Examining Monitoring Strategies and Synergies for Grassland Soil Carbon and Rangeland Forage Production in British Columbia:

First Steps In Establishing A Payment For Ecosystem Services Program For Soil Carbon

Prepared for:

The Grasslands Conservation Council of British Columbia

Prepared by:

William Harrower MSc. RP Bio.

High-Country Consulting Ltd.

Table of Contents

1.0 Abstract 1

2.0 Introduction 1

3.0 Background 2

4.0 Goals 3

5.0 The Problem 3

5.1 Addressing Scientific Uncertainty 4

5.2 Carbon Sequestration 5

5.1 Soil Carbon Conservation 8

6.0 Baselines and Additionality 10

7.0 Management and Monitoring Issues 15

8.0 Conclusion 18

9.0 References: 19

List of Figures

Figure 1: Examples of soil pits and surrounding vegetation in two different soil types occurring in Lac du Bois protected area near Kamloops British Columbia. Soils at upper elevations have more above ground plant cover comprised of different plant communities, and these soils are typically darker with more organic content. 6

Figure 2: Examples of soil pits and surrounding vegetation in two different soil types occuring in Lac du Bois protected area near Kamloops British Columbia. Soils at upper elevations have developed deeper, more textured soils as they occur in areas with abundant plant growth and more abundant rainfall. 8

Figure 3: Gradient showing the relative amount of carbon stored in soils of different land uses. 9

Figure 4: Outline of basic steps to developing a Payment for Ecosystem Services (PES) program for soil carbon on British Columbia rangelands. 12

Figure 5: Outline of how the Environment Farm Plan program would work to develop Payment for Ecosystem Services (PES) programs on individual ranches.. 14

Acknowledgements

I would like to sincerely thank Dave Zender from Ecosystem service initiatives and Scott Benton at the Grassland Conservation Council of British Columbia for there support, comments, reviews, and long discussions about ecosystem services and how we might provide payments to ranchers who manage for them.

1.0 Abstract

There is an emerging interest in managing rangelands in British Columbia to receive payments of ecosystem services (PES). One components of PES programs would be management for increased soil carbon on rangelands. However, ranchers are concerned about what a soil carbon management program would look like, and how that program might influence forage production. Since forage production is the primary focus of most ranching operations, identifying synergies between soil carbon management and forage production is essential. Managing for soil carbon can be accomplished in two ways. Conservation of rangelands is the primary method of maintain soil carbon stocks as any land use that disturbs native rangeland reduces its ability to store carbon. Alternatively, grazing management on native rangeland can increase soil carbon by promoting healthy plant communities and increasing the amount of soil carbon transferred from liable organic stocks to more recalcitrant mineral forms. this has the added benefit of increasing forage production. The process of increasing the size of recalcitrant carbon stocks, and how it relates to grazing management, differs depending on the type of rangeland being examined. Uncertainty of how grazing management and rangeland type influence carbon stocks is considerable, but should not impede the development of a PES program for soil carbon, because there appears to be positive links between management of grazing for increased soil carbon and increased forage production. An adaptive management program aimed at defining specific relations between rangeland type, grazing management, forage production, and soil carbon should allow a PES program to move forward despite scientific uncertainty. This program would include mapping carbon stores by rangeland types, experimental trails to determining the relationship between rangeland type and grazing, land-use mapping to determine how grazing management can influence carbon stocks, development of standards to ensure consistent and internationally recognized monitoring programs, and continued refinement and incorporation of scientific and management information aimed at expanding PES programs to water and biodiversity services as well as refining the quality of existing forage production and soil carbon models. There are many positive benefits in managing rangelands for both forage production and soil carbon, and programs designed to provide PES to ranchers promise to improve both the financial and operational viability of ranches.

2.0 Introduction

In British Columbia, there is growing interest in developing a mechanism for ranchers to receive payments for the ecological services. One of the areas of increasing interest for ranchers is in receiving payments for either protecting existing soil carbon stores, or enhancing soil carbon sequestration on rangelands. Managing rangelands for carbon may lead not only to a new revenue source for ranchers by also to increased forage production for livestock. Other ecosystems services such as conserving or enhancing water quality, storage and flows, or enhancing biodiversity benefits like endangered species protection, pollination services for orchards and berry crops, and provision of habitat for harvestable species like deer, elk, and trout. Programs designed to provide payments to ranchers for managing these additional services are also under development, but the potential for programs designed to manage for soil carbon and forage production simultaneously still needs to be explored.

Ranchers need to be aware of potential tradeoffs when developing these new sources of income from a Payment for Ecosystem Services (PES) program. There is potential for new practices to interfere with current ranch operations and income sources. Ranchers in British Columbia are already operating on very tight profit margins and continued market and environmental stressors (i.e., BSE, drought, low cattle prices and high overhead) already threaten the financial viability of many ranches. New programs need to add value both financially and operationally. Forage production from natural rangelands are a key factor in contributing to success to both criteria, and ranches cannot sacrifice this key resource in favor of simply managing for improved soil carbon.

New projects aimed at providing incremental value and or PES to ranchers are being designed not to interfere with forage production, and if implemented properly, will likely benefit forage production along with the long-term economic and ecological sustainability of individual ranches. Incorporation of PES programs into the British Columbia ranching and agricultural industry promises to benefit these industries as a whole, not only improving an already positive ‘social license to operate’, but possibly improving the ability to market products and increasing the market share of livestock products.

In this report I examine some of the issues associated with linking a PES program to the current farm management framework in British Columbia, with specific regard to identifying synergies between the production of forage for livestock and a PES for soil carbon storage and sequestration. I will describe the basic structure and data gaps associated with a soil carbon PES program and through that process describe how such a program will benefit existing systems of forage production.

3.0 Background

Some ecosystem services in rangelands are already monetized; ranchers are paid for the livestock (i.e., food) they produce with rangelands This is an important way that humans have benefited from ecosystems that are marginal for growing domesticated crops for thousands of years (Asner et al. 2004). Rangelands cover more area than any other form of land use by humans, as over 25% of the global land surface is used to raise livestock (Asner et al. 2004)and this area is expanding. Under modern agricultural systems and using a PES program, additional ecosystem services could be monetized so that direct financial benefits could be received by ranchers for the services they often already provide society as a whole (Swinton et al. 2007). One of the barriers preventing this from happening is the lack of a recognized monitoring and evaluation systems that provide data to confirm the broad ecological benefits ranchers provide. The proper management and good stewardship or rangelands provides no only an income to ranchers, but results in storage of Natural Capital and provisions of many ecosystem services to society in general. The storage of carbon in rangelands is one such resource. Soil carbon pools are a form of Natural Capital which similar to money in a bank, store resources for later use. In this case soil carbon stores often result in good forage production in future years. Second, increasing the rate at which carbon in stored in grasslands provides one mechanism to reduce the amount of carbon already in the atmosphere. Other resources like water filtration, flood management, temperature regulation, and the provision of biodiversity are also examples of services or capital provided by good soil management but these are likely subsidiary to the soil carbon - forage production benefits.

At present ranchers are receiving only ancillary benefits for practicing good management. This includes things like better forage production by not overgrazing and thus maintaining beneficial plant communities, better long-term water availability from not degrading soil resources or water bodies, healthier animals from controlling access to watering areas, or better forage production from rich healthy soils. Monetary benefits are seldom received for these services and increased financial pressures often result in decisions that have more immediate financial returns. These financial pressures and short-term benefits often mean a ranch can continue to operate but also result in a decrease in the environmental quality of rangelands and ultimately a reduction long-term forage production. For example, ranchers sometimes overgraze lands to preserve stocking rates at or near the capacity of their grasslands during drought in order to ensure suitable financial returns or even sometimes the survival of the ranch. If monetary compensation system were in place that recognized the value of ranch resources like soil carbon, water quality and quantity, and biodiversity ranchers would not need to stock rangelands at or near capacity thereby avoiding inadvertent 'or forced' overstocking in poor years. By monetizing more and varied ecosystem services, like soil carbon, water resources and biodiversity, and by incorporating multiple services into a PES program, the trade-offs between short- and long-term benefit can become more explicit and will hopefully benefit both financial and ecological sustainability of the ranching operation.

4.0 Goals

1) Evaluate the relationship between soil carbon and rangeland forage production as an ecosystem service to identify what, if any, synergies can be gained by incorporating explicit management of soil carbon into existing management activities.
2) Define the parameters of a inventory monitoring and evaluation system for soil carbon and how it might integrate with existing monitoring systems for water and biodiversity. Indicate how these systems may support a Payment for Ecosystem Services (PES) program.

5.0 The Problem

Developing a PES monitoring and evaluation scheme for soil carbon is difficult for a number of reasons:

1) scientific uncertainty;
2) defining added benefit; and
3) monitoring and administering PES program;

The primary question is: can we actually manage rangelands to conserve and even increase soil carbon and will this benefit forage production for livestock? To answer this question we first need to address each problem associated with the development of the PES program.

Box 1: Types of ecosystem services and how they provide benefit to ranches				
Supporting Services	**Type of service**	**Description**	**Examples of Services**	**Examples of Goods**
	Provisioning	- products that can be obtained from ecosystems; pools	- livestock forage, wildlife (food), fiber (trees), crop production, pollination services,	- Timber, cereals, meat, wildlife, carbon pools/soil formation
processes and pools that are necessary for the production of all other ecosystem services	Regulating	- regulation of ecosystem processes; processes	- water purification, flood control, disease regulation (e.g., lyme's disease), local/global climate regulation,	- drinking water, flood protection, human health, clean air, reduced climate variability (heat, cold, storms), ability to be free from disease, carbon sequestration
e.g., soil formation, nutrient cycling, primary production	Cultural	- non-monetary benefits that ecosystems provide humans	- cultural heritage, sense of place/community, inspirational, educational, aesthetic, recreation, spiritual	- human health and well being, healthy communities, ability to earn a living

5.1 Addressing Scientific Uncertainty

Scientific understanding of soil carbon systems in rangelands is impeded by uncertainty in: the link between management (grazing regime) and both carbon pools and sequestration in different grassland types; which types of soil pools are important and their volatility under different grazing regimes; equilibrium conditions and plateaus in carbon storage potential of grassland types (almost completely unknown); the link between plant community composition or plant functional groups, litter amounts and quality, and carbon sequestration (especially on different grassland types and with alternative management methods).

Research is ongoing in each of these areas (e.g., Dr. Lauchlan Fraser and his students at Thomson Rivers University, Dr. Cam Carlyle and Dr. Edward Bork at University of Alberta) and each of these problems posed by scientific uncertainty are not insurmountable. More importantly, the considerable scientific uncertainty that does exist is not an impediment to moving forward with a PES program. Adaptive management frameworks can incorporate continual progress on administrative and scientific problems into ongoing activities, and are likely the best approach to addressing these types of resource management problems.

An adaptive management approach will provide short-term benefit to producers while helping solve long-term issues. However, the combined and coordinated efforts of both scientists, managers, and producers will be required to achieve these goals, and each will need to move forward without knowing if the program will be effective.

Adaptive management approaches often fail because of an inability to find ways to incorporate results from scientific findings into future management actions. Because of this , defining these experimental, monitoring, and management alternation frameworks is essential. The documentation of the planning, experiment, monitoring, and adjustment approach will provide the credibility and transparency required to ensure a long-term and stable program. Moving forward with PES program development is an essential step in reducing the scientific uncertainty surrounding soil carbon systems in British Columbia grasslands.

The following highlights portions of the scientific uncertainty and how this uncertainty might impact the link between soil carbon management and forage production. I finish with a brief review of what a soil carbon management program might look like and what specific pieces are needed to develop that program.

5.2 Carbon Sequestration

Soil carbon can be managed in two ways: conservation or sequestration. Conservation is maintaining current carbon pools. Sequestