EVALUATING THE GRAZING RESPONSE INDEX OF THREE KEY FORAGE SPECIES IN THE SOUTHERN INTERIOR OF BRITISH COLUMBIA BY USING MULTIPLE CLIPPING TREATMENTS TO DETERMINE IMPACT ON PLANT VIGOUR

By

VANESSA VOLPATTI

Bachelor of Natural Resources Sciences, Thompson Rivers University, 2011

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCES

in the Faculty of Science

in

Environmental Science

Thesis Supervisor:
Dr. Wendy Gardner

Committee Members:
Dr. Lauchlan Fraser
Dr. Reg Newman
Lavona Liggins

2013

Thompson Rivers University

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Wendy Gardner for all of her guidance and support that she gave me through this process and always kept me going. My committee members also provided me with a lot of help and instruction: Lavona Liggins for all her coordination with Agriculture and Agri-Food Canada and particularly during my first field season of work helping me find my study sites and especially finding extra helping hands to assist me. Reg Newman for all his help with my statistical design and analysis as well as helping to locate study sites. Lauchlan Fraser for helping decide the best ways to use my large amounts of data and providing valuable insight and direction.

I thank my research assistants Katie Clark and Kayla Holtslag for their many hours of monotonous work counting tillers and measuring tiller heights and making my research and work fun and interesting, rain or shine; Erika Tessier, Tori Waites and Mahesh Khadka for filling in whenever I needed extra assistance.

My family and friends have been a great support network throughout the duration of my Master's. My parents Reno and Sandra Volpatti for giving me a lot of emotional, physical and financial support; my siblings, Gina, Trevor and Craig for their emotional and physical support. Chris Maciel for his continued encouragement and support that never let me forget I could accomplish all of my goals and that anything worth doing is worth doing right.

A final thank you to Agriculture and Agri-Food Canada for supporting and funding this project.

DEDICATION

This paper is dedicated to my two late Grandfathers, Joseph Volpatti and Fred Chantler, both of whom were kind hearted, hardworking men who each gave me a piece of themselves. For my Grandpa Volpatti who spent his whole life dedicated to farming, agriculture and his family and gave me those same passions that he once had. For my Grandpa Chantler, who was a soft spoken man with a strong connection with nature and the great out-doors and gave me a keen interest and respect for the natural world.

ABSTRACT

In British Columbia, many practices related to rangeland management are not working as effectively as they used to due to fluctuating environmental factors. The Grazing Response Index (GRI) is a tool which was developed in Colorado, USA to help rangeland managers and producers evaluate the effects of grazing in a current year by integrating management and climate factors which relate directly to growing conditions. To determine if this tool could be used in the Southern Interior of British Columbia, in conjunction with range condition assessments and range health assessments, the effectiveness of the GRI was determined by comparing the responses of three key forage species to various levels of clipping: clipped once at 40% or 70% or clipped three times at 40% or 70% removal of biomass. Results varied by species: bluebunch wheatgrass was impacted greater by intensity of clipping rather than frequency, rough fescue showed interactions between frequency and intensity while pinegrass results were variable. Though results varied by species, the GRI scoring for each species response was considered appropriate though it was conservative in its scoring of the more severe treatments. I conclude that the GRI could be a beneficial tool for annual range management in the Southern Interior to supplement long term management tools.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX FIGURES

CHAPTER 1: GENERAL INTRODUCTION

1.1 BRITISH COLUMBIA RANGELANDS

There are many land types within British Columbia (B.C.) that are considered rangeland; such as grasslands, wetlands, forest and alpine ranges. Rangelands are important forage sources for wildlife and livestock and provide a multitude of economic and social benefits. Rangelands in British Columbia are most often found between the Rocky Mountains in the east and the Coastal mountains in the west but also include the Peace River zone in the northeast where the Great Plains extend from Alberta into British Columbia (Fig. 1) (Bawtree 2005, Wikeem and Wikeem 2004). The spread of rangelands across the province, with variations in climate, soils and topography, is represented by a wide variety of distinct plant communities, which make rangelands in British Columbia some of the most diverse rangelands in North America (Wikeem *et al.*1993). There are 14 distinct biogeoclimatic ecosystem classification (BEC) zones characterized within the province, 11 of which make up the core of British Columbia's range resources (Campbell and Bawtree 1998). These zones are reflective of the broadest vegetation complexes and regional climate and are named after one or two dominant species within the zone. For example, the bunchgrass zone is dominated by bluebunch wheatgrass and rough fescue which are bunchgrass species. Zones can further be broken down into subzones and variants; it is at these levels where most management decisions are made. The diversity and classification of British Columbia's rangelands makes it apparent that management of these zones, not only for rangeland resources but other values as well, can be difficult.

The Southern Interior is one of the driest and warmest regions in the province and to discuss the rangelands within this region it is best to refer to them as forested zones and open grasslands (Bawtree 2005). Approximately 7.6 million hectares of land in the Southern Interior is considered rangeland (Mclean 1967, McLean 1972) most of which is forested.

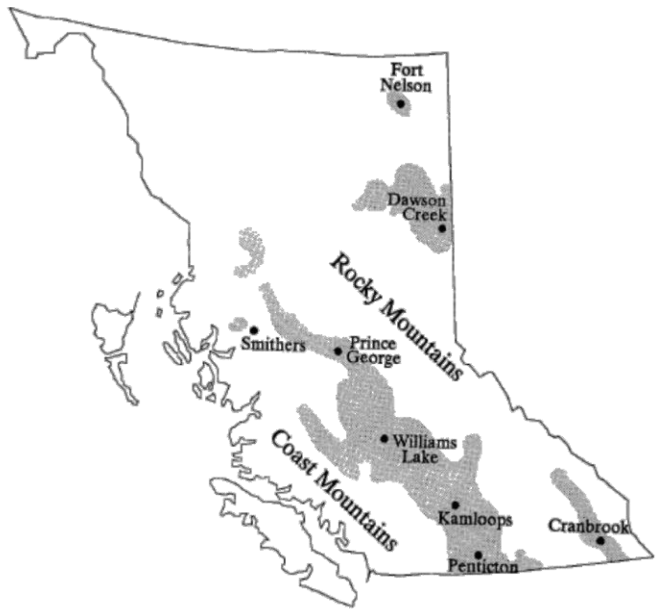


Figure 1: Approximate area and location of British Columbia's range resources (Wikeem and Wikeem 2004).

These forested zones produce less forage per hectare than open grasslands, but the volume of forested rangeland is much greater; 80% of rangeland in B.C. is forested (Wikeem *et al.*1993). Douglas-fir, ponderosa pine and engelmann spruce trees are the climax dominant species that form the canopies in most of the forested rangelands in the Southern Interior (Wikeem *et al.*1993). Some forested rangeland has been seeded to improve forage on cut blocks (50,000 hectares in B.C. since 1960) often with agronomic species; lodgepole pine is typically the tree species dominating the cut block canopies (Wikeem *et al.* 1993). Based on the elevational gradient (which also results in a moisture gradient), the grassland areas of the Southern Interior can separated into three distinct zones of lower, middle and upper grasslands. The upper grasslands are in fact classified as being in the grassland phase of the Interior Douglas-fir BEC zone as soil moisture is great enough in this area to support tree growth (Ministry of Environment, Lands and Parks 2000). Often, encroachment of trees into the upper grasslands can become a management concern. Rangeland, regardless of type, is either public or private land.

Approximately 80% of forested rangeland and 10% of grassland rangeland is owned by the provincial government (Campbell and Bawtree 1998) with livestock producers often leasing the land under grazing licenses (10 years) or grazing permits (5 years) (Ministry of Forests, Lands and Natural Resource Operations, 2013a). Currently there are grazing leases (21 years) in existence in some areas of the province, though no new ones have been granted recently (Ministry of Forests, Lands and Natural Resource Operations, 2013b). Provincial land makes up 60% of total forage requirements for ranchers while the remaining 40% is gained from private rangeland and irrigated pasture land (Wikeem *et al.* 1993). With approximately 410,600 head of cattle (bulls, cows, heifers, steers and calves) in B.C. as of January 2013, and an industry that on average produces an economic contribution of $600 million annually, continued due diligence and improvement for management of range resources is crucial for economical sustainability of B.C.s cattle industry (Statistics Canada 2013, B.C. Cattlemen's Association 2013).

1.2 RANGE MANAGEMENT AND PLANT GROWTH

Range management is defined by the Society for Range Management as: "A distinct discipline founded on ecological principles and dealing with the use of rangelands and range resources for a variety of purposes. These purposes include use as watersheds, wildlife habitat, grazing by livestock, recreation, and aesthetics, as well as other associated uses." (Society for Range Management 1989). The type of management on rangelands is dependent upon the management objective. Rangeland management is a process that is continually being altered and improved through research and application of grazing management plans and rangeland assessments; these tools aid in reaching desired production levels or goals while maintaining suitable levels of sustainable use. Research relating to range management first began in the United States in the beginning of the 1900s (Pyke *et al.* 2002) and, in the following years, it was decided research was needed in matters affecting the range industry (such as plant community and integrity) as ecological and environmental awareness caused public concern for proper management of rangelands (Milroy and McLean 1980). This research over the past century has led to the development of many different management strategies for the grazing (and well as other uses) of rangelands.

Essentially, managing rangelands for grazing purposes is accomplished by understanding the basic principles of defoliation and how plant vigour is impacted by defoliation. Removal of photosynthetic material through grazing or other methods of defoliation can result in reducing a plant's capacity to form carbohydrates and proteins, though this can be dependent upon the amount of material removed. (Holechek *et al.* 2011). The vigour of a plant is identified as characteristics of a plant which relate to the ability of productivity, reproduction, and competition (Caldwell 1984). A plants ability to quickly produce vegetative and reproductive shoots, store nutrient reserves and have effective rooting systems are key indicators of vigour (Caldwell 1984). There are many studies that support the fact that intensity and timing of grazing can significantly affect the vigour and productivity of plants. This can further be impacted by the frequency of defoliation as well as seasonal influences such as temperature and precipitation; with precipitation being a very important factor in determining type and productivity of vegetation in an area (Holechek *et al*. 2011). Depending upon the frequency, intensity, or timing of defoliation, plants may utilize carbohydrate reserves to produce new photosynthetic material in order to return to pre-defoliation photosynthetic rates (Campbell and Bawtree 1998, Richards 1993). Root growth can also be affected by defoliation as root elongation has been shown to slow or stop after 40-50% onetime removal of biomass while fine roots may begin to die and decompose soon after defoliation (Holechek *et al*. 2011, Richards 1993, Ryle and Powell 1975).

Frequency refers to the number of times a plant is defoliated in a growing season and is related to duration, how long animals remain in a given area. Often, the greater number of times a plant is defoliated, the more detrimental defoliation becomes (Ferraro and Oesterheld 2002) as generally there is an inverse relationship between plant yield and frequency of defoliation (Ellison 1960). A single grazing of a plant will often not lead to severe, long term impacts on plant vigour since loss of old leaves can have less of a negative impact than loss of newer leaves (Richards 1993) but consecutive grazing occurrences will remove the new regrowth on previously grazed plants which can result in loss of vigour (Briske 1986). Each subsequent defoliation event results in loss of new regrowth causing greater energy expenditure of the plant to recover the lost photosynthetic material (Briske 1986). Frequency can be impacted by intensity of defoliation since multiple defoliations can be tolerated by most plants at low intensities; however moderate to severe intensities with increased frequency will result in decreased plant vigour (Richards 1993).

Intensity, the amount of photosynthetic material removed, is related to stocking rate which is defined by Holechek *et al.* (2011) as the relationship between the number of animals per grazing area over a period of time. What is considered to be light, moderate and heavy grazing intensities varies upon the range type as each range type can differ in precipitation and plant community composition (Holechek *et al.* 2011). On many rangelands, light/conservative grazing is considered to be 40% or less removal of biomass, moderate grazing usually is represented by 41-50% of biomass removed, while heavy grazing is between 51-60% and severe grazing is greater than 60% removal of biomass (Holechek *et al.* 2006). Light grazing can have positive impacts when compared to ungrazed plants as grazing may result in more growth during the growing season and a higher total biomass production by the end of the growing season (Holechek *et al.* 2006, Ganskopp and Bedell 1981, Johnson 1956). Moderate grazing can be defined as "take half leave half" (Holechek *et al.* 2011). Removing no more than 50% of the biomass would not have any positive impacts on the grazed plant and aside from the recovery of lost photosynthetic material, plant vigour would likely not be negatively impacted. (Holechek *et al.* 2011, Reed *et al.* 1999). Heavy and severe grazing has negative impacts on plant vigour that could require years of recovery (Briske *et al.* 2008, Blaisdell and Pechanec 1949). The impact of intensity on a plant can vary by species and timing of defoliation (growth stage). The removal of meristematic tissue can be more detrimental to plant vigour than the removal of equal proportions of vegetative tissue (Richards 1993); and removal of a significant portion of biomass often results in reduced photosynthetic capacity (Briske *et al.* 2008), carbohydrate storage and in some cases, root growth (Richards 1993, Campbell and Bawtree 1998, Ferraro and Oesterheld 2002).

Recovery of a plant after defoliation can depend on a variety of factors but opportunity for growth (via resource availability and timing of defoliation) before defoliation or regrowth after defoliation plays an important role. Most plants require a sufficient amount of time to store energy during the growing season to maintain vigour; this can be related to time of year that grazing occurs, and how long animals remain in a pasture (time and timing) (Reed *et al.* 1999). The less time a plant has to recover from defoliation, the more negative the effects of defoliation will likely be (Ferraro and Oesterhel 2002). Grazing within certain times of the growing season can change how a plant responds; most often grazing a plant during dormancy at a higher intensity will not do as much damage compared to a plant that is actively growing or has its growing points elevated (Holechek *et al.* 2011, Ferraro and Oesterheld 2002, Branson 1956). Grazing plants in a vegetative stage often results in less damage as reproduction and carbohydrate storage is not active at this point and growing points are typically not elevated enough for grazing cattle to remove (depending upon the species) (Holechek *et al.* 2011, Branson 1956). There will be less opportunity for a plant to regrow when it is defoliated in a reproductive stage (elevated growing points and low carbohydrate levels) when compared to defoliation at a vegetative stage. It is the combination of intensity, frequency and opportunity that influences how a plant responds to defoliation. It is important to understand that grazing can modify plant vigour, growth and plant interactions with the surrounding environment in a multitude of complex ways, all of which can influence the over-all impact of grazing on plant vigour and growth (Hilbert *et al.*1981).

Plant species on rangelands will vary in their response to defoliation due to different morphological and physiological characteristics (Holechek *et al*. 2011). In order to manage range resources for long term sustainable livestock grazing, managers not only need to understand the concepts of plant growth and the principles that determine recovery after defoliation but also need to have a strong knowledge of the range areas they are managing. Range use history, species composition, climate, soils and disturbances are other factors that can influence plant productivity and vigour on rangelands and these factors can change over time. Regardless of what may cause these changes over time, it is important to know the effectiveness of management of range resources and determine how the range has changed over a period of time.

1.3 RANGELAND MONITORING

In 1949, Dyksterhuis developed a quantitative procedure for rangeland monitoring through evaluating range condition by measuring foliar cover of various plant species labeled as increasers, decreases and invaders and comparing them to the climax community (Dyksterhuis 1949, Briske *et al.* 2005). This procedure, known as the range condition method, is based on successional theory developed by Clements in 1916 (Briske *et al.*2005). Depending upon the proportion of these species found, the range is considered to be in “excellent, good, fair or poor” condition. To use this method it is suggested that permanent transects be put in place and re-monitored at 2 year intervals (Dykersterhuis 1949). This method considers what the rangeland should look like without human interference as well as having the desired plant community (what managers would like to see) (Dyksterhuis 1949). The range manager can adjust the management strategies accordingly to ensure objectives are being met. The desired plant community is one that has been decided upon to meet the needs and values of people with a vested interest in the management of the land and is set in place by a management plan (Borman and Pyke 1994). This means the desired plant community may not always reflect what would typically be seen on an undisturbed range site (climax plant community) and instead economic considerations (forage production) may require the desired plant community to be a different condition class (Dyksterhuis 1949).

The range condition model could only show change in a plant community along a single axis, from poor to excellent condition, and couldn’t account for other changes in a community such as invasive species, tree encroachment, fire, or other disturbances. Another model was introduced which accounts for the dynamics of plant communities and their abilities to have vegetation changes occur in more than one direction (Briske *et* *al.* 2005). The state and transition model can represent vegetation change along several different axes, some reversible and some not; these changes in vegetation can occur quickly (fire) or very slowly (encroachment of trees into grasslands) and can be caused by natural or anthropogenic events (Westoby *et al.* 1989). This theory acknowledges that ecological processes such as weather variation, soil erosion and fire can cause shifts in vegetation communities (Briske *et al.* 2005) and gives a better idea of overall rangeland health, not just range condition. This has lead to a range monitoring method that not only takes into account plant communities but other broader ecosystem properties (Briske *et al.* 2005) and is used between specific time periods to assess change.

From these two main models, range condition class and state and transition, different long term monitoring tools have been developed. In British Columbia, most past range assessments were based on the Dyksterhuis (1949) range condition concept (Campbell and Bawtree 1998). This method is still in use today but some modifications have been made to the methodology with the main one being that seral stages (early, mid, late and potential natural community) are used instead of condition classes. The state and transition model is the basis for two range health assessment methods currently used in BC, the British Colombia Ministry of Forest and Range Uplands Function Checklist assessment and the Grassland Monitoring Manual for British Columbia (Newman *et al.* 2011). The Uplands Function Checklist measures the following parameters: hydrology and soils, biotic/vegetation, erosion/deposition, and mineral cycle (Fraser 2009). The Grasslands Monitoring Manual measures the following parameters: plant community composition/structure, nutrient and hydrological cycle, site stability, and invasive plants (Delesalle 2009). These assessments can be used to monitor plant community change over time to observe a trend in range health. To observe a trend, accurate assessments of rangeland health should be conducted at the start and the end of a definitive time period (five years or more on native rangelands) (Vallentine 1990).

Regardless of what monitoring method is applied, the common methods of assessment involve long term monitoring over a period of several years to observe trends. Rangeland managers are often faced with limited time, money and personnel to return to assess these permanent monitoring sites at regular intervals (Campbell and Bawtree 1998) and this can often result in the rangeland being negatively impacted without detection. Short term (yearly) monitoring tools could prove to be a useful supplement to the existing long term monitoring tools. Determining impacts of grazing and disturbance on plant communities at the end of every growing season would provide opportunity for adaptive management of rangelands allowing range managers and livestock producers to plan ahead for future grazing.

1.4 THE GRAZING RESPONSE INDEX

As reviewed in a previous section, forage production in the BEC zones in the Southern Interior is heavily influenced by annual weather patterns. While current assessments tools are no doubt essential, combination with an annual grazing assessment tool that can factor in weather patterns and climate would enhance the ability of range managers to keep track of negative and positive impacts on range condition between years of more comprehensive rangeland health assessments.

In recent decades, climate change has become more prevalent causing fluctuations in weather patterns that influence plant growth which in turn has caused variances in how plants respond under grazing pressures as growing conditions change. Water availability in particular determines how well a plant grows before and after a grazing event (Rustad 2008). In British Columbia, it is expected that changes in precipitation may lead to increases in drought occurrences and an increase of the average temperature by 0.5°C per decade (Hamann and Wang 2006). The impacts of climate change on rangeland resources and the recognition that changes in range condition are not always easily detected between growing seasons. This indicates that something more is needed to aid land managers in meeting their objectives between the longer periods of time when rangeland condition or range health assessments are conducted. This is the reasoning for the creation of the Grazing Response Index (GRI). This index is a tool that gives a numerical score to rangeland after the end of the growing season of each grazing year. The scores are based on the three principles of plant growth: frequency, intensity and opportunity

(Reed *et al.* 1999). Each principle is scored and then all three are totaled to give a final GRI score. Based on the score given (positive, neutral or negative) the range manager can make important decisions on next year's grazing such as reducing stocking rates, increasing cattle dispersal or changing the season of use (Reed *et al.* 1999). Essentially the GRI is a supplemental management tool used on an annual basis to allow for adaptive management of rangelands. It is a tool that may work within the plant communities of the Southern Interior of British Columbia and would be beneficial to livestock producers and land managers in the years between larger and more comprehensive rangeland condition assessments and rangeland health assessments.

