand that my identity and any identifying information obtained will be kept confidential.

I understand that I may refuse to participate or withdraw my participation in this project at any time without any negative consequences.

I understand that I may ask any questions or register any complaint I might have about the project with either the chief researcher named above or with the Chair of the TRU Research Ethics Board (REB), telephone:250-828-5000, email: TRU-REB@tru.ca.

I have received a copy of this consent form.

Name: (Please Print) CLINT THOMPSON

Address: Box 94, 150 Mile House, B.C. V0K 2G0

Participant's signature ____________ Date August 22, 2014

Investigator's signature ____________ Date Aug. 22/14

....

I agree to have digital audio data recorded and used for future reference material if the need exists will be destroyed by deleting all copies by May 2021.

Participant's signature ____________ Date August 22, 2014

My signature on this form indicates that I understand the information regarding this research project, including all procedures, and that I voluntarily agree to participate in this project.

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I understand that I may refuse to participate or withdraw my participation in this project at any time without any negative consequences.

I understand that I may ask any questions or register any complaint I might have about the project with either the chief researcher named above or with the Chair of the TRU Research Ethics Board (REB), telephone:250-828-5000, email: TRU-REB@tru.ca.

I have received a copy of this consent form.

Name: (Please Print) DAVID ZIRNHELT

Address: P.O. BOX 3

BIG LAKE RANCH P.O. BC V0L 1G0

Participant's signature David Zirnhelt Date 18 Aug, 2014

Investigator's signature Dan Dart Date Aug 18, 2014

....

I agree to have digital audio data recorded and used for future reference material if the need exists will be destroyed by deleting all copies by May 2021.

Participant's signature David Zirnhelt Date 18 Aug, 2014

APPENDIX H - Interview questions

1. Tell me about the history of your ranch
   i.e., What has been done in terms of management, seeding, irrigation, fertilization, etc.?
2. How has the land changed over time based on your knowledge and/or experience?
3. i.e., Have you noticed any differences in the soil, vegetation, productivity, etc. since you've been managing it intensively?
4. What do you think the impacts of your grazing management practices are/have been on the soil and in terms of carbon sequestration?
5. How do you think other management practices (e.g., those of other ranches in your area) might affect ecosystem services such as carbon sequestration, soil integrity (infiltration, erosion, compaction, etc.)?
6. How do you think your management practices are more beneficial (socially, environmentally, economically) than others?
7. Have you read the books on MiG by Jim Gerrish? If so, what were your impressions?
   -How do you think your management practices are similar to those described in Jim's book? How are they different?
8. What other strategies do you use to manage the land simultaneously for healthy soil, vegetation and grazing animals?