1.5 STUDY SITE

The wide variety of plant communities and range types within British Columbia can make determining an area for study sites difficult. The Lac du Bois Grasslands Protected area in Kamloops, British Columbia has provided many research opportunities due to its distinct environmental gradient (moisture gradient due to precipitation and elevation) which produces distinct plant communities (Ministry of Environment, Lands and Parks 2000). The surrounding area also provides several distinct vegetation zones common throughout the Southern Interior making it an ideal area to conduct research. Livestock grazing, homesteading and recreation have been common place in this area for the last 150 years and for a better part of the 1900s much of it was overgrazed by cattle and horses (Campbell and Bawtree 1998, Ministry of Environment, Land and Parks 2000). Since 1976 rotational grazing has been in place in the pastures of Lac du Bois and this, along with restricted motorized recreation, has allowed the area to begin recovering from past use events (Ministry of Environment, Lands and Parks 2000).

The soils of Lac du Bois are most commonly Chernozems. The lower grasslands tend to have dry, thin, well drained soils which make these areas sensitive to disturbance and making the cryptogrammic crust particularly important in these areas for preventing erosion (Ministry of Environment, Lands and Parks 2000). These areas also tend to have lower species diversity and soils that are well drained compared to other areas (Ministry of Environment, Lands and Parks 2000). As the elevation rises, soils contain more gravely till which provides better moisture retention for plants and with increase plant community biomass, darker chernozemic soils occur (Ministry of Environment, Lands and Parks 2000).

Species such as bluebunch wheatgrass (*Pseudoroegneria spicata*) and big sagebrush (*Artemitia tridentata*) are the dominant plant species found at the lower elevations. With increasing elevations, big sagebrush becomes less dominant but still is present in the middle grasslands, while bluebunch wheatgrass remains the dominant grass species and needle and thread grass (*Hesperostipa comata*) becomes more prevalent. Arrow leaf balsam root (*Balsamorhiza sagittata)*, nodding onion (*Allium cernuum*), mariposa lily (*Calochortus macrocarpus*) and Thompson's paintbrush (*Castilleja thompsonii)* are all common throughout the lower and middle grassland phases (Ministry of Environment, Lands and Parks 2000).

Rough fescue (*Festuca campestris)* becomes the dominant grass species in the upper grasslands while bluebunch wheatgrass can still be found on some sites and aspen trees (*Populus tremuloides*) can be found in wetter areas (Ministry of Environment, Lands and Parks 2000). A host of other flowering plants and some shrubs are found in the upper grasslands as well, including arrow leaved balsam root, upland larkspur (*Delphinium nuttallianum*), chocolate lily (*Fritillaria lanceolata*), sticky geranium (*Geranium viscosissimum*) and few flowered shooting star (*Dodecatheon pulchellum*). Forage production in these grassland zones can be as low as 110 kg/ha on the dry lower grassland sites but up to 1300 kg/ha in the upper grassland areas (Wikeem *et al.* 1993, Campbell and Bawtree 1998). This large difference in production is primarily due to soil moisture which increases with elevation (Wikeem *et al.* 1993, Campbell and Bawtree 1998).

Just outside the upper borders of Lac du Bois is the forested zone where much grazing still occurs. This area ranges from very open canopy forests to closed canopy forests. Pinegrass (*Calamagrostis rubescens*) is the dominant grass species in this area. Many other forbs and shrubs are abundant such as wild strawberry (*Fragaria virginiana*), northern bedstraw (*Galium boreale*), tiger lily (*Lilium columbianum*), common red paintbrush (*Castellija miniata*), soopolallie (*Shepherdia canadensis*), tall Oregon-grape (*Mahonia aquifolium*) and common snowberry (*Symphoricarpos albus*). Forage production varies depending upon species composition, precipitation averages and the amount of canopy closure but it can range from being unproductive in mature stands, up to 900 kg/ha in open canopy or cut block sites (Wikeem *et al.* 1993, Campbell and Bawtree 1998).

1.6 OUTLINE OF THESIS

Chapter 2 will present the research conducted through manipulation experiments in Lac du Bois Grassland Provincial Park and outlying area near Kamloops, British Columbia. The study is based on three dominant plant species found in distinct plant communities: bluebunch wheatgrass in the lower grassland, rough fescue in the upper grassland and pinegrass in the Interior Douglas-fir zone. The main research of this study involves clipping each species at specific frequency and intensity levels and determining the impact on plant vigour. Chapter 3 takes the information from Chapter 2 and uses it to determine if the Grazing Response Index is a short term monitoring tool that can aid in the management of rangelands in the Southern Interior of British Columbia.

CHAPTER 2: EFFECT OF FREQUENCY AND INTENSITY OF CLIPPING ON BLUEBUNCH WHEATGRASS (*Pseudoroegneria spicata*), ROUGH FESCUE (*Festuca campestris*) AND PINEGRASS (*Calamagrostis rubescens*) IN THE SOUTHERN INTERIOR OF BRITISH COLUMBIA

2.1 INTRODUCTION

Over the last century, studies involving the clipping of various grass species have been a common way to simulate grazing pressure in a variety of plant communities. Many studies have focused on the response of a plant to various levels of defoliation (intensity), the number of times defoliation occurs (frequency), and the time (season) at which the defoliation occurs. The information gained from these studies resulted in the development of many useful tools for evaluating the effects of grazing on plant communities and specific plant species. As more and more is learned, we continue to create new management practices and refine others. This study focuses on the recovery of plants after clipping at varying frequencies and specific intensity levels with consideration for soil moisture and weather patterns. The three key grass species in the Southern Interior: bluebunch wheatgrass (*Pseudoroegneria spicata*), rough fescue (*Festuca campestris*), and pinegrass (*Calamagrostis rubescens*) are the focus of this research as they make up the majority of grazed species within their respective plant communities. Bluebunch wheatgrass has been the subject of many clipping studies while fewer studies have focused on rough fescue and pinegrass.

Bluebunch wheatgrass has been the subject of many studies in the Pacific Northwest region of the United States, while fewer studies have focused on the northern communities of bluebunch wheatgrass in Canada, specifically in British Columbia (BC). This species is an important forage source for livestock and wildlife and is found throughout the grasslands of BC, but dominates in the lower and middle grasslands (Ministry of Environment, Lands and Parks 2000, Wikeem and Wikeem 2004). In a study by McLean and Wikeem (1985a) in the Southern Interior, bluebunch wheatgrass plants were subjected to 10 different clipping treatments which varied in either the date and frequency of clipping, or intensity of clipping. They found that clipping bluebunch wheatgrass to a stubble height (amount of herbaceous material remaining after defoliation) of 5 cm on a weekly basis between the end of April and May resulted in high mortality, or significantly reduced vigour in the surviving plants at a lower grassland site. At a similar lower grassland site, the same result was found when plants were clipped to a stubble height of 5 cm on a weekly basis between mid May and late June. The clippings described above occurred when bluebunch wheatgrass was in its boot stage (transition from vegetative to reproductive) or early flowering stage, which is more susceptible to injury (Quinton *et al.* 1982). At this time the plant has used much of its carbohydrate storage, and would likely not have opportunity for regrowth before summer dormancy when clipped to such levels (McLean and Wikeem 1985a). Weekly clipping at a 20 cm stubble height, season long when compared to clipping only in the fall showed no significant difference in plant health when compared to the control treatment whereas weekly clipping to a stubble height of 15 cm and 10 cm from mid April to summer dormancy resulted in moderate to heavy mortality at both sites (McLean and Wikeem 1985a). Clark *et al.* (1998) found that live basal area of bluebunch plants decreased when the whole plant was clipped to a stubble height of 7.6 cm, compared to control plants (unclipped) and plants that only had half of their biomass cut to 7.6 cm which both saw an increase in live basal area.

The general trend of published research shows that early defoliation of bluebunch results in limited negative effects on plant vigour as long as the plant has enough time to regrow prior to summer dormancy but with later, more frequent, or higher intensity defoliation, more deleterious effects occur (Blaisdell and Pechanec 1949, Mclean and Wikeem 1985a, Quinton *et al.* 1982, Clark *et al.* 1998, Meays *et al.* 2000). Quinton *et al.* (1982) showed that fall grazing when the plant is dormant will not cause injury to the plant itself and will remove unpalatable stems, allowing for better quality forage the following spring, however; Ndwala-Senyimba *et al.* (1971) and Wikeem *et al.* (1989) found that removing the canopy structure of bluebunch wheatgrass can result in less rain and snow capture and less protective litter which may result in reduced growth the following year.

Rough fescue is another very important forage species in regions of BC and is the dominant grass species in the upper grasslands, but is also found the middle grasslands and occasionally in the lower grasslands on north and east facing slopes (Stout *et al*. 1980). McLean and Wikeem (1985b) found high mortality or severely reduced vigour in rough fescue plants that were defoliated to a 5 cm stubble height weekly from mid-May to late June. Willms (1991) also found that rough fescue was very susceptible to negative impacts of defoliation during the growing season, regardless the frequency or intensity of clipping. In McLean and Wikeem's (1985b) study, when clipping was stopped before the end of vegetative growth or when stubble heights of 10 cm, 15 cm and 20 cm remained, injury to the plant was reduced. Limiting defoliation to the fall was the only treatment which did not show adverse effects to, or reduced vigour of, the plant. In a greenhouse study, King *et al.* (1998) noted that rough fescue declined in vigour when defoliated multiple times (clipped three times to 3.5 cm at four week intervals followed by ten weeks of 16 hour photo-periods) in a season compared to a single defoliation at the end of the growing season. Summer appears to be the most detrimental time to defoliate rough fescue because this species appears to have reduced resilience at temperatures that are above their optimal growing condition of 17^{o}C day time temperature and13^{o}C night time temperature (King *et al.* 1998).

Though bluebunch wheatgrass and rough fescue are important forage species and provide the majority of grazing biomass within their own ecosystems, these species are mainly located in the Bunchgrass zone of the province; this zone in total makes up approximately 300,000 hectares (Campbell and Bawtree 1998). When including the grassland phase of the Interior Douglas-fir zone, grassland area increases to 1.2 million hectares of the total rangeland within the province (Campbell and Bawtree 1998). Pinegrass, though providing lower amounts of biomass per unit area than fescue and bluebunch, is the dominant species in the Interior Douglas-fir and Montane Spruce zones and is also present in 4 other zones (Ministry of Forests 1997). Within the Interior Douglas-fir zone alone, pinegrass accounts for 50% of forage and 80% of total plant cover in the understory (Mclean 1967, McLean 1972).

It appears that pinegrass growth periods are related more heavily to environmental conditions than to specific plant characteristics. This can make it difficult to manage this species at a specific grazing level without considering environmental conditions such as precipitation and temperature (Stout and Quinton 1986). The quality of pinegrass forage decreases significantly as the plant matures, and often is unpalatable to livestock by late summer (McLean 1967) though some fall re-growth can occur in late August and September if environmental factors (mainly soil moisture) are favourable (Stout and Brooke 1985a, Stout *et al.* 1980). Freyman (1970) conducted clipping research on plots of pinegrass for three years with twelve different treatments. All clipping was done to a 15 cm stubble height because pinegrass is seldom grazed lower because of unpalatable material. Plots clipped multiple times during the growing season showed reduced protein levels versus plots clipped once or twice in August (Freyman 1970). Plots clipped once in June or once in July and once in August tended to yield more protein than plots clipped only once or twice in August (Freyman 1970). All clipping treatments (done bi-weekly) from Stout *et al.* (1980) resulted in decreased yield in the following year, with clipping to 15 cm during growing season and clipping to 5 cm during dormancy, resulting in the least amount of yield decrease. Tiller number was also severely affected in clipping treatments that had a stubble height of 5 cm, and clipping from May 15 to September 15, July 1 to September 15, and May 15 to August 1. Pinegrass seems to respond negatively to more severe treatments (higher intensity of biomass removal) but this can vary based on the time of clipping and environmental factors.

Many studies conclude that grazing pinegrass is most detrimental in mid-July, after the active growing phase and before summer dormancy (Freyman 1970, Stout *et al.* 1980, Stout and Brooke 1985a). Freyman (1970) recommended either grazing pinegrass from July until September, or grazing for two weeks in the beginning of June and again for two weeks at the beginning of August. Stout *et al.* (1980) preferred the later recommendation made by Freyman (1970), but recommended that if the range must be grazed in July, it should have a subsequent year of rest.

There is no shortage of literature on simulated grazing through clipping; however, a majority of the literature relates the amount of use in terms of stubble height rather than intensity of clipping. While stubble height gives a clear indication of amount remaining, percent utilization cannot be determined from this measurement without knowing the initial size of the plant, or by determining which stubble height equals a specific amount of photosynthetic material removed. Using specific intensity percentages (*e.g.* 40% removal of biomass) and frequency may provide managers with more information on the impact of grazing by livestock on rangelands.

Another useful source of information on the recovery of range plants after grazing is initial regrowth. Often in the current literature, clipped plants are measured bi-weekly or monthly after clipping, or even annually to determine impact on plant vigour. These measurements are useful and provide important information on plant recovery, but this does not capture the initial recovery of plants, or the initial impact on plant vigour. Large changes occur within a plant in the hours after defoliation (inhibited root function and reduced carbohydrate pools) while certain compensatory processes begin (allocation of carbon and nitrogen) to aid in the recovery of photosynthetic material (Richards 1993). Studying the recovery process after defoliation could improve understanding of the effects environmental factors have on plant regrowth as well as the state of the defoliated plant during recovery; delayed recovery may result in lower vigour for the remainder of the growing season (Richards 1993).

The objective of this study was to determine how varying levels of frequency and intensity of simulated grazing (clipping) impact the vigour of bluebunch wheatgrass, rough fescue and pinegrass plants as indicated by regrowth, biomass, tiller number and canopy height. This was done over two growing seasons and looked to meet the following objectives:

1. Determine if regrowth of bluebunch wheatgrass, rough fescue and pinegrass is impacted by intensity of treatment or soil moisture within the first two weeks after clipping.

2. Determine how biomass, tiller number and canopy height of bluebunch wheatgrass, rough fescue and pinegrass is impacted through treatments of various frequency and intensity clippings and whether intensity and frequency have interacting effects in biomass, tiller number and canopy height.

2.2 MATERIAL AND METHODS

Study sites

The study was conducted in the Lac du Bois Grasslands Protected area (upper and lower grasslands) and Pass Lake (Interior Douglas-fir zone), North of Kamloops, British Columbia. The soils in Lac du Bois are predominantly chernozemic with orthic brown chernozems in the lower grasslands, orthic black chernozems in the upper grasslands and orthic luvisols in the Interior Douglas-fir zone (Ministry of Environment, Lands and Parks 2000). The geographical features in Lac du Bois and surrounding area are primarily due to past glaciation and glacial deposits (Ministry of Environment, Lands and Parks 2000). The area rises in step-formation from the valley bottom into the higher elevations, with rolling hills and small mountains in the grassland area reaching up to 1400 m (Ministry of Environment, Lands and Parks 2000).

This elevation gradient contributes to the presence of a large number of diverse ecosystems and plant communities, which within the grassland area, are divided into lower (300-700 m), middle (700-1000 m) and upper grasslands (900-1000 m) (Campbell and Bawtree 1998). The upper grasslands border the Interior Douglas-fir zone (IDF) (Ministry of Environment, Lands and Parks 2000). Within these communities there is an abundance of grass and herbaceous species, some of which dominate more than others. In the lower grasslands, bluebunch wheatgrass is the dominant grass species and as the elevation increases into the middle and upper grasslands, rough fescue becomes more abundant and bluebunch becomes slightly less abundant. Transitioning from open grasslands into the IDF, bluebunch wheatgrass and rough fescue decrease in abundance and pinegrass becomes the dominant grass species as canopies become more enclosed. Data collection sites were located near weather stations currently established in Lac du Bois and in pre-existing exclosures (Fig. 2). These exclosures were built to keep out cattle but would not limit grazing by other animals.

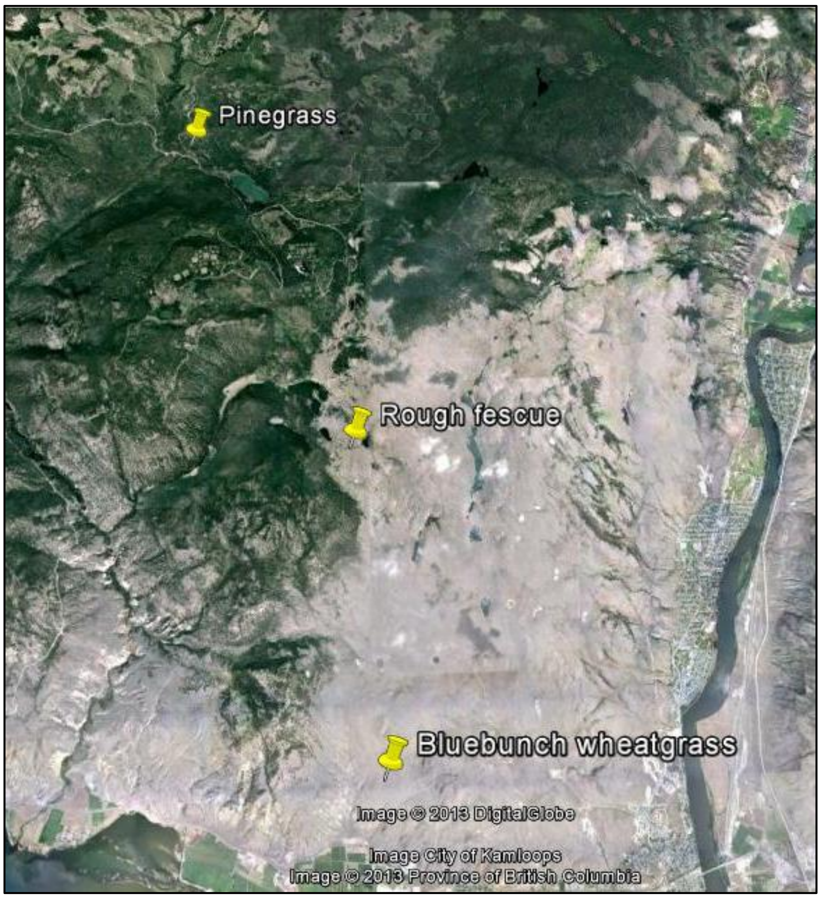


Figure 2: Aerial image of study sites. Bluebunch wheatgrass and rough fescue sites fall within the Lac du Bois Grasslands Protected area boundaries, while the pinegrass site lies within an unused pasture on Agriculture and Agri-Food Canada property (Google Earth 2013).

The bluebunch wheatgrass exclosure was located in the lower grasslands of the Thompson Very Dry Hot Bunchgrass variant (BGxh2) at an elevation of 566 m with a south facing aspect. The selected research plants within the exclosure were estimated to occupy 900 m^2 of the exclosure while the exclosure itself was approximately 1800 m^2. This area typically receives between 230 mm-250 mm of precipitation annually (Campbell and Bawtree 1998). Other native plants species found within this area included big sage brush (*Artemisia tridentata*), balsam root (*Balsamorhiza sagittata*), Sandberg's bluegrass (*Poa secunda*), prickly pear cactus (*Opuntia fragilis*), pasture sage (*Artemisia frigida*), long-leaved daisy (*Erigeron corymbosus*), Thompson's paintbrush (*Castilleja thompsonii*), and sage brush mariposa lily (*Calochortus macrocarpus*).

The rough fescue exclosure was located in the Thompson Very Dry Hot Interior Douglas-fir (IDFhx2) variant at an elevation of 903 m with an east facing aspect. Estimated size of exclosure was determined to be 800 m^2, with the study plans occupying half of this space. Annual precipitation averages vary between 300 mm and 700 mm (GCC 2011). Rough fescue was the primary plant within the area, but there was a presence of yellow rattle (*Rhinanthus minor*), few-flowered shooting star (*Dodecatheon pulchellum*), common harebell (*Campanula rotundifolia*), pasture sedge (*Carex petasata*), nodding onion (*Allium cernuum*), yellow bell (*Fritillaria pudica*), chocolate lily (*Fritillaria lanceolata*), and sticky geranium (*Geranium viscosissimum*). Prickly rose (*Rosa acicularis*) was also found, but only in the north-eastern corner of the exclosure. The surrounding area contains a few trembling aspen (*Populus tremuloides*) copses and isolated Douglas-fir (*Pseudotsuga menziesii var. glauca*) trees.

The pinegrass exclosure was near Pass Lake in the Thompson Dry Cool Interior Douglas-fir (IDFdk1) variant at an elevation of 998 m. The area within the exclosure occupied by the selected plants was approximately 7000 m^2, this is such a large number because plants were spread throughout the exclosure in order to make sure each sample was located in similar growing conditions to all others. The total area of the exclosure was approximately 120,000 m^2. Annual precipitation averages vary between 300 mm and 700 mm (GCC 2011). The dominant tree species is the Douglas-fir, intermixed with trembling aspen and lodgepole pine (*Pinus contorta*). A wide array of plant species are found in this area including shrubs such as soopolallie (*Shepherdia canadensis*), tall Oregon-grape (*Mahonia aquifolium*), common snowberry (*Symphoricarpos albus*), twinflower (*Linnaea borealis*), kinnikinnick (*Arctostaphylos uva-ursi*) and prickly rose (*Rosa acicularis*). In addition, many forbs such as field pussytoes (*Antennaria neglecta*), common red paintbrush (*Castellija miniata*), common harebell (*Campanula rotundifolia*), wild strawberry (*Fragaria virginiana*), northern bedstraw (*Galium boreale*), tiger lily (*Lilium columbianum*), and showy daisy (*Erigeron speciosus var. speciosus*) are also found in the area.

Experimental design

For each of the three species, 75 individual plants were selected in a semi-random fashion. In order to reduce variability, all 75 plants were selected to be of average size and shape. Plants were marked with pin flags labeled with treatment details and individually numbered with metal tags staked into the ground near the base of the plant. Plants were randomly assigned a treatment using a random number generator. Including a control treatment, a total of five clipping treatments (n=15) were applied:

- Control – no clipping
- Clipped once at 40% removal – frequency of 1, intensity of 40% (F1I40)
- Clipped once at 70% removal – frequency of 1, intensity of 70% (F1I70)
- Clipped three times at 40% removal – frequency of 3, intensity of 40% (F3I40)
- Clipped three times at 70% removal – frequency of 3, intensity of 70% (F3I70)

Plants were clipped to approximately forty and seventy percent removal of photosynthetic material (intensity) and were clipped one or three times, with the multiple clippings each occurring one week apart (frequency). For multiple frequency clippings, the second and third removal of biomass was done at 40% of the original volume, not by remaining volume (all three clippings where done to the same height). All three plant species received the same treatments however, clipping dates varied due to the elevation/temperature gradient (lower elevations initiate growth before higher elevations) and clipping also took into consideration when these species are typically grazed on rangelands in BC. The amount of photosynthetic material removed was determined by clipping 10 plants from each species one week before initial clippings. Using these clippings, a height versus weight regression analysis was conducted to determine what stubble height plants needed to be clipped at to obtain a specific intensity (Appendix 1); this followed the methods of Lommasson and Jensen (1943). To obtain 40 and 70% removal, bluebunch wheatgrass was clipped to respective stubble heights of 16.5 cm and 8.3 cm. Rough fescue was clipped to respective stubble heights of 17 cm and 8.7 cm and pinegrass was clipped to respective stubble heights of 16.4 cm and 8 cm.

Measurements

Clipping and biomass

Timing of clipping was based on growth of plants: boot/head stage for bluebunch wheatgrass, heading stage for rough fescue, and 3 leaf stage for pinegrass. Both years of treatments were applied during the same growth stage. In the first year (2011) bluebunch wheatgrass was clipped initially on May 19th, and twice more at one week intervals for high frequency treatments. Rough fescue was clipped initially on June 6th, and twice more at one week intervals for high frequency treatments. Pinegrass was clipped initially on June14th, and twice more at one week intervals for high frequency treatments. Initial clippings were bagged, dried and weighed but second and third clippings were not. The same plants were clipped for the second year of treatment (2012) but initial dates changed due to growth stage. Bluebunch wheat grass was clipped on May 10th, rough fescue on May 31st and pinegrass on June 5th. All clippings from each time period were oven dried in brown paper bags at 60°C until a constant weight was reached and samples were then weighed. After final measurements in the last year of study, all plants were clipped to ground level for final biomass.

Regrowth

Regrowth was measured on all single clipping treatments (F1I40 and F1I70). Immediately after initial clipping, ten tillers were randomly selected along a linear line through each plant, marked with different color paper clips, and were measured by length to the nearest millimeter. Paper clip color ensured that tiller growth over time was accurately recorded and tracked. Length measurements were taken again on each of the five, seven, nine, eleven and thirteen days after initial clipping to see a change in regrowth over time. The change in length between measurement days was calculated to achieve cumulative regrowth over 13 days.

Tiller count and canopy height

Live tillers were counted to determine total tiller count. Canopy height was determined by measuring the ten tallest live tillers and then averaging those numbers. A tiller was determined to be live as long as it was visibly green. These measurements were done on all 225 individuals. All samples were measured once prior to treatment application and then were measured once every two weeks until the beginning of August. During August, species growth slows due to high temperatures and low soil moisture and measurements were then taken monthly until the end of the growing season. In 2011, the final measurements dates were October 6th for bluebunch wheatgrass, October 31st for rough fescue, and October 4th for pinegrass. In 2012 the last measurement dates for bluebunch, fescue and pinegrass were September 27th, October 18th, and September 25th respectively.

Due to high numbers of tillers on rough fescue plants, tillers were only counted for a quarter of each plant. Measurement triangles were fabricated with a 90 degree angle with sides of 35 cm and an area of 306 cm^2 to ensure the measurement of a quarter of the plant. Rough fescue plants were measured to find the plant center where a pin flag was then placed and an additional pin was placed in the right corner of the triangle to ensure placement of the triangle was consistent. Canopy height for rough fescue was still measured over the entire plant. Due to the rhizomatous growth form of pinegrass, identifying an individual plant was not a possibility; therefore a 35 cm x 35 cm portable square was used to designate the measurement area to approximate an individual plant and obtain an adequate number of tillers for measurements. To mark plots, pin flags were placed in opposite corners of square to ensure consistency of measurements.

Soil moisture and soil temperature

A POGO Portable Soil Sensor paired with Stevens Hydra Probe II and Stevens HydraMon Windows CE program was used for determining soil moisture and soil temperature at each field site. On every measurement day, this probe was inserted to a depth of 6 cm within 15 cm of the base of each individual plant. The measurements of soil moisture are given in Volumetric Water Content (VWC) which is essentially a water to soil ratio. Data are presented in decimal form but can be related to the percentage of water found in the soil by multiplying by 100.

Statistical analysis

All data were transformed into logarithmic scale for statistical analysis but figures presented show untransformed data. Biomass, tiller count and canopy height data, even after transformation, could not be considered normal but the ANOVA is considered robust enough to accommodate this (McDonald 2009). The Shapiro-Wilk test was used to determine normality. Non-cumulative regrowth and soil moisture were analyzed using regressions to determine correlations between the two factors. Cumulative regrowth was also analyzed for differences between treatments using a linear mixed model (repeated measures). One-way ANOVA was used to analyze final and cumulative 2012 biomass, tiller counts and canopy height. A source of variation table for the one-way ANOVA is shown below (Table 1). Two-way ANOVAs were also used for these measurements to observe interactions between frequency and intensity. A source of variation table for the two-way ANOVA is also shown below (Table 2). If ANOVAs revealed a significant difference ($P \leq 0.05$), a Tukey's HSD *post hoc* was conducted. Since the tiller counts are a repeated measures experiment, it was decided to select the highest and lowest tiller counts in each year, for each plant, to create the maximum and minimum tillers counts to analyze so that standard ANOVAs could be used in place of repeated measures statistics. Data was only analyzed within each measurement year; there was no statistical comparison between years. Significance levels were set at $P<0.05$, however due to potential ecological significance and importance of this information for managers, P-values significant to 0.1 will be discussed as trends. All data was analyzed using the statistical program R (R Core Team 2012).

Table 1: Source of variation for one-way ANOVA.

Source	**Degrees of Freedom**	**Mean Square**	**F**
Treatment (between groups)	5-1=4	SS_t/df	MS_t/MS_e
Error (within groups)	75-5=70	SS_e/df	
Total	75-1=74		

Table 2: Source of variation for two-way ANOVA.

Source	**Degrees of Freedom**	**Mean Square**	**F**
Factor A (Frequency) (between groups)	2-1=1	SS_a/df_a	MS_a/MS_e
Factor B (Intensity) (between groups)	2-1=1	SS_b/df_b	MS_b/MS_e
Interaction	(2-1)(2-1)=1	SS_{ab}/df_{ab}	MS_{ab}/MS_e
Error (within groups)	60-4=56	SS_e/df_e	
Total	60-1=59		

2.3 RESULTS

Weather

Weather stations near each species site have been in place since 1979 and long term averages were used to create growing season climate normal's for each site over a period of 32 years (1979-2010) with one exception of pinegrass climate normal's in April which reflected 8 years (2002-2010). Data from the 2011 and 2012 measurement years have been compiled together with climate averages in figures 3-5. The bluebunch wheatgrass site appears to have had both average high and average low temperatures in 2011 and 2012 that were outside of the climate normal (Fig. 3a and 3b). Precipitation in 2011 was slightly above normal in May, but appeared to be lower in the fall. Precipitation in 2012 peaked in June significantly above the climate normal (Fig. 3c). The rough fescue site had temperature ranges within the standard deviation of the climate normal in both years (Fig. 4a and 4b) while precipitation showed the same trend as for the bluebunch wheatgrass site (Fig. 4c). The pinegrass site had temperatures within the standard deviation of the climate normal in both years (Fig. 5a and 5b). Again precipitation in both years is greater in the spring and lower in the fall when compared to the climate normal (Fig. 5c).

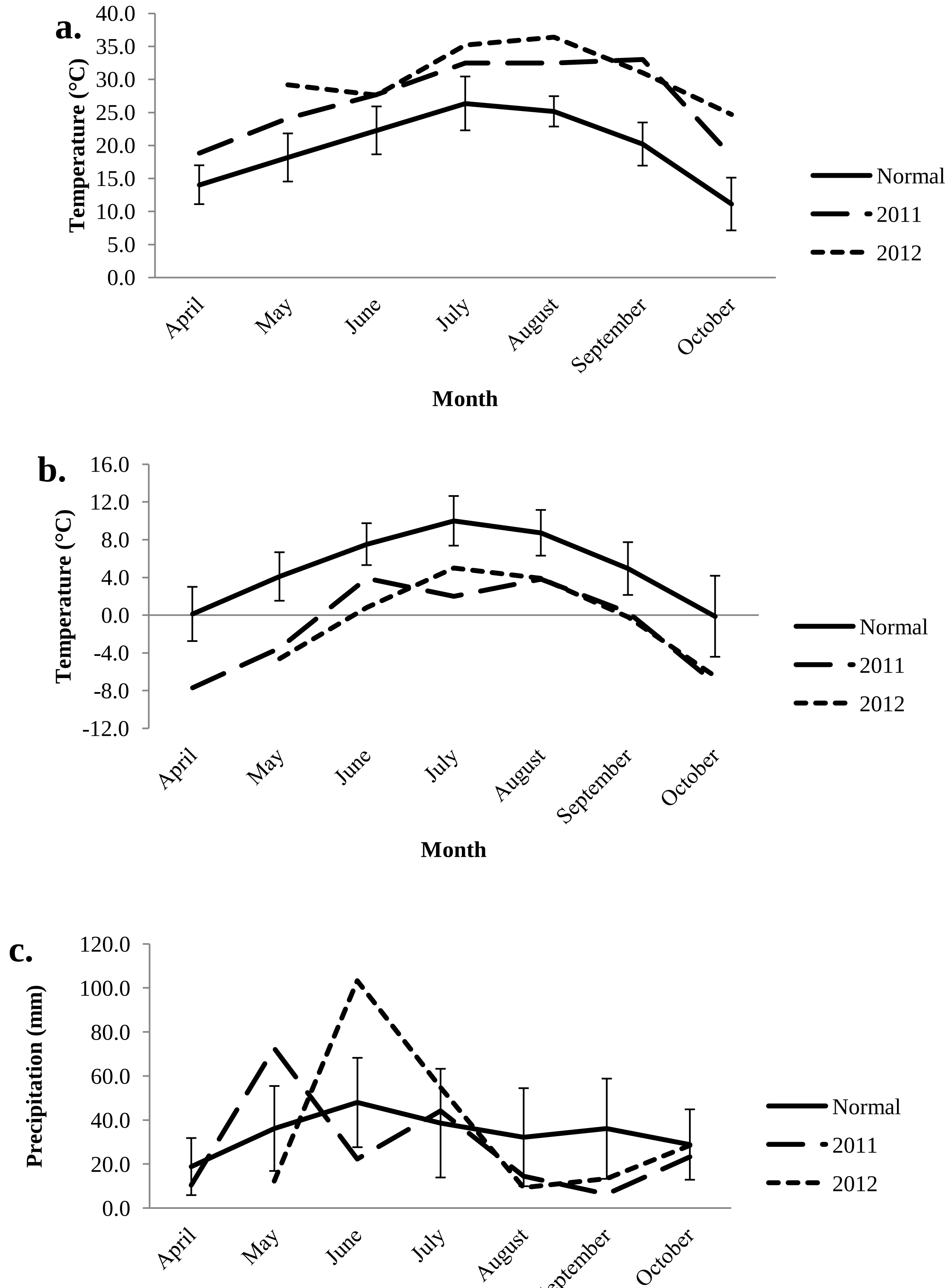


Figure 3: Climate normal and 2011 and 2012 weather data for bluebunch wheatgrass site. a). Average high temperature (°C). b). Average low temperature (°C). c). Precipitation (mm). Error bars on climate line indicate standard deviation of untransformed data.

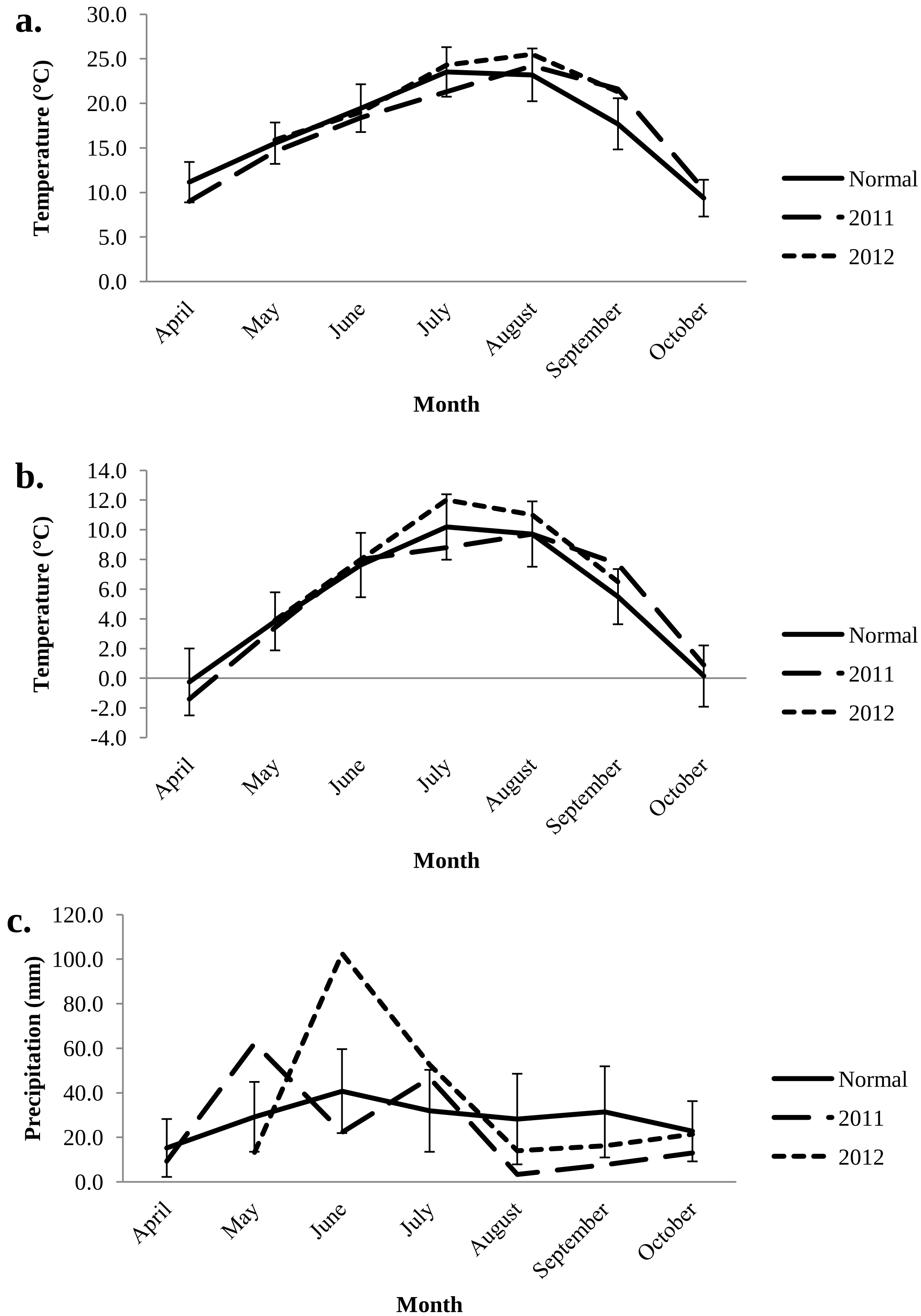


Figure 4: Climate normal and 2011 and 2012 weather data for rough fescue site. a). Average high temperature (°C). b). Average low temperature (°C). c). Precipitation (mm). Error bars on climate line indicate standard deviation of untransformed data.

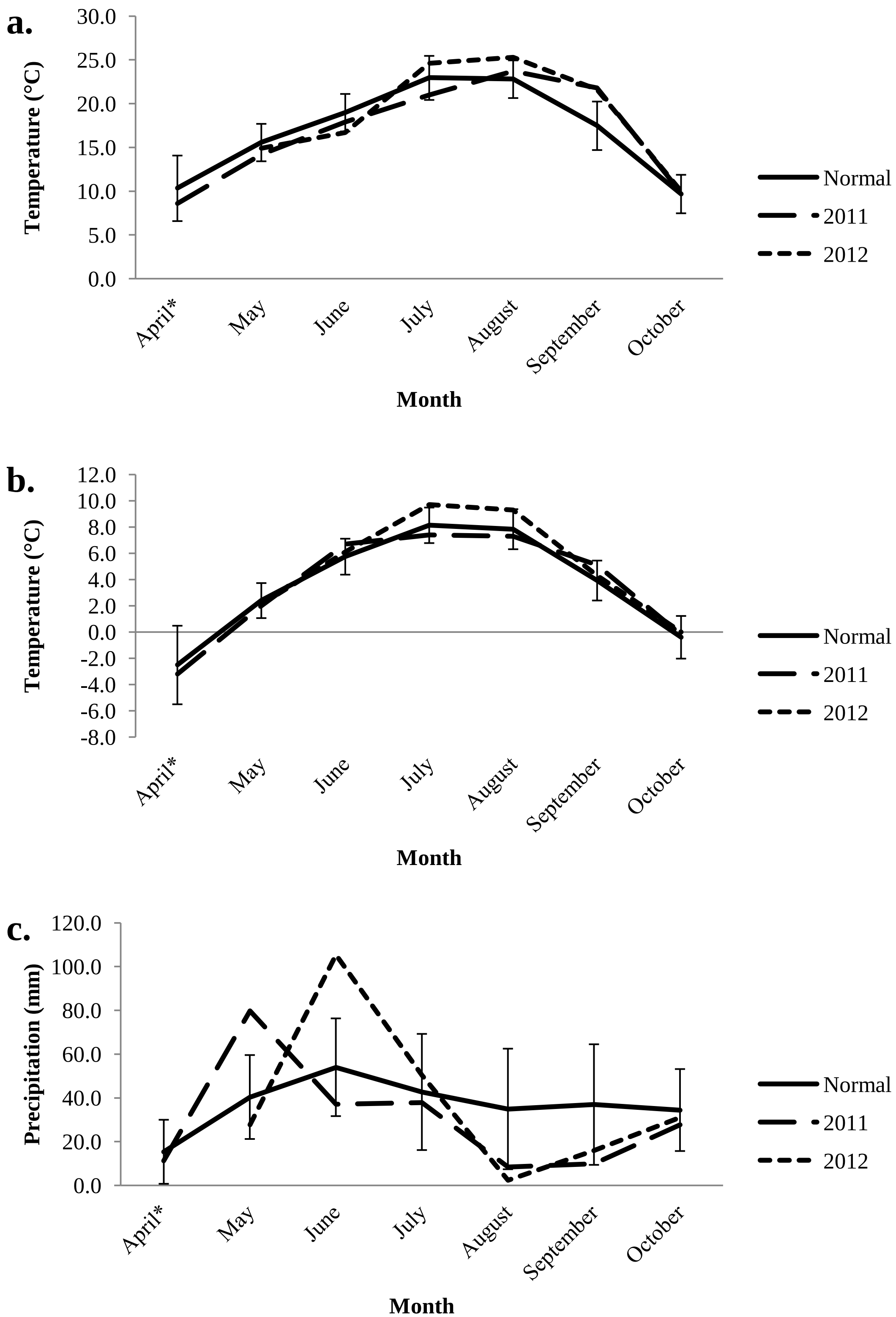


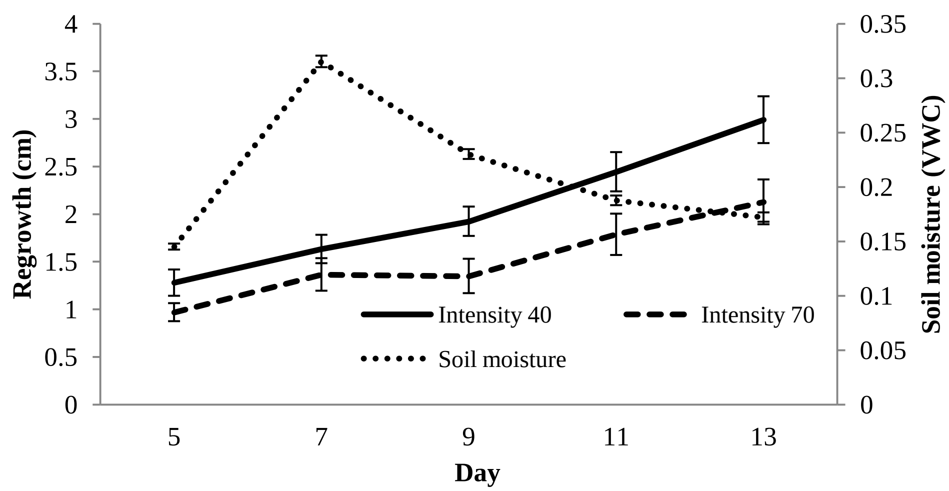
Figure 5: Climate normal and 2011 and 2012 weather data for pinegrass site. a). Average high temperature (°C). b). Average low temperature (°C). c). Precipitation (mm). Error bars on climate line indicate standard deviation of untransformed data. * April climate average only includes 8 years of data.

Regrowth and soil moisture

Bluebunch wheatgrass

In 2011, the statistical analysis of cumulative regrowth between the low intensity treatment (I40) and high intensity treatment (I70) showed no significance (Fig. 6a) ($P \leq 0.05$), (DF = 144, P = 0.0878). Using the soil moisture data, a regression was done for 2011 non-cumulative regrowth and 2011 soil moisture collected at the time of regrowth measurements. While the R-squared value was relatively low ($R^2 = 0.1111$) the regression showed a correlation between non-cumulative regrowth and soil moisture (F = 16.21, DF = 131, *Significance* F = 9.55E-05). In 2012, cumulative regrowth of the low intensity and high intensity treatments was similar (Fig. 6b) and no significance between treatments was found (DF = 144, P = 0.11). The regression of soil moisture and non-cumulative regrowth for 2012 showed a slightly higher R-squared value than that in 2011 ($R^2 = 0.2737$) and a correlation between non-cumulative regrowth and soil moisture (F = 23.83, DF = 68, *Significance* F = 6.82E-06).

a.



b.

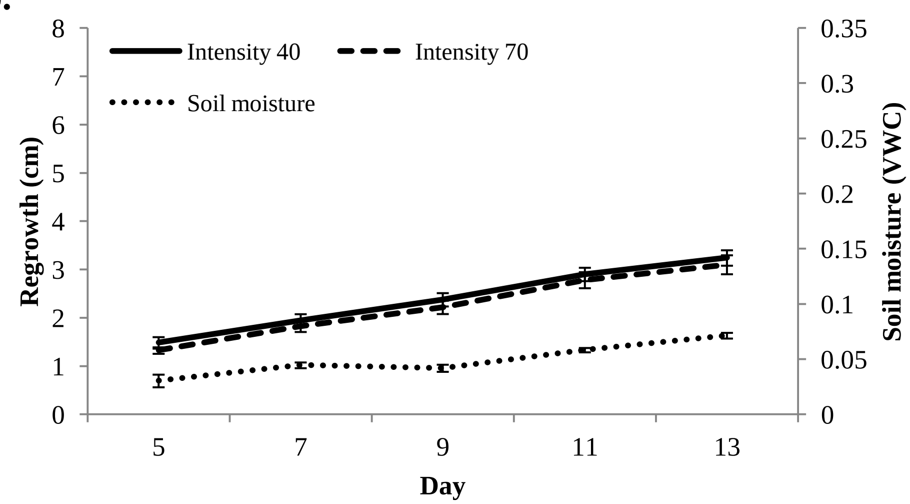
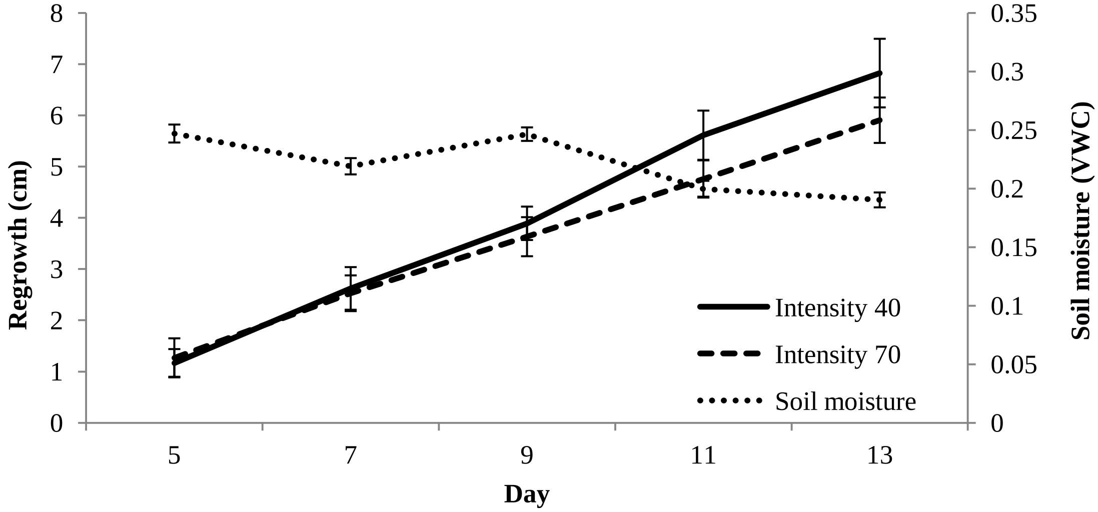


Figure 6: Cumulative regrowth (cm) and soil moisture (VWC) of bluebunch wheatgrass, 5, 7, 9, 11, and 13 days after removing 40% or 70% of total biomass. a.) Bluebunch wheatgrass regrowth and soil moisture in 2011. b.) Bluebunch wheatgrass regrowth and soil moisture in 2012**.** Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data.

Rough fescue

In 2011, cumulative regrowth of the low intensity treatment was not different than that of the high intensity treatment (Fig. 7a) (DF = 144, P = 0.1248). The regression of soil moisture and non-cumulative regrowth for 2011 showed a very low R-squared value (R^2 = 0.0242) and showed no correlation between regrowth and soil moisture (F = .442, DF = 141, *Significance* F = 0.507). In 2012, cumulative regrowth of the low intensity and high intensity treatments was similar (Fig. 7b) and no significance between treatments was found (DF = 144, P = 0.3261). The regression of soil moisture and non-cumulative regrowth for 2012 showed a slightly higher R-squared value than that in 2011 (R^2 = 0.0799) and correlation between non-cumulative regrowth and soil moisture was found (F = 12.54, DF = 147, *Significance* F = 0.000534).

a.



b.

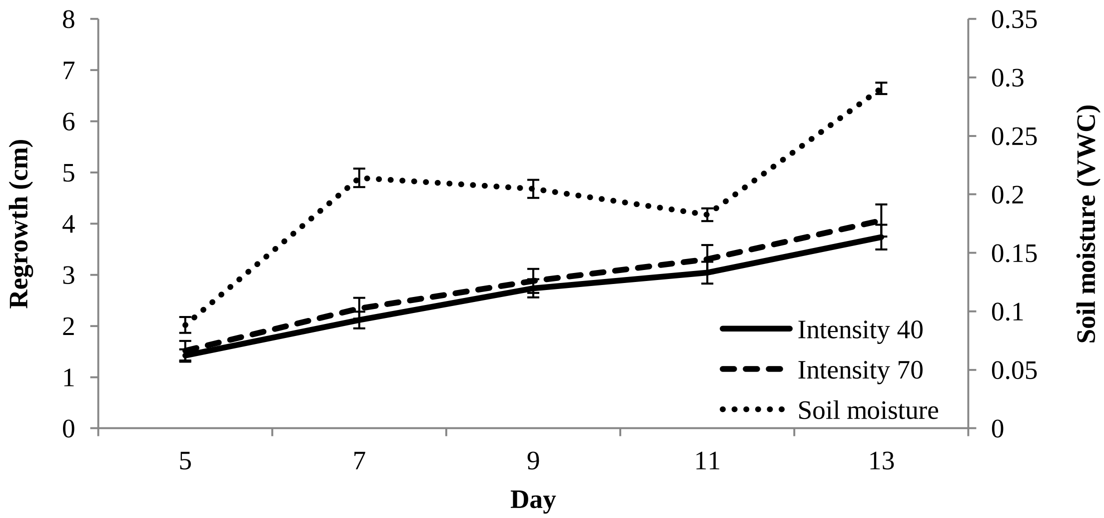
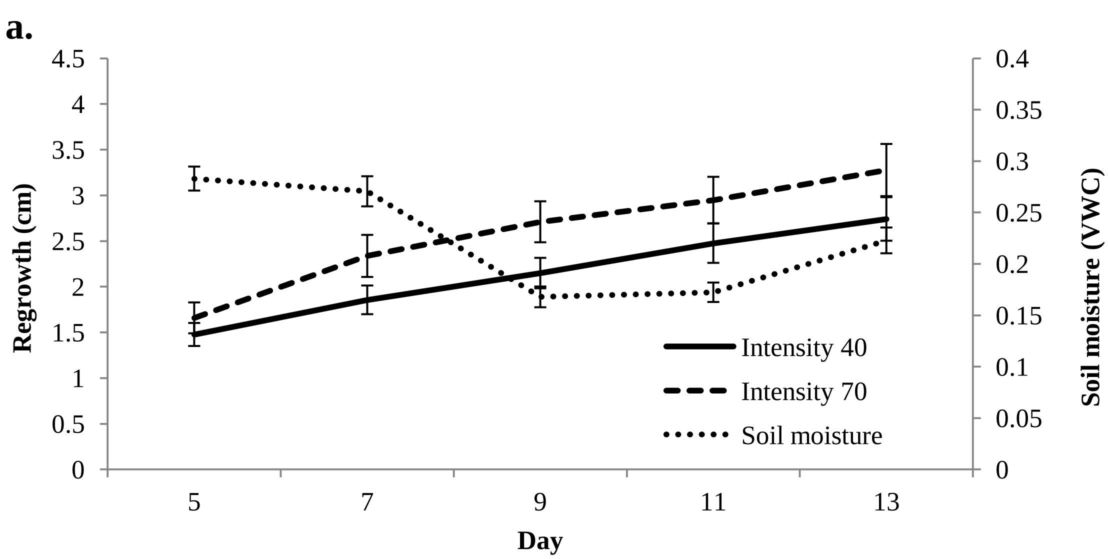


Figure 7: Cumulative regrowth (cm) and soil moisture (VWC) of rough fescue, 5, 7, 9, 11, and 13 days after removing 40% or 70% of total biomass. a.) Regrowth and soil moisture of rough fescue in 2011. b.) Regrowth and soil moisture of rough fescue in 2012. Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data.

Pinegrass

In 2011, cumulative regrowth of the low intensity treatment was lower than the high intensity treatment on each of the measurement days (Fig. 8a); statistical analysis showed significance (DF = 149, P = 0.0072). The regression of soil moisture and non-cumulative regrowth for 2011 showed a low R-squared value (R^2 = 0.0806) and there was no significant correlation between non-cumulative regrowth and soil moisture (F = 3.697, DF = 140, *Significance* F = 0.0565). In 2012, cumulative regrowth of the low intensity and high intensity treatments was very similar (Fig. 8b) and no significance between treatments was found (DF = 149, P = 0.4376). The regression of soil moisture and non-cumulative regrowth for 2012 found a slightly higher R-squared value than that in 2011 (R^2 = 0.1104) while correlation between non-cumulative regrowth and soil moisture was found (F = 17.76, DF = 148, *Significance* F = 4.36E-05).



b.

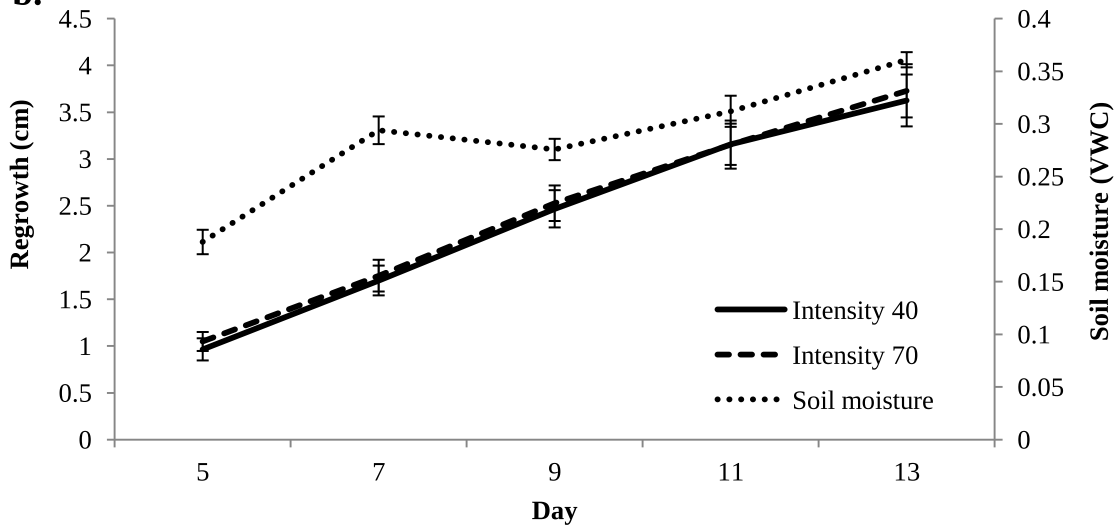


Figure 8: Cumulative regrowth (cm) and soil moisture (VWC) of pinegrass, 5, 7, 9, 11, and 13 days after removing 40% or 70% of total biomass. a.) Pinegrass regrowth and soil moisture for 2011. b.) Pinegrass regrowth and soil moisture for 2012. Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data.

Final biomass

Final biomass represents the product of complete clipping of the above ground material for each plant at the end of the 2 year study. No interactions for final biomass were observed for bluebunch wheatgrass or pinegrass. Rough fescue did show a significant interaction term between frequency and intensity (F = 5.149, Residuals = 56, P = 0.0272) (Fig. 9).

Bluebunch wheatgrass final biomass in treatments with low intensity (F1I40, F3I40) did not differ significantly from one another, regardless of frequency. However, clipping at a high intensity (F1I70, F3I70) significantly reduced final biomass regardless of whether the clipping was once (F1) or three times (F3). This data indicates that intensity is having more of an impact on bluebunch wheatgrass final biomass than frequency (Fig. 10a).

Rough fescue did not show as clear of an effect for higher intensity of clipping yet high intensity at high frequency (F3I70) still showed statistical significance in lower final biomass when compared to other treatments (Fig. 10b).

The results for pinegrass differed from both bluebunch and rough fescue. Pinegrass final biomass shows a declining trend as treatment becomes more severe (Fig. 10c). All treatments were significantly different from the most severe treatment, while the least severe treatment was also significantly different from the F3I40 treatment.

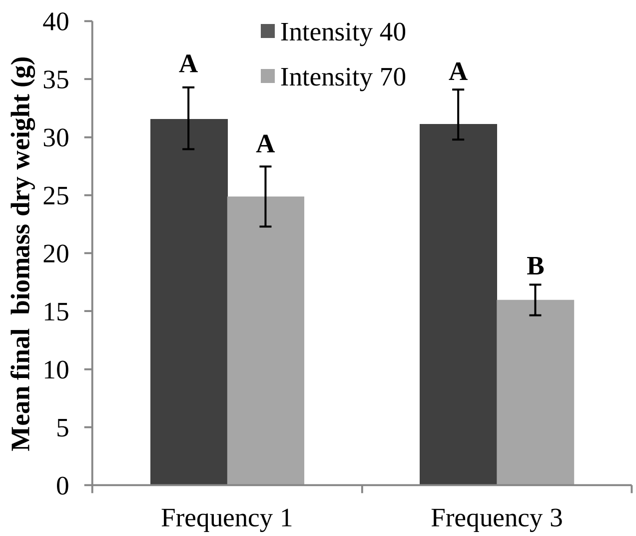


Figure 9: Interactions between frequency and intensity for rough fescue final biomass (g). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data.

Cumulative 2012 biomass

Cumulative biomass from 2012 included the final biomass (complete clipping of the plants at the end of the season) plus all of the biomass removed during each of the clipping events.

Bluebunch wheatgrass displayed a significant difference in biomass occurring in plants clipped at higher intensity when compared to lower intensity treatments (Fig. 10d). The control treatment was significantly different from both high intensity treatments but not significantly different from the low intensity treatments.

Rough fescue showed no significant difference in cumulative biomass across most of the treatments. The most severe treatment of high frequency/high intensity (F3I70) had a significantly lower cumulative biomass than all of the other treatments (Fig. 10e).

In pinegrass, the control was not significantly different from any of the treatments. However the F1I70 treatment had higher final biomass than both of the high frequency treatments (Fig. 10f). The control and F1I40 treatment do display a trend of being higher than both high frequency treatments ($P<0.1$).

No interactions were found for bluebunch wheatgrass or pinegrass, but there was an interaction found between intensity and frequency for rough fescue ($F = 10.053$, Residuals = 56, $P = 0.0025$) (Fig. 11).

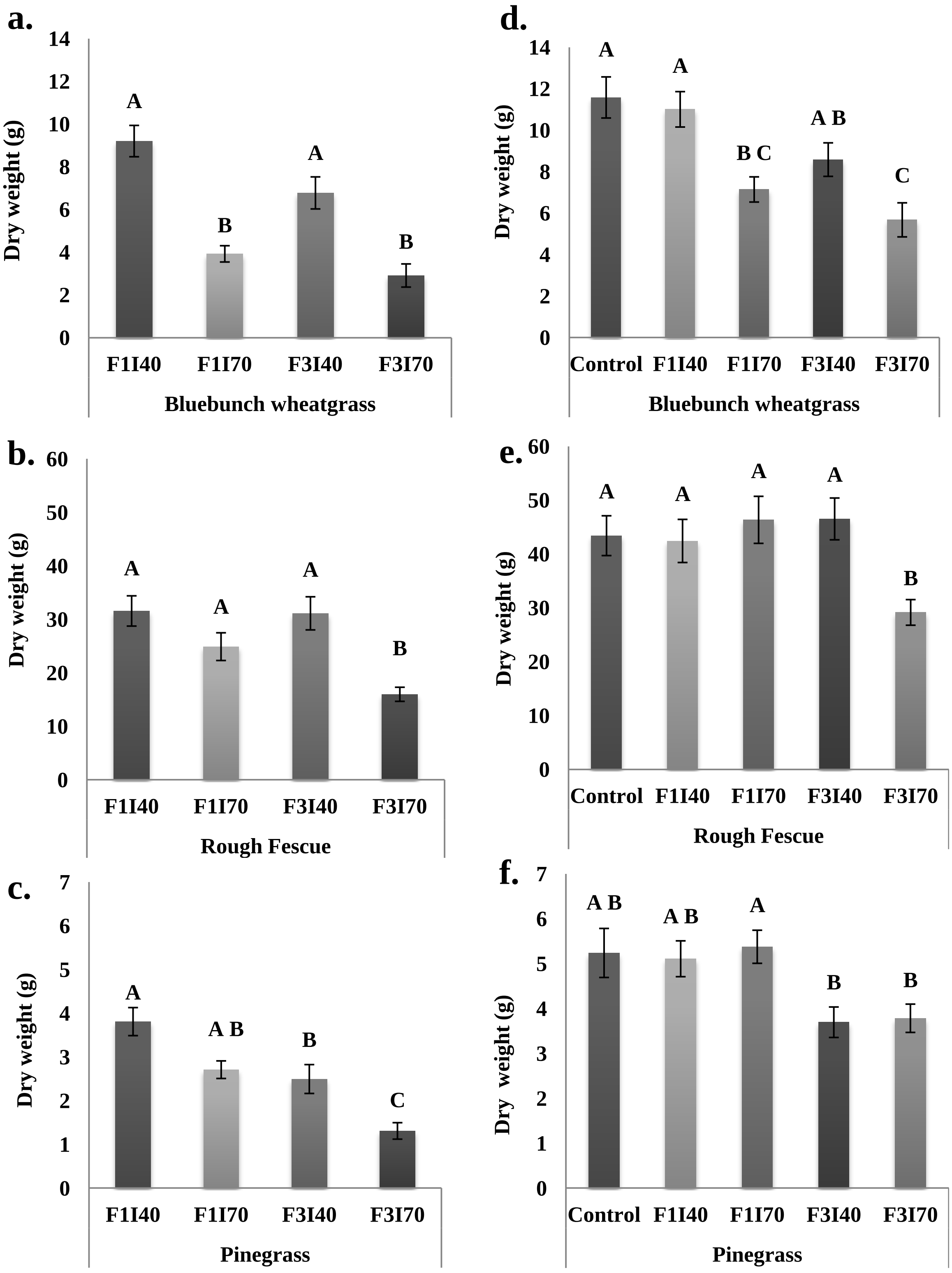


Figure 10: Final biomass (g) and cumulative biomass 2012 (g) clippings from 2012 of all three plant species. a.) Bluebunch wheatgrass final biomass. b.) Rough fescue final biomass. c.) Pinegrass final biomass. d.) Bluebunch wheatgrass cumulative biomass. e.) Rough fescue cumulative biomass. f.) Pinegrass cumulative biomass. Letters denote a significance level of P<0.05. Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

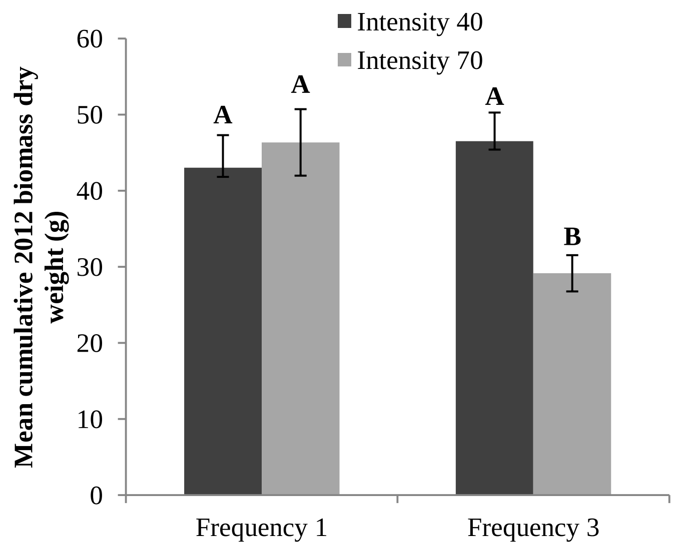


Figure 11: Interactions between frequency and intensity for rough fescue cumulative biomass 2012 (g). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data.

Maximum tillers

In 2011 maximum tiller counts for all species showed no significant differences between treatments (Appendix 2, 3 and 4). In the second year of measurements, there were significant differences shown in two of the three species at varying levels. No interactions between frequency and intensity were found for maximum tiller count in any species in both 2011 and 2012. For bluebunch wheatgrass, multiple clippings at a high intensity (F3I70) resulted in decreased tiller numbers when compared to all treatments except the F1I70 (Fig. 12).

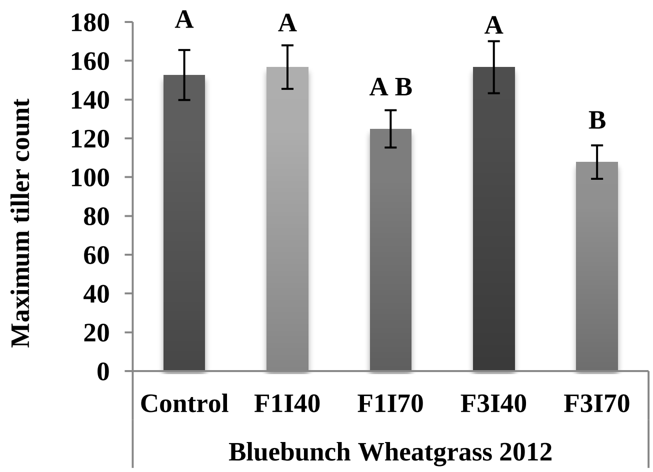


Figure 12: Maximum tillers counts of bluebunch wheatgrass plants in 2012. Letters denote significance levels (P<0.05). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Rough fescue maximum tiller counts resulted in no significant difference among any of the treatments in either 2011 or 2012.

For pinegrass there was no treatment effect in 2011 but in 2012 the multiple frequency (F3) treatments resulted in a lower number of tillers than the F1I70 treatment but neither were different from the control or F1I40 treatment (Fig. 13).

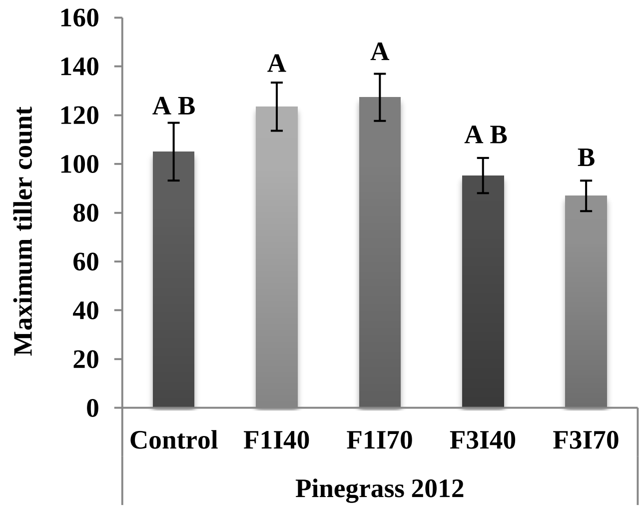


Figure 13: Maximum tillers counts of pinegrass plants in 2012. Letters denote significance levels (P<0.05). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Minimum tillers

There were no significant interactions between frequency and intensity for any species in either 2011 or 2012 for minimum tiller count. For bluebunch wheatgrass the F3I70 treatment resulted in a significantly lower number of tillers than all of the other treatments in 2011 (Fig. 14a). In 2012 both the F1I70 and F3I70 treatments had lower tiller numbers (Fig. 14b). This is a similar trend to biomass and maximum tiller count for this species.

Minimum tiller number was not significant by treatment for rough fescue in 2011 and 2012 or for pinegrass in 2011(Appendix 5 and 6). Pinegrass minimum tiller counts in 2012 show that the control treatment is not significantly different from any of the other treatments, however, the most severe treatment (F3I70) has a significantly lower number of tillers than the remaining clipping treatments (Fig. 15).

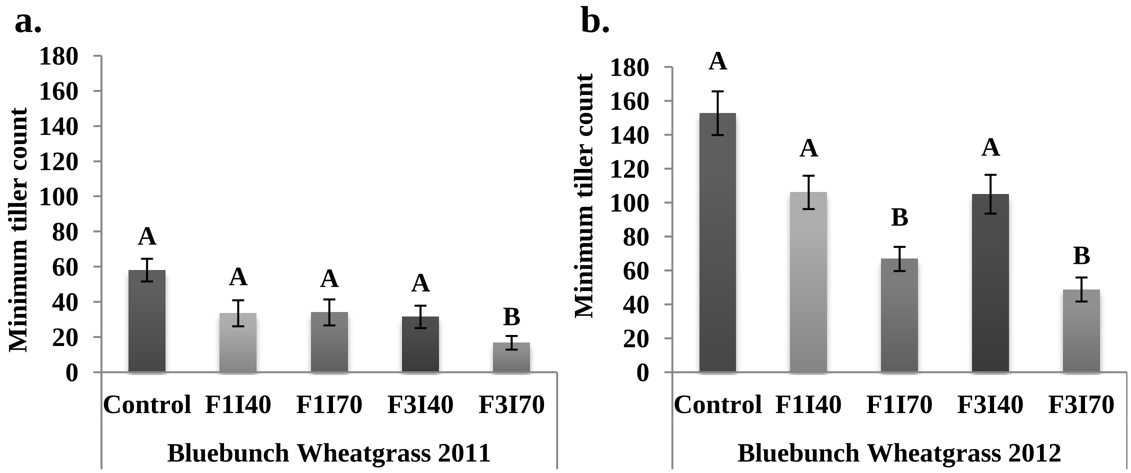


Figure 14: Minimum tiller counts for bluebunch wheatgrass. a.) Minimum tiller counts for 2011. b.) Minimum tiller counts for 2012. Letters denote significance levels ($P<0.05$). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

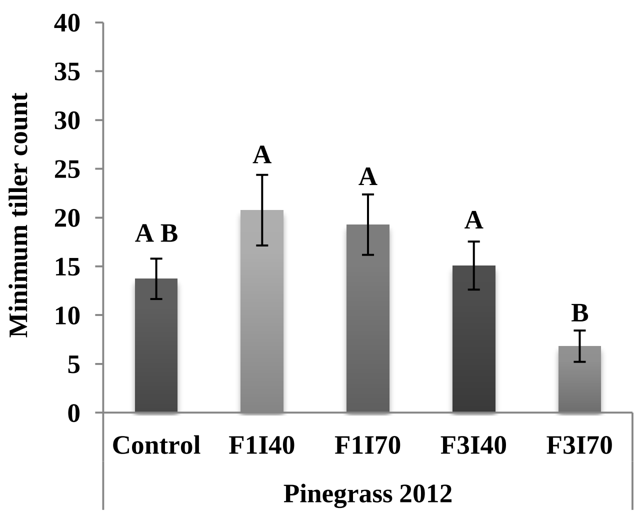


Figure 15: Minimum tiller counts for pinegrass in 2012. Letters denote significance levels ($P<0.05$). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Canopy height

All species over both years showed varying degrees of difference for canopy height among treatments. In 2011, bluebunch wheatgrass showed a gradual decrease in canopy height as severity of the treatment increased (Fig. 16a). In 2012 the control canopy height was significantly different from all other treatments while those of both low intensity treatments were significantly different from the heights of high intensity treatments (Fig. 16b). The low frequency/high intensity treatment also had significantly different canopy height from the most severe treatment, which was significantly different from all treatments.

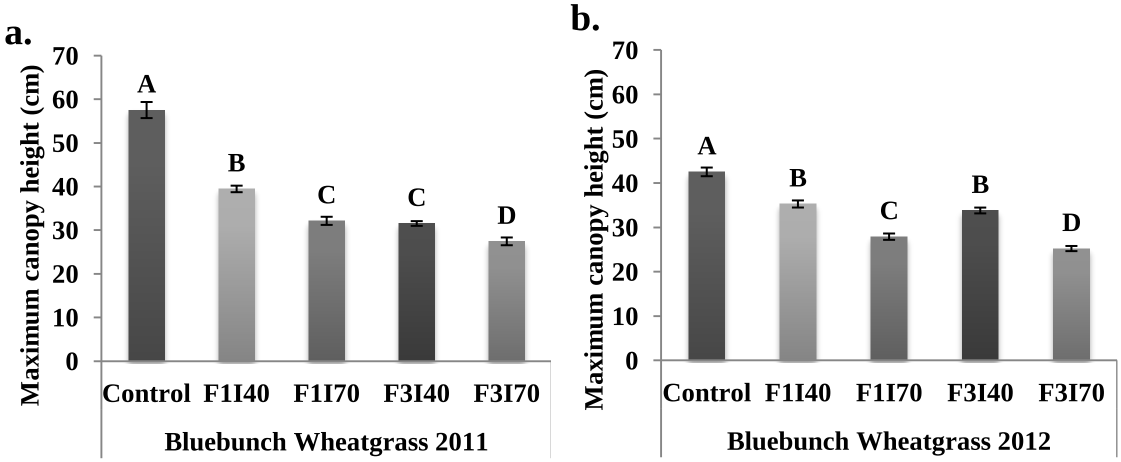


Figure 16: Bluebunch wheatgrass canopy height (cm) for 2011 and 2012 seasons. a.) 2011 canopy height. b.) 2012 canopy height. Letters denote significance levels ($P<0.05$). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Rough fescue in both 2011 and 2012 showed significantly higher canopy for the control from all clipping treatments. The most severe treatment (F3I70) had a significantly lower canopy height from all clipping treatments. All of the other treatments were not significantly different from one another (Fig. 17). Significant interactions between frequency and intensity were also found for rough fescue canopy heights in 2011 (F = 6.644, Residuals = 56, P = 0.01266) and in 2012 (F = 6.476, Residuals = 56, P = 0.01377) (Fig. 18) but not for bluebunch wheatgrass or pinegrass.

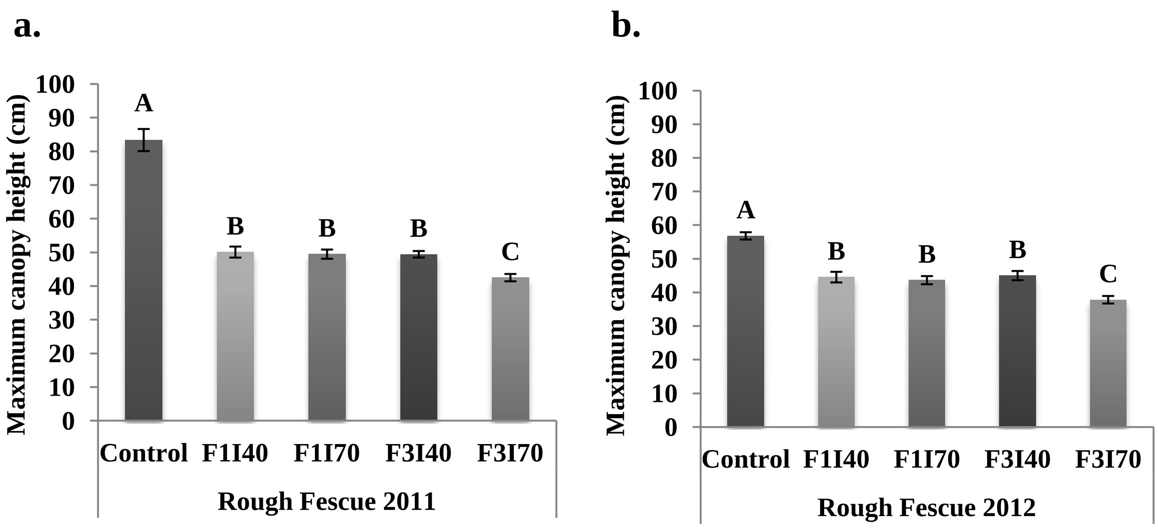


Figure 17: Rough fescue canopy height (cm) for 2011 and 2012 seasons. a.) 2011 canopy height. b.) 2012 canopy height. Letters denote significance levels ($P<0.05$). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

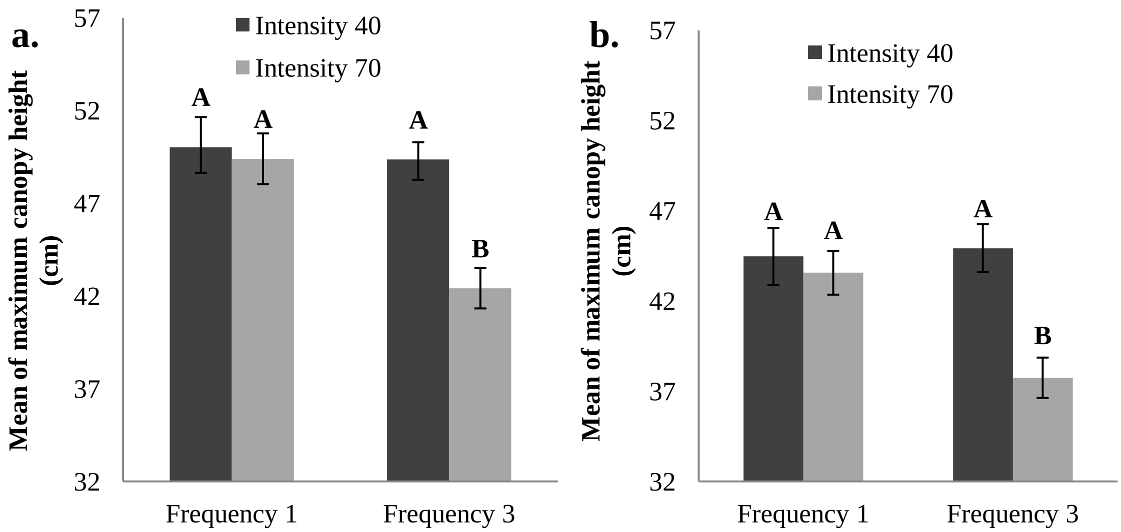


Figure 18: Interactions between frequency and intensity of clipping in rough fescue canopy height (cm) in 2011 and 2012. a.) Rough fescue canopy height 2011 interactions. b.) Rough fescue canopy height 2012 interactions. Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data.

The pinegrass control treatment had a higher canopy measurement than all other treatments in both 2011 and 2012. For each year, the result of the clipping treatments on canopy height was slightly different (Fig. 19) but the general trend was a reduction in height with increasing intensity and frequency of clipping. There was little to no significant difference between F1I40, F1I70 and F3I40 treatments in both years. Control was always significantly different from all other treatments.

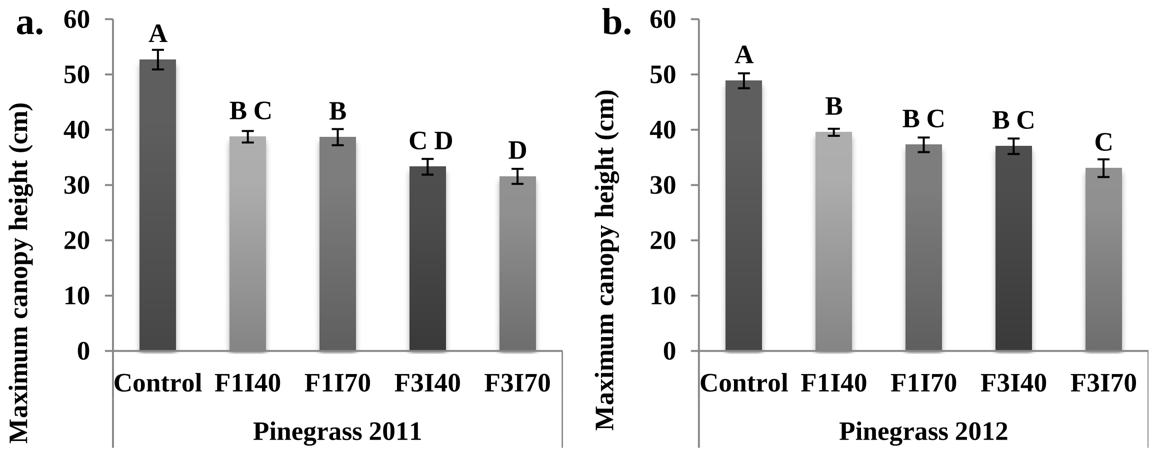


Figure 19: Pinegrass canopy height (cm) for 2011 and 2012 seasons. a.) 2011 canopy height. b.) 2012 canopy height. Letters denote significance levels (P<0.05). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

2.4 DISCUSSION

Regrowth and soil moisture

Regrowth varied between species and between years, though it appears that in 2012 regrowth between treatments was very similar within each species. Soil moisture was found to be correlated with regrowth most years for the three species. In cases where the correlation was not significant to P=0.05, it was shown to be significant to P=0.1. Due to the soil probe being limited to a depth of 6 cm, it represents a coarse estimate of soil moisture available to the plants. There is little literature on these three species that relates specifically to initial regrowth of mature plants.

Bluebunch wheatgrass

While there was no statistically significant ($P<0.05$) results for regrowth of bluebunch wheatgrass in 2011 or 2012 there was a strong trend ($P<0.1$) in 2011 which indicated the results may have ecological significance and should be discussed. It has been shown that the canopies of bluebunch wheatgrass plants direct and concentrate rain water to the base of the plant (Ndawula-Senyimba *et al.* 1971) and the loss of aerial plant parts may result in reduced soil moisture recharge through decreased snow capture and increased frost damage to plants (Wikeem *et al.* 1989). The low intensity clipping would leave more canopy than the higher intensity treatment allowing for greater collection of rainwater at the plant's base; this appears to have occurred in 2011 when soil moisture was at a much higher level than in 2012. The water collection mechanism would provide greater opportunity for regrowth for plants with larger canopy size. With the low soil moisture levels in 2012, the canopy size of a plant after treatment most likely had little effect on opportunity for rainfall direction and concentration as little to no rainfall was recorded during the regrowth measurement period. This likely resulted in the same growing opportunity which is shown by almost identical regrowth patterns between treatments in 2012. No winter data is available to determine if there was more snow cover and less frost damage on the lower intensity plants however the low soil moisture levels in 2012 may be partially attributed to reduced soil moisture recharge. While regrowth is not explained by soil moisture in either 2011 or 2012, there is a strong correlation with regrowth and soil moisture indicating that increased soil moisture is associated with increased regrowth. In 2011, soil moisture was likely not limiting, but was found to be correlated with regrowth. In 2012 soil moisture appeared to be limiting, and this limitation is likely correlated with the low regrowth of both treatments in 2012.

Rough fescue

The lack of a significant difference in rough fescue regrowth across treatments in both years could be related to the interactions between frequency and intensity found in some of the rough fescue vigour parameters. A single clipping at the prescribed intensities was likely not severe enough to cause significant difference in regrowth response between treatments. In 2011 soil moisture generally had a decreasing trend while regrowth continued to increases at a steady rate, though no correlation was found in this year to P=.0.05, there is likely an ecological significance to this as this correlation would be significant at P=0.1 and soil moisture likely did play some role in regrowth for rough fescue in this year. In both years soil moisture did not appear to be limiting nor over adequate. The exclosure in which rough fescue was studied was a long term exclosure which results in the plants likely having very high vigour after many years of not being grazed by livestock.

Pinegrass

In 2011, the high intensity treatment (I70) regrew significantly more than the low intensity treatment (I40), contrary to the expected outcome. This trend could be explained by either the high intensity clipping allowing more sunlight through (Grant *et al.* 1981) to lower, newer leaves, or by resource sharing. Allowing more sunlight through the canopy may have allowed for lower, previously shaded, leaves to become more photosyntheticlly active (Grant *et al.* 1981). Soil temperature was relatively constant between treatments (averaging 20°C during regrowth measurements), so extra sunlight did likely not increase soil temperatures in high intensity treatments to encourage more growth. Stout and Brooke (1985b) found that rhizome connections in pinegrass between cut and uncut tillers allowed for the exchange of food reserves. Other rhizomatous grasses such as tussock grass (*Schizachyrium scoparium*) and big bluestem (*Andropogon gerardi*) can share resources between tillers (Derner 2012, Archer and Delting 1984). Plants surrounding the pinegrass plots were not clipped during the trial therefore it is possible that tillers outside of plots were sharing resources with the cut tillers within plots. It is possible that the high intensity clipping created a “resource sink” where treated plants drew in more resources from surrounding tillers than the low intensity treatment, which cut to a height of 17cm, may not have triggered the movement of incoming resources. In

2012 over all regrowth was slightly greater than 2011 and soil moisture was found to impact regrowth in this year; soil moisture in 2012 was recorded to be greater than that in 2011 particularly during last 4 measurement dates. Soil moisture did not appear to be limiting in either years during the regrowth measurement period, nor was it over adequate. No correlation was found between soil moisture and regrowth in 2011 though there is a strong trend ($P<0.1$) suggesting that there still might be some relation between the two factors, though there are many other factors influencing regrowth as well. Soil moisture and regrowth correlation in 2012 again shows that while regrowth is not explained solely by soil moisture, it is an influencing factor.

Measurements of plant vigour

Final and cumulative 2012 biomass, tiller counts and canopy heights were all used to evaluate plant vigour response to clipping treatments. These measurements were found to be some of the most common measurements used in published research papers to quantify how various treatments affect plant vigour. Counting reproductive tillers is another measurement method often used, however it was not used in this study because all three plant species needed to have the same measurements recorded and because pinegrass is an infrequently-flowering grass species (Stout and Quinton 1986). For the purposes of this discussion, the vigour of a plant is related to the general size of the plant and its parts (leaves and tillers), growth rate of the plant and its ability to reach a larger size within a plant population (Price 1991).

Bluebunch wheatgrass

A consistent trend among the vigour parameters for bluebunch wheatgrass was that higher intensity clipping had a greater effect on plant vigour than frequency. This trend was significant in all measurements except for canopy height in 2011. Intensity may impact bluebunch wheatgrass vigour more than frequency for several different reasons. An early study of bluebunch wheatgrass by Wilson *et al.* (1966) noted that different frequencies at various times of the growing season resulted in different implications for plant growth. It was found that clipping in the boot stage resulted in the highest impact on plant vigour likely due to greater effects on root growth and carbohydrate accumulation during this stage (Wilson *et al.* 1966). Clipping earlier in the season would allow new leaves to grow which could meet the photosynthetic needs of the plant allowing for continued root growth and carbohydrate storage (Wilson *et al.* 1966). In our experiment, bluebunch wheatgrass was cut two years in a row during boot stage which could explain why intensity impacted plant vigour to a greater degree than frequency. The high intensity treatment (when compared to the lower intensity treatment) may have impacted carbohydrate reserves, removed more elevated growing points and removed more photosynthetic material which would cause a decrease in photosynthesis occurring within a plant. McLean and Wikeem (1985a) determined that leaving more foliage resulted in less damage to the plant and suggested that this was due to a better ability to replenish carbohydrate reserves as a result of the photosynthetic material remaining. McLean and Wikeem also cited Wilson *et al.* (1966) observing that a 20 cm clipping height, compared to clipping more intensively to lower stubble heights, improved plant yields. Removal of growing points may also result in the death of tillers which leads to production of new tillers; this is a much slower process when compared to leaf expansion of surviving tillers (Dahl and Hyder 1977). The high intensity treatments probably saw a net loss in tiller number due to less new tillers being produced than were lost.

Rough fescue

Consistent results across rough fescue vigour parameters were also found with the most severe treatment (F3I70) always being significantly different from control and other clipping treatments. Rough fescue was also the only species to show interaction effects for final and cumulative biomass, and canopy height in both 2011 and 2012. Final biomass and canopy height interactions are additive, where the combined effects of frequency and intensity impact the plant response. Cumulative 2012 biomass interactions show a reversed interaction (though not significant) where high frequency treatments show a reversed interaction compared to the low frequency treatments. Some literature suggests that frequency has a greater effect on plant vigour than intensity however it is stated that rough fescue is quite susceptible to any type of defoliation during the growing season (King *et al.* 1998, McLean and Wikeem 1985b, Willms and Fraser 1992, Willms 1991). Based on the literature it was expected that all treatments would be significantly different from the control in terms of biomass however this was not the case. The clipping treatments were conducted when rough fescue plants were leaving the boot stage and entering into the heading. At this time rough fescue can be sensitive to defoliation of growing point locations. The similarities between treatments for biomass results may be linked to the amount of photosynthetic material remaining after clipping. McLean and Wikeem (1985b) found stubble heights of 10, 15 and 20 cm resulted in reduced injury to plants compared to a stubble height of only 5 cm. For this experiment the low intensity clipping (40% intensity) of rough fescue yielded a stubble height of 17 cm while the high intensity clipping (70% intensity) yielded a stubble height of 8.7 cm. The remaining stubble height on both intensity treatments may have been sufficient for the treated plants to maintain a high enough level of photosynthesis to mitigate clipping impacts. In the case of the most severe treatment, F3I70, the combination of a high frequency and high intensity was enough to impact plant growth and subsequently, biomass.

The lack of significance in all rough fescue tiller measurements is not representative of what has been found in other studies. Willms and Fraser (1992) found that rough fescue tiller numbers were impacted by intensity and frequency of clipping. Plants being cut at lower frequencies had similar tiller numbers to that of an unclipped control and a one-time clipping event and appeared to stimulate tiller growth possibly because of removal of self-shading. The lack of significance in our data could potentially be related to the methodology used to count tillers; if green was visible on a tiller, it was considered live. From personal observation it was noted that typically 2 or 3 leaves grow out from the crown of one tiller. Often what was seen on the higher severity treatments (*e.g.* F3I70) was that the majority of leaves on one tiller were dead, while one green leaf remained and so this tiller was counted as live. This resulted in the more severe treatments having a larger amount of dead rather than live material compared to control and less severe treatments (*e.g.* F1I40) even though when tillers were counted, the numbers were approximately the same.

Pinegrass

Pinegrass did not have as clear of a trend as bluebunch wheatgrass or rough fescue but typically the high frequency and high intensity treatment (F3I70) showed a consistently, significantly lower vigour response than most other treatments. Stout and Quinton (1986) demonstrated that clipping biweekly for successive years to stubble heights of 5 cm or 10 cm decreased stand density and that when stubble heights of 15 cm were used a 20% decrease was found. It is important to note that these differences were not found to be significant after 4 years (Stout and Quinton 1986). Freyman (1970) indicated that pinegrass yield was higher in treatments with low clipping frequencies which is similar to the results found in the experiment presented in this thesis. The cumulative 2012 biomass did show that the higher frequency treatments had lower yields than the F1I70 treatment, but were not significantly different from control and F1I40. However due to a trend in the control and F1I40 having elevated yields when compared to the high frequency treatments ($P<0.1$) these findings still agree with those of Freyman (1970).

Maximum and minimum tiller counts were only significant in 2012 but the results showed that the control was not significantly different from any of the treatments; there were only significant differences between some of the treatments. In maximum tiller counts, both low frequencies were significantly different from the high frequency high intensity clipping and there was a trend that the low frequency treatments had slightly greater tiller counts than the F3I40 treatment ($P<0.1$). This trend was not found in minimum tiller counts for 2012. These results could again be related to the findings of Freyman (1970) with frequency impacting pinegrass growth greater than intensity.

The variability of significance between treatments for the various vigour measurements could be more closely related to environmental conditions or grazing history of the plant; Stout *et al.* (1980) stated that these two factors influence a plants response to defoliation and to observe a distinct plant response to treatments, multiple years of manipulation may be required. While the F3I70 treatment is consistently the lowest mean of measurements groups, it is often not significantly different from the control means for cumulative 2012 biomass and minimum and maximum tiller counts in 2012.

2.5 CONCLUSION

All three species responded to treatments in different ways which is expected as each species has its own unique physiological and morphological characteristics and ideal growing conditions. Though the responses are dissimilar, this data does highlight the idea that management of rangelands should keep frequency and intensity of grazing under careful consideration. The response of these species to the treatments might change based on season of use and competition from other plants. This study only clipped selected species and did not clip surrounding vegetation. In a grazing scenario, other plants would be grazed as well resulting in different competitive effects as Mueggler (1972) showed that reduced competition can offset the effects of clipping.

In British Columbia, the focus of management tends to be on stocking rates and stubble heights which in themselves are indicators of intensity; however, grazing rotations are very common in the Southern Interior which often results in livestock being in pastures for a long duration. This duration of animals in a pasture can typically mean a high frequency of defoliation for plants. For a species like bluebunch wheatgrass, managing only for intensity may make sense as this appears to be what affects plant vigour the most, but for other species such as rough fescue (interactions between frequency and intensity) and pinegrass (high variability) incorporating other factors such as frequency into management considerations would be beneficial. Opportunity for growth or regrowth should always be considered when making management decisions as precipitation (soil moisture), temperature and disturbances can all impact plant vigour.

CHAPTER 3: EVALUATING THE GRAZING RESPONSE INDEX

3.1 INTRODUCTION

Chapter 2 presented results of a clipping study that manipulated frequency and intensity of clipping on three different plant species that dominate plant communities in the Southern Interior of British Columbia. This study was designed in a manner that manipulated frequency and intensity at specific levels in order to determine how these factors influenced plant vigour. The results and discussion presented in chapter 2 will aid in the determination of the answers to the following management question: Can the Grazing Response Index be used to predict plant response to grazing in the Southern Interior?

3.2 THE GRAZING RESPONSE INDEX

In the 1990s, Colorado State University Range Extension Program and Integrated Resource Management Program developed a tool to evaluate the effects of grazing in a current year while integrating climatic factors and thus the growing conditions of forage species (Reed *et al.* 1999). The information collected from this tool allows land managers to gain beneficial use of available forage resources while maintaining a vigorous plant community. This tool has been found to be effective and simple by the Rocky Mountain Region Forest Service who has adopted this approach for evaluating grazing impacts (Reed *et al.* 1999). The grazing response index (GRI) centers around three basic factors relating to plant health:

- Frequency – The number of times a plant is subject to defoliation.
- Intensity – The amount of photosynthetic material that is removed at one time of defoliation.
- Opportunity – The opportunity a plant has to grow before defoliation, or regrow after defoliation. This is linked closely with environmental conditions.

Frequency

This factor is important for plant recovery after defoliation as the more times a plant is defoliated, the more energy it must put into regrowing new tissue to account for the lost photosynthetic capacity. Studies by Briske (1986) determined that seven to ten days is needed for a plant to initiate enough regrowth for it to be selected for grazing another time. At this time the plant has invested enough energy (in the form of carbohydrates) into the new tissue that another defoliation event may have negative implications. These studies also showed that if defoliation occurred three or more times in one growing season, plant vigour was negatively impacted. If this trend continued, plants would have a lessened ability to persist in the community (Ellison 1960). Table 3 shows how to score the frequency of defoliation. To determine how many times a plant will be subject to defoliation, the number of days livestock are in a pasture (or a known portion of pasture) is divided by the regrowth period of seven to ten days. If plant regrowth is faster, seven days is used to determine frequency, while if plant growth is slower, ten days is used. Seven days is considered to be a conservative number if exact growth rate is not known (weather can also play a factor in regrowth) (Reed *et al.* 1999). For example, if livestock are in a pasture for 14 days then individual plants were exposed to potential defoliation at least twice (14/7 = 2) and the GRI score would be 0.

Intensity

The most important part of intensity of defoliation (percent utilization of the plant) is the total amount of photosynthetic material that remains on the plant, as this is what will enable the plant to recover from the event (Reed *et al.* 1999). Intensity of clipping is also important in terms of the removal of growing points. This is dependent upon the growth stage of the plant, but generally, higher intensity defoliations may remove more growing points than lower intensity defoliations. Table 3 shows the scoring of intensity. Intensity is visually estimated immediately after animals are removed from pasture. The use of cages, placed in representative areas, can be an effective way to help determine intensity levels (Reed *et al.* 1999).

Opportunity

Opportunity for the plant to grow before defoliation, or re-grow after defoliation will have the most impact on plant health and vigour compared to the other two factors. This is why opportunity has a larger scoring scale (Reed *et al.* 1999). Table 3 shows the scoring for opportunity. Scoring opportunity is based on an individual's judgment of the appearance of the vegetation at the end of the growing season. The score is influenced by environmental factors such as precipitation and temperature as well as various disturbances such as fire, insects, and excess trampling. It also takes into account the growth stages of plants when cut, as removal of growing points at stages of growth such as boot stage or flowering stage can be more detrimental to a plant than at a vegetative stage.

Table 3: The GRI scoring values for frequency, intensity and opportunity. Adapted from Reed et al. 1999.

Frequency (Number of defoliations)	**Value**
1 (≤ 7 days)	1
2 (8 - 14 days)	0
3 or more (>14 days)	-1
Intensity (Amount of biomass removed)	**Value**
Light (≤ 40 %)	1
Moderate (41-55%)	0
Heavy (≥ 56 %)	-1
Opportunity (To grow before grazing or regrow after grazing)	**Value**
Full Season	2
Most of Season	1
Some Chance	0
Little Chance	-1
No Chance	-2

Creating a score

After scoring out each portion of the GRI, numbers are totaled and the resulting number (positive, neutral or negative) will provide an evaluation of the grazing management. A positive score means the plant community is benefiting from the management, neutral score means the management is neither harmful nor beneficial to the community, and a negative score means the management is harming the community and overall health and vigour is decreasing (Reed *et al.* 1999). One year with a negative score may not cause significant damage but continuing to manage grazing at the same levels will result in continued degradation.

The GRI is directly linked to the management of a rangeland, where stocking rates, timing of grazing, and duration of grazing play an important role in each of the three index measurements (Reed *et al.* 1999). The GRI should be scored on a yearly basis which will allow land managers to see changes in plant vigour after each season. In larger pastures, multiple sites may need to be scored as some areas may receive heavier use than others; areas where livestock access water will often receive heavier use than other areas which are a greater distance from water sources.

The GRI allows for adjustments to management and planning between assessments of current plant community and desired plant community. Essentially, the GRI provides opportunity for short term management in conjunction with long term management and long term rangeland assessments. Referring back to chapter 1, the range condition and range health assessments are conducted at intervals of several years and have a greater depth of assessment than the GRI, however; applying the GRI to rangelands on an annual basis would allow for more frequent evaluation of vegetation conditions. The accumulation of annual scores can provide the opportunity to observe potential trends (positive or negative) of the plant community's response to grazing. By observing these scoring trends, managers can make the decision to change or maintain management plans at the end of every grazing season while using the current assessments every few years to confirm the accuracy of trends being observed through the GRI.

3.3 EVALUATING THE GRAZING RESPONSE INDEX BASED ON PLANT VIGOUR RESPONSE TO CLIPPING TREATMENTS

To address the management objective "Can the Grazing Response Index be used to predict plant response in the Southern Interior?" the differences in plant response should be addressed. Using the GRI in the Southern Interior would result in the scoring of many different plant communities with the same indices and if the differences are too distinct, then the scores given by the GRI may not accurately reflect the response of all plant communities in this region.

The outcome of results for bluebunch wheatgrass (summarized in Appendix 7a) indicates that intensity impacts plant vigour more than frequency (Fig. 10a,d). This becomes more apparent in the second year of treatments for tiller counts (Fig. 12 and 14a,b) and canopy height (Fig. 16a,b) as significance levels change to show lower intensity treatments general have more tillers or higher canopies than the high intensity treatments.

While the tiller counts of rough fescue were unfortunately not reflective of what was likely happening with regards to plant vigour (Appendix 3 and 5), final and cumulative biomass (Fig. 10b,e) are good indicators of plant vigour and canopy height measurements (Fig. 17a,b) also showed significant differences (summarized in Appendix 7b). The rough fescue results present a pattern that indicates the most severe treatment is always significantly different from the control and all other clipping treatments. We did see an additive effect of intensity and frequency in the interactions for both biomass measurements as well as for canopy height in both years. This indicates that defoliation at only high frequencies or only high intensity may not be enough to impact plant vigour, however high frequency and high intensity clipping will impact plant vigour.

Similar to rough fescue, pinegrass typically saw the most severe treatment (F3I70) being significantly different from most other treatments, though there were no interactions found. Several vigour measurements (cumulative 2012 biomass, minimum and maximum tiller counts in 2012) found that control was often not significantly different from the most severe treatment to $P<0.05$ however a general trend was that control exhibited slightly higher means than the F3I70 treatment (P<0.1) (Appendix 7c). Overall, the results of pinegrass are quite variable compared to that of rough fescue and bluebunch wheatgrass. This variability may be related to the grown form of pinegrass (rhizomatous) or environmental conditions.

With this review of results it becomes clear that these three forage species do not respond to defoliation in a similar manner. There were differences in response to treatments and these differences are most likely due to many factors such as plant physiology and growth form (bunchgrass *vs*. rhizomatous grass) as well as weather and resources. These plants were also chosen representatives of their plant communities as they are the dominant forage species, but their responses to these treatments may not reflect responses of the rest of the plant community. Though each plant species showed different responses in measurement to the treatments, the overall indications lead me to conclude that the general trend is decreasing vigour for increasing severity of treatment.

The reason the GRI has the potential to be such a useful tool, is because it is simplified. To adjust the tool for each individual plant community based on slightly different responses would cause the GRI to lose its effective methodology. The GRI was created with the intention of being used over a wide variety of plant communities and its flexibility and simplicity in scoring leads to the conclusion that it should be robust enough to score the plant communities in the Southern Interior.

Scoring of three key forage species by treatment

I scored the treatments (F1I40, F1I70, F3I40 and F3I70) using the GRI methods and compared these scores with general plant vigour response to treatment based on the results of biomass, tiller counts and canopy height. Scoring was done for the last year of treatments (2012) as this is when more significant differences were found within vigour parameters and when the final biomass measurements were obtained. Final biomass is an important measure as it has been shown to be the plant component most affected by defoliation (Ferraro and Oesterheld 2002).

Frequency scoring

For frequency it is deemed that seven to ten days are required for enough regrowth to occur that the removal of this regrowth through another grazing event would impact plant vigour. Seven days is used as a conservative number if plant growth is fast, and ten days if plant growth is slower. Scoring this will require knowledge about the dominant plant species in the pasture being scored and how they grow.

For bluebunch wheatgrass regrowth in 2012 the low intensity (40%) and the high intensity (70%) treatments had an average of 1.9 and 1.8 cm of regrowth respectively (Fig. 6b). Removing this amount of regrowth would likely impact the vigour of bluebunch wheatgrass plants as they were cut during boot/head stage when carbohydrate reserves are typically low (Miller *et al.* 1986) and soil moisture is limiting on sites bluebunch wheatgrass typically grows on, therefore seven days is appropriate to score bluebunch wheatgrass for frequency of grazing.

Regrowth for rough fescue in 2012 after seven days was averaged at 2.1 and 2.3 cm for low intensity and high intensity treatments respectively. Removing this amount of regrowth would likely impact rough fescue vigour and it has been shown that frequency is often a factor of grazing that will negatively impact rough fescue vigour, and grazing rough fescue while it is actively growing will likely result in some decrease of vigour (King *et al.* 1998, McLean and Wikeem 1985b, Willms and Fraser 1992, Willms 1991). Seven days is an appropriate number to use to score frequency for rough fescue.

Pinegrass results for regrowth indicated an average of 1.7 cm for both intensity treatments. While 1.7 cm may not be a significant amount of regrowth, pinegrass tends to have higher yields when cut at lower frequencies (Freyman 1970) and the fact the environmental conditions play an important role in pinegrass growth (Stout *et al.* 1980) it is best to use the more conservative application of seven days for frequency.

With all three species determined to be impacted by a second grazing event after seven days, frequency scores for each treatment (for each species) are shown in table 4.

Intensity scoring

Intensity scoring for the GRI is based on the amount of photosynthetic material (by biomass, not by height) removed at the end of the grazing period. While this is based on the amount removed, what is important about intensity is the amount of photosynthetic material remaining after grazing that will enable the plant to recover. Bluebunch wheatgrass clipping intensity results indicated that lower intensity treated plants had significantly more biomass (final and cumulative) and higher tiller counts and canopy heights and generally were not significantly different from the control plants which lead to the conclusion that a removal of 40% intensity did not negatively impact plant vigour. The high intensity treatments were significantly lower than control which indicates a negative impact on plant vigour.

Due to the interactions observed with rough fescue, there was no clear indicator of how these plants responded to the intensity of treatment, however, when a high intensity was paired with high frequency for a treatment, there was always a significant difference between this treatment and all others. Initial vigour of these plants would likely mitigate response to high intensity of treatment (as all rough fescue plants in this study were contained in a long term exclosure) however, if this study was conducted for several more years, trends in intensity may have become more apparent over time. Taking this into consideration, the categories of intensity presented by the GRI would likely reflect rough fescues response to intensity of defoliation.

Pinegrass results were variable and make it difficult to give a clear suggestion as to which intensity categories each treatment correlates with. Intensity might be easier to categorize if pinegrass was clipped at a later time, but for this study it was at the three leaf stage (vegetative growth) and therefore growing points were likely not affected resulting intensity not having as great of an impact as frequency. Grazing does not always take place during vegetative growth of pinegrass; therefore it is better to remain with slightly more conservative scoring.

All three species were determined to fit into the categories of intensity presented in the GRI and thus the scoring for intensity for each treatment is shown in table 4.

Opportunity scoring

With clipping dates and weather data, it would be possible to determine a relative opportunity score, but this component of the GRI is meant to be scored visually at the end of the growing season over an area based on appearance of the pasture. This is difficult to do with plants dispersed around an exclosure and without there being bias between the treatments as the results of impact of plant vigour have already been shown and discussed.

Opportunity is often the most difficult aspect of the GRI to score as there are many considerations to make. Climate conditions, timing of defoliation, past use and disturbance can all play a role in a plant opportunity to grow or regrow which is why the opportunity carries the most weight in producing the final GRI score. Bluebunch wheatgrass was assigned slightly different opportunity for growth and regrowth for two main reasons: time of clipping and weather data indicated that precipitation in 2012 was outside of the standard deviation of the climate average at time of clippings (May) and average high temperature in 2012 was outside the standard deviation of climate normal throughout all of 2012. Temperature and precipitation for rough fescue and pinegrass sites where not outside of the standard deviation of the climate normal.

All control plants receive an opportunity score of +2 (full season) as they were not clipped. The F1I40 treatments received a score of +1 (most of season) for all three species as this treatment was not significantly different from the control in any of the vigour parameter measurements (with the exception of canopy heights). The F1I70 treatment for bluebunch wheatgrass opportunity received a score of 0 (some chance), where rough fescue and pinegrass received a score of +1. The opportunity score of bluebunch wheatgrass was decreased by one for this treatment because of timing of clipping which likely resulted in the removal of growing points as bluebunch wheatgrass was in boot stage at this time. The initiation of new tillers likely results from these clippings, which can be a slow process therefore the opportunity for regrowth was diminished. Scoring for the F3I40 treatment opportunity was 0 for all species because of multiple clippings in the beginning/middle of the growing season resulted in the plants have less time to regrow compared to single frequency clippings. The most severe treatment, F3I70 was scored as a 0 for rough fescue and pinegrass. There was some change for growth and regrowth for these species. This treatment was scored as a -1 for bluebunch wheatgrass, again because of the high intensity removing growing points and the multiple clippings. Visual observations of most plants receiving this treatment showed insignificant amount of regrowth. All opportunity scores and total scoring for each species is shown in table 4.

Table 4: The GRI scores for each treatment based on 2012 results.

Treatment	Frequency score All Species	Intensity score All Species	Opportunity: Bluebunch wheatgrass	Opportunity: Rough fescue and pinegrass	Total Score: Bluebunch wheatgrass	Total Score: Rough fescue and pinegrass
Control	+1	+1	+2	+2	+4	+4
F1I40	+1	+1	+1	+1	+3	+3
F1I70	+1	-1	0	+1	0	+1
F3I40	-1	+1	0	0	0	0
F3I70	-1	-1	-1	0	-3	-2

Evaluation conclusion

It is important to keep in mind that the growing seasons for these species are not all the same which may result in different opportunity scores by species. An elevational and temperature gradient results in bluebunch wheat grass initiating growth before the other two species, while rough fescue initiates growth before pinegrass. All species become dormant when summer temperatures rise above optimal growth levels. In some cases, bluebunch wheatgrass sites may have lower opportunity because these areas are more prone to low soil moisture levels and higher temperatures than the rough fescue and pinegrass sites. Over all, these relative opportunity scores do provide useful information in terms of presenting a completed GRI score, though opportunity was not directly manipulated or researched within this experiment aside from collecting soil moisture and weather data.

After reviewing the scoring of the GRI by each category for each species, the final scores were produced. These scores provide an accurate indication of plant response to these defoliation treatments. Comparing the statistical analysis to the scores given by the GRI, it is realized that there may be some discrepancies. An example of such discrepancy would be the pinegrass control plants not being significantly different from even the most severe treatments, which is not reflected in the scoring of the GRI where the control plants receive a +4 and the most severe treatment (F3I70) receives a -2. Firstly, this study was conducted over a period of two growing season; a relatively short time to obtain definitive answers. Secondly, it is likely that the scoring of the GRI might be conservative on certain treatments. Perhaps the most severe treatment for pinegrass did not respond as negatively to treatments a predicted by the GRI, however over several more years, repeating this treatment would likely result in negative consequences for these plants. This indicates a conservative scoring of the most severe treatment for pinegrass; better to be cautious and score conservatively for such treatments as it is a strong possibility that this treatment would become more detrimental over time. Conservative scoring of other treatments may be occurring as well. The bluebunch wheatgrass treatment F3I40 being scored the same as the F1I70 treatment (final score of 0), even though the F3I40 treatment showed significantly higher biomass means. While the F3I40 may have show higher means in the plant vigour measurements, perhaps an extension of this study would reveal an eventual change in significance. The GRI is showing a trend that indicates the continued defoliation of this kind would not benefit the vigour of these plants under these conditions. Given a longer application of the GRI to real grazing occurrences, the scores given would provide an accurate indication of vegetation conditions over time for these three forage species.

3.4 FINAL CONCLUSION

The rangelands of the Southern Interior of British Columbia are diverse and unique among the rangelands of North America and require diligent and consistent management to ensure continued sustainable use of these valuable ecosystems. The livestock industry is heavily reliant on the proper functioning of these rangelands and a host of other social and economical values (watersheds, recreation, wildlife, forestry, aboriginal values) can be impacted if rangelands become degraded. Currently the range condition and range health assessments are two long term monitoring tools used in British Columbia for rangeland management that provide useful and accurate representation of the status of vegetation and over all ecosystem function. Rangelands in the Southern Interior do have a history of over-grazing from the early 1900s and because of proper management many of these systems have recovered or are recovering. It is not a question of if current management is working effectively, but a question of how can we continue to improve upon what we already know. To strive for continued improvement of our management strategies is what will guarantee continued sustainable use and decreased degradation on the range.

Management with a short term assessment tool like the Grazing Response Index (GRI) in conjunction with the long term assessments will give managers, but also livestock producers themselves, a tool that can be used every growing season to track short term changes in vegetation. The GRI breaks down the three main principles of plant growth (frequency, intensity and opportunity) to a simplistic form that still remains effective. Using this tool would allow range managers and producers alike to manage for more than just stocking rates and utilization but for duration in a pasture and even climatic conditions.

Plant response results from Chapter 2 indicate that the dominant forage species in the Southern Interior respond in different ways to different treatments of frequency and intensity but overall, the more severe the treatment, the more significant the decrease in plant vigour. The use of the GRI by land managers or livestock producers does require knowledge about the rangeland or pastures that are being scored, and this knowledge will help to determine the differences in response to frequency and intensity so different plant communities can be scored accurately by managers.

It is realized that this study was short term. To obtain a clearer understanding of how the GRI will truly work on the rangelands in the Southern Interior, it must be incorporated into management practices and applied to real grazing events, not just simulated grazing (clipping). Once used over a period of years, rangeland condition assessments and rangeland health assessments should provide an accurate account of how the GRI is predicting plant response to grazing in this region. The implementation of the GRI in rangeland management in British Columbia will require some practice and training for managers and livestock producers in order to ensure correct usage and understanding of the tool and its indices. Once this process of introduction of the GRI to rangelands in British Columbia is completed, future management can be adjusted on an annual basis that will best benefit the livestock producers as well as the plant communities.

To summarize the GRI in simpler terms think of the native rangelands being a bank account. In good years investments are made into the land to increase its value (increasing vigour and plant health) but eventually there will be bad years when withdrawals will need to be made (heavier grazing, drought, disturbance). Bad years will occur, but if the investments are greater than the withdrawals there will always be a positive balance (healthy, vigourous plants). With that idea, consider the GRI to be the rangelands balance book. On a yearly basis scores are given to determine if an investment (positive score) or a withdrawal (negative score) is made. Tracking these investments and withdrawals gives a year to year statement on the wealth of your account (vigour of your plants). Now, because the GRI is not a stand-alone tool, consider the long term rangeland condition assessments to be your audits. Audits are required every few years to make sure the balance book isn't being cheated. The rangeland assessments ensure that the GRI scoring is reflective of the actual plant community and gives a much clearer picture on the overall vigour of rangeland plant species.

LITERATURE CITED

Archer, S., Detling, J.K. 1984. The effects of defoliation and competition on regrowth of tillers of two North American mixed-grass prairie graminoids. Oikos. 43(3):351-357.

Bawtree, A.H. 2005. A history of range use in British Columbia. Rangelands. 27(6):36-39.

B.C. Cattlemen's Association. 2013. B.C. Beef Cattle Industry. Accessed on August 11, 2013. URL: http://www.cattlemen.bc.ca/overview.htm

Blaisdell, J.P., Pechanec, J.F. 1949. Effects of herbage removal at various dates on vigour of bluebunch wheatgrass and arrowleaf balsamroot.Ecology. 30(3): 298-305.

Borman, M.M., Pyke, D.A. 1994. Successiona theory and the desired plant community approach. Rangelands. 16:82-84.

Branson, F.A. 1956. Quantitative effects of clipping treatments on five range grasses. Journal of Range Management. 9(2):86-88.

Briske, D.D. 1986. Plant response to defoliation: morphological considerations and allocation priorities. pp. 425-427. In: P.J.Joss, P.W. Lynch and O.B. Williams (eds.) Rangelands: A Resource under Siege. Cambridge University Press.

Briske, D.D., Fuhlendorf, S.D., Smeins, F.E. 2005. Sate-and-Transition models, thresholds and rangeland health: A synthesis of ecological concepts and perspectives. Rangeland Ecology and Management. 58:1-10.

Briske, D.D., Derner, J.R., Brown, S.D., Fuhlendorf, W.R., Teague, K.M. 2008. Rangeland Ecology and Management. 61:3-17.

Caldwell, M.M. 1984. Plant requirements for prudent grazing. Developing strategies for Rangeland Management. Westview Press, Boulder, Colorado; pp.117-152.

Campbell, C. W., Bawtree, A.H. 1998. Rangeland handbook for BC. Pp. 1-203. B.C. Cattlemens Association. Kamloops, B.C.

Clark, P.E., Krueger, W.C., Bryant, L.D., Thomas, D.R. 1998. Spring defoliation effects on bluebunch wheatgrass: II. basal area. Journal of Range Management. 50(5): 526-530.

Dahl, B.E., and D.N. Hyder. 1977. Developmental morphology and management implications. P. 258-290. In: R.E. Sosebee (ed.) Rangeland Plant Physiology. Range Sci. Series No. 4, Soc. Range Manage., Denver, Colo.

Delesalle, B.P., Coupe, B.J., Wikeem, B.M., Wikeem, S.J. 2009. Grasslands Monitoring Manual for British Columbia: A Tool for Ranchers. Grasslands Conservation Council of British Columbia. Accessed on: March 11, 2011. Available from: http://www.bcgrasslands.org/monitoringmanual.htm

Derner, J.J, Briske, D.D., Polley, W.H. 2012. Tiller organization within the tussock grass *Schizachyrium scoparium*: a field assessment of competition-cooperation tradeoffs. Botany. 90:669-677.

Dyksterhuis, E.J. 1949. Condition and management of rangeland based on quantitative ecology. Journal of Range Management. 2:104-115.

Ellison L. 1960. Influence of grazing on plant succession of rangelands. Botanical Review. 26:1-78.

Ferraro, D.O., Oesterheld, M. 2002. Effect of defoliation on grass growth. A quantitative review. *Oikos*. 98(1):125-133.

Fraser, D.A. 2009. Range resources assessment procedures. 2nd ed. B.C. Min. For. Range. Range Br., Kamloops, B.C. Rangeland Health Brochure 9. Accessed on: March 11, 2011. Available from: http://www.for.gov.bc.ca/hra

Freyman, S. 1970. Effects of clipping on pinegrass.Canadian Journal of Plant Science. 50: 736-739.

Ganskopp, D.C., Bedell, T. 1981. An assessment of vigour and production of range grasses following drought. Journal of Range Management. 34:137-141.

Google Earth. 2013. Google Earth. Asscessed on July 10, 2013. URL: http://earth.google.com

Grant, S.A., Barhtram, G.T., Torvell, L. 1981 Components of regrowth in grazed and cut Loliumperenne swards. Grass and Forage Science. 36:155-168.

Grasslands Conservation Council of British Columbia (GCC). 2011. Where are BC's grasslands? Accessed on March 11, 2011. URL: http://www.bcgrasslands.org/wherearebcgrasslands.htm

Hamann, A. & Wang, T. 2006. Potential effects of climate change on ecosystem andt species distribution in British Columbia. Ecology. 87:2773–2786.

Hilebert, D.W., Swift, D.M., Detling, J.K., Dyer, M.I. 1981. Relative growth rates and grazing optimization hypothesis. Oecologia. 51:14-18.

Holechek, J.L., Baker, T., Boren, J.C., Galt, D. 2006. Grazing impacts on rangeland vegetation: What we have learned. Rangelands. 28(1):7-13.

Holechek, J.L., Piper, R.D., Herbel, C.H. 2011. Range management principles and practices. 6th ed. Prentice Hall, One Lake street, Upper Saddle River, N.J.

Johnson, W.M. 1956. The effect of grazing intensity on plant composition, vigour and growth of pine-bunchgrass ranges in central Colorado. Ecology. 37:790-798.

King, J.R., Hill, M.J., Willms, W.D. 1998. Temperature effects on regrowth of 3 rough fescue species. Journal of Range Management. 51(4): 463-468.

Lommasson, T., Jensen, C. 1943. Determining utilization of range grasses by height-weight tables. Journal of Forestry. 41 (8): 589-593.

McDonald, J.H. 2009. Handbook of biological statistics (2nd ed.) Sparky House publishing, Baltimore, Maryland. Pp150-154. Accessed on: July 7, 2013. URL: http://udel.edu/~mcdonald/statnormal.html

McLean, A. 1967. Beef production on lodgepole pine-pinegrass range in southern British Columbia. Journal of Range Management. 20(4): 214-216.

McLean, A. 1972. Beef production on lodgepole pine-pinegrass range in the Cariboo region of B.C. Journal of Range Management. 25:10-11.

McLean, A., Wikeem, S. 1985a. Season and intensity of defoliation on bluebunch wheatgrass survival and vigour in southern British Columbia. Journal of Range Management. 38(1): 21-26.

.

McLean, A., Wikeem, S. 1985b. Rough fescue response to season and intensity of defoliation. Journal of Range Management. 38(2): 100-103.

Meays, C.L., Laliberte, A.S., Doescher, P.S. 2000. Defoliation response of bluebunch wheatgrass and crested wheatgrass: Why we cannot graze these two species in the same manner. Rangelands. 22(6): 16-18

Miller, R.F., Seufert, J.M., Haferkamp, M.R. 1986. The ecology and management of bluebunch wheatgrass (Agropyron spicatum): A review. Agricultural Experiment Station. Oregon State Univesity. Station bulletin 669.

Milroy, J.E., McLean, A. 1980. History of range administration and research in British Columbia. Rangelands. 2(2):56-59.

Ministry of Forests. 1997. The Pinegrass complex. Accessed on: January 18, 2013. URL: http://www.for.gov.bc.ca/hfp/publications/00049/pinegras.pdf.

Ministry of Environment, Lands and Parks. 2000. Lac du Bois grasslands park management plan background document. Kamloops BC. Accessed on: Janurary 25, 2011. URL: http://www.env.gov.bc.ca/bcparks/planning/mgmtplns/lacdubois/lacdubois.pdf.

Ministry of Forests, Lands and Natural Resource Operations, 2013a. Range Act. Accessed on: July 16, 2013. URL: http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/00_04071_01#part1_division2

Ministry of Forests, Lands and Natural Resource Operations, 2013b. Range Program. Accessed on July 16, 2013. URL: http://www.for.gov.bc.ca/hra/Legislation/grazing.htm

Mueggler, W.F. 1972. Influence of competition on the response of bluebunch wheatgrass to clipping. Journal of Range Management. 25:88-92.

Ndawula-Senyimba, M.S., Brink, V.C., Mclean, A. 1971. Moisture interception as a factor in the competitive ability of bluebunch wheatgrass. Journal of Range Management. 24(3): 198-200.

Newman, R., Krizic, Wallace, B. 2011. Linking range health assessment methodology with science: rough fescue grasslands of British Columbia. B.C. Min. For. Range, For. Sci. Prog. Victoria, B.C. Tech. Rep. 062. Availavle online at: www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tro62.htm

Price, P.W. 1991. The plant vigor hypothesis and herbivore attack. Oikos. 62:244-251.

Pyke, D.A., Herrick, J. E., Shaver, P., Pellant, M. 2002. Rangeland health attributes and indicators for qualitative assessment. Journal of Range Management. 55(6): 584-597.

Quinton, D.A., Mclean, A., Stout, D.G. 1982. Vegetative and reproductive growth of bluebunch wheatgrass in interior British Columbia. Journal of Range Management. 35(1): 46-51.

R Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Reed, F., Roath, R., Bradford, D. 1999. The grazing response index: A simple and effective method to evaluate grazing impacts. Rangelands. 21(4):3-6.

Richards, J.H. 1993. Physiology of plants recovering from defoliation.Proceedings of the XVII International Grassland Congress. 1993:85-94.

Rustad L.E. 2008. The response of terrestrial ecosystems to global climate change: Towards an integrated approach. Science of the Total Environment. 404: 222-235.

Ryle, G.J.A., Powell, C.E. 1975. Defoliation and regrowth in graminaceous plant: the role of current assimilate. Annals of Botany. 39:297-310.

Society for Range Management. 1989. A glossary of terms used in range management. 3rd ed. Denver, Colorado.

Statistics Canada. 2013. Cattle Industry by Province. Accessed on August 11, 2013. URL: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/prim50a-eng.htm

Stout, D.G., Brooke, B. 1985a. Growth and development of pinegrass in the interior British Columbia. Journal of Range Management. 38(4): 312-317.

Stout, D.G., Brooke, B. 1985b. Rhizomes and root below clipped pinegrass tillers have a higher percentage of carbohydrate when attached to other non-clipped tillers. Journal of Range Management. 38:276-277.

Stout, D.G., McLean, A., Brooke, B., Hall, J. 1980. Influence of simulated grazing (clipping) on pinegrass growth. Journal of Range Management. 33(4): 286-291.

Stout, D.G., Quinton, D.A. 1986. Pinegrass: an important forage species in Interior B.C. Research Branch, Agriculture Canada. Kamloops British Columbia.

Vallentine, J.E. 1990. Grazing Management. Acedemic Press Inc., San Diego, California. Pp398.

Westoby, M., Walker, B., Noy-Meir, I. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management. 42(4): 266-274.

Wikeem, B.M., Newman, R.F., van Ryswyk, A.L. 1989. Effect of fertilization and litter removal on grassland forage production. Journal of Range Management. 42(5):412-415.

Wikeem, B.M., McLean, A., Bawtree, A.H., Quinton, D.1993. An overview of forage resources and beef production on Crown land in British Columbia. Canadian Journal of Animal Science. 73:779-794.

Wikeem, B. And Wikeem, S. 2004. Grasslands of British Columbia.Grassland Conservation Council of British Columbia.Accessed on: March 21, 2013. URL: http://www.bcgrasslands.org

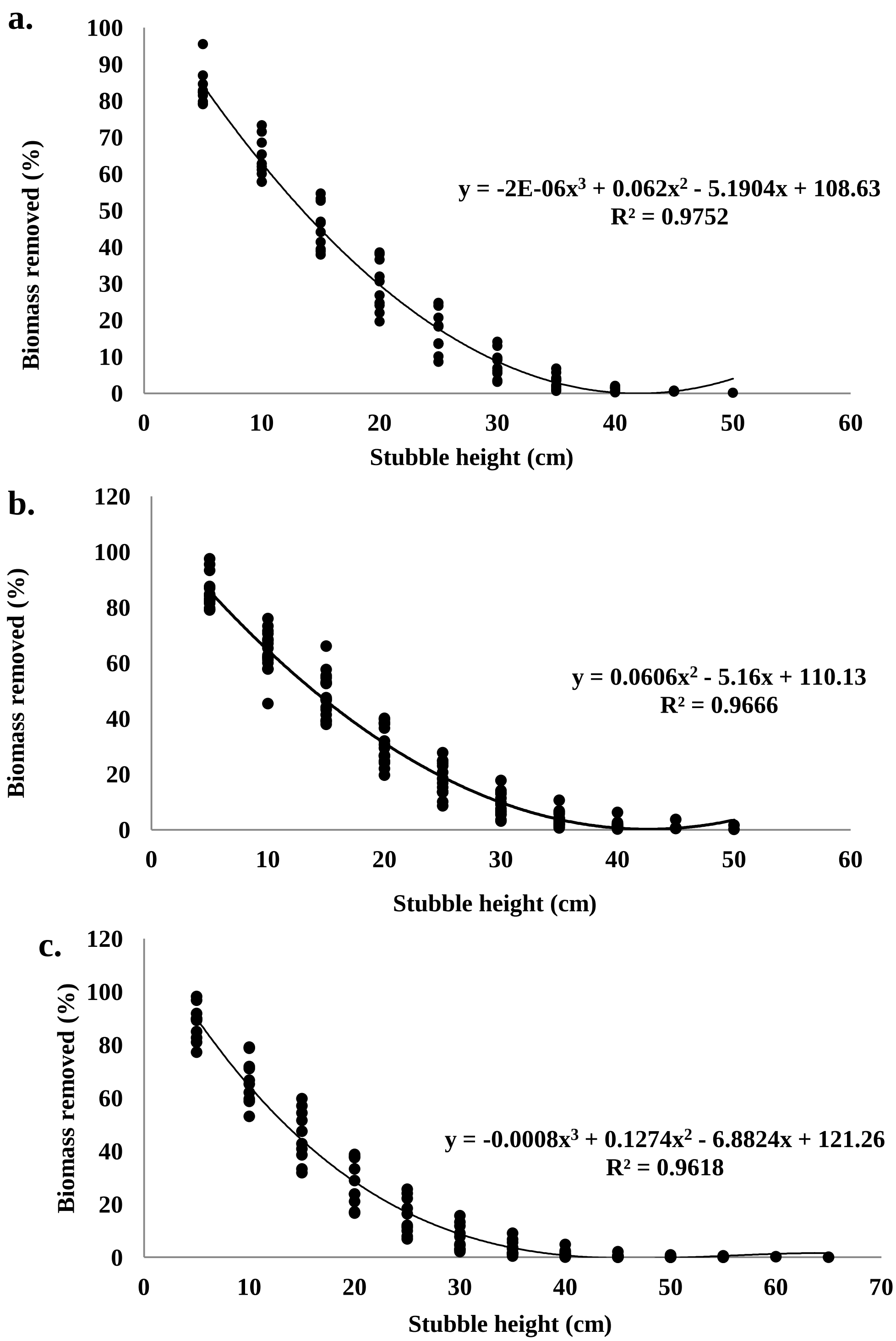
Willms, W.D. 1991. Cutting frequency and cutting height effects on rough fescue and parry oat grass yields. Journal of Range Management. 44(1): 82-86.

Willms, W.D., Fraser, J. 1992. Grwoth characteristics of rough fescue (*Fesctuca scabrella* var.*campestris*) after three years of repeated harvesting at scheduled frequencies and heights. Canadian Journal of Botany. 70:2125-2129.

Wilson, A.M., Harris, G.A., Gates, D.H. 1966. Cumulative effects of clipping on yield of bluebunch wheatgrass. Journal of Range Management. 19:90-91.

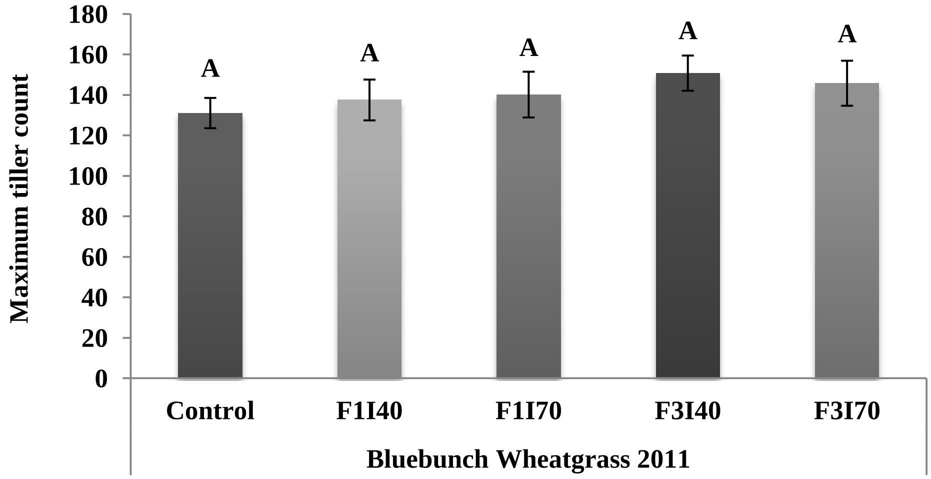
APPENDICES

Appendix 1



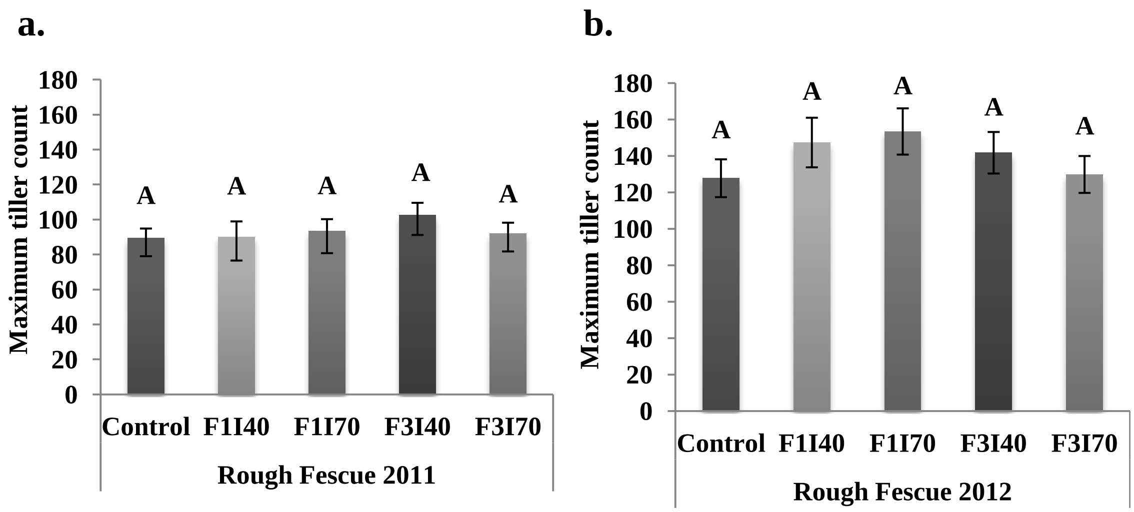
Appendix 1: Regressions of stubble height (cm) *versus* plant biomass (g) for each species. a.) Bluebunch wheatgrass. b.) Rough fescue. c.) Pinegrass. Untransformed data used for regression.

Appendix 2



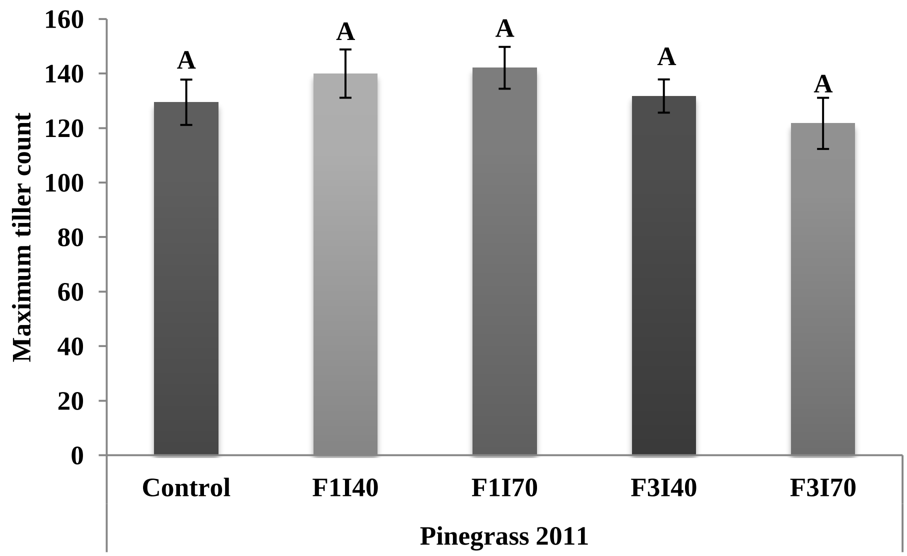
Appendix 2: Maximum tiller counts for bluebunch wheatgrass in 2011. Letters denote significance (P<0.05). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Appendix 3



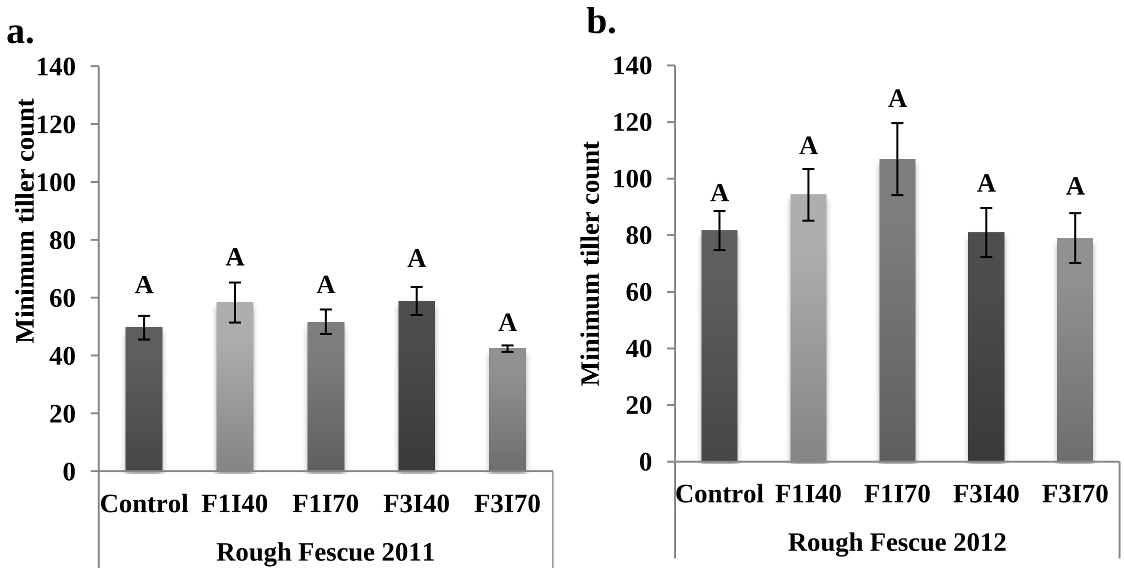
Appendix 3: Maximum tiller counts for rough fescue. a.) Rough fescue maximum tiller count in 2011. b.) Rough fescue maximum tiller counts in 2012. Letters denote significance (P<0.05). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Appendix 4



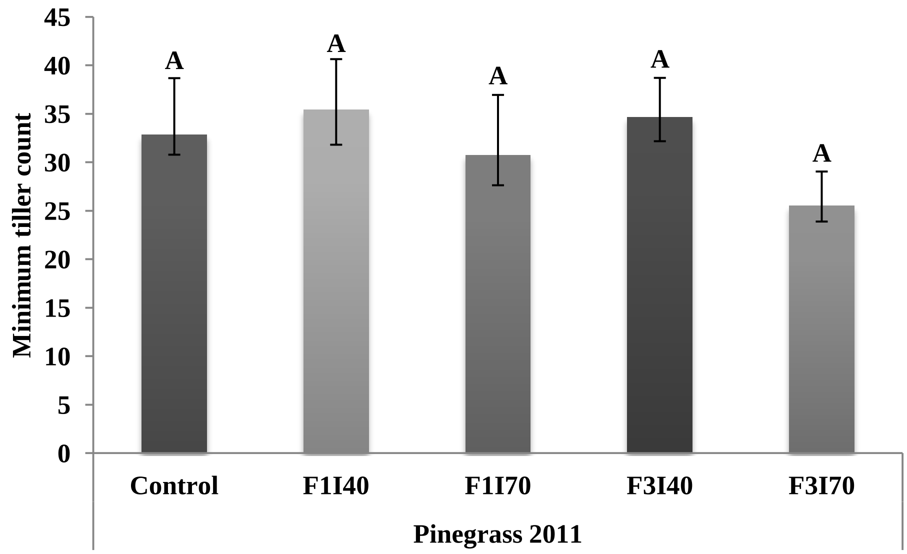
Appendix 4: Maximum tiller counts for pinegrass in 2011. Letters denote significance (P<0.05). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Appendix 5



Appendix 5: Minimum tiller counts for rough fescue. a.) Rough fescue minimum tiller count in 2011. b.) Rough fescue minimum tiller counts in 2012. Letters denote significance ($P<0.05$). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Appendix 6



Appendix 6: Minimum tiller counts for pinegrass in 2011. Letters denote significance (P<0.05). Data in graph represents untransformed data and error bars are for untransformed data while statistical analysis was done with transformed data. Control – No clipping, F1I40 – clipped once at 40% removal, F1I70 – clipped once at 70% removal, F3I40 – clipped three times at 40% removal, F3I70 – clipped three times at 70% removal.

Appendix 7

a.

	Bluebunch wheatgrass															
	Final Biomass (g)		Cumululative 2012 (g)		Max. Tiller 2011		Max. Tiller 2012		Min. Tiller 2011		Min. Tiller 2012		Canopy Height 2011(cm)		Canopy Height 2012(cm)	
Treatment	*μ*	*Sig.*	*μ*	*Sig.*	*μ*	*Sig.*	*μ*	*Sig.*	*μ*	*Sig.*	*μ*	*Sig.*	*μ*	*Sig.*	*μ*	*Sig.*
Control	N/A	N/A	11.6	A	131	A	153	A	58	A	153	A	57.5	A	42.5	A
F1I40	9.2	A	11	A	138	A	157	A	33	A	106	A	39.4	B	35.3	B
F1I70	3.9	B	7.1	BC	140	A	125	AB	34	A	67	B	32.1	C	27.9	C
F3I40	6.8	A	8.6	AB	151	A	157	A	31	A	105	A	31.5	C	33.8	B
F3I70	2.9	B	5.6	C	146	A	108	B	16	B	49	B	27.5	D	25.2	D

b.

	Rough fescue															
	Final Biomass (g)		Cumulative 2012 (g)		Max. Tiller 2011		Max. Tiller 2012		Min. Tiller 2011		Min. Tiller 2012		Canopy Height 2011 (cm)		Canopy Height 2012 (cm)	
Treatment	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*
Control	N/A	N/A	43.4	A	89	A	128	A	50	A	82	A	83.3	A	56.7	A
F1I40	31.6	A	42.4	A	90	A	147	A	58	A	94	A	50	B	44.5	B
F1I70	24.9	A	46.3	A	93	A	153	A	52	A	107	A	49.4	B	43.6	B
F3I40	31.1	A	46.5	A	103	A	142	A	59	A	81	A	49.4	B	44.9	B
F3I70	16	B	29.1	B	92	A	130	A	42	A	79	A	42.4	C	37.7	C

c.

	Pinegrass															
	Final Biomass (g)		Cumulative 2012 (g)		Max. Tiller 2011		Max. Tiller 2012		Min. Tiller 2011		Min. Tiller 2012		Canopy Height 2011 (cm)		Canopy Height 2012 (cm)	
Treatment	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*	*μ*	*sig.*
Control	N/A	N/A	5.2	AB	129	A	105	AB	33	A	14	AB	52.6	A	4.8	A
F1I40	3.8	A	5.1	AB	140	A	123	A	35	A	21	A	38.7	BC	39.5	BC
F1I70	2.7	AB	5.4	A	142	A	127	A	31	A	19	A	38.6	B	37.2	BC
F3I40	2.5	B	3.7	B	132	A	95	AB	35	A	15	A	32.3	CD	37	BC
F3I70	1.3	C	3.8	B	122	A	87	B	26	A	7	B	31.5	D	33	C

Appendix 7: Summary of significance values and means for all vigour measurements in all three species. a.) Bluebunch wheatgrass. b.) Rough fescue. c.) Pinegrass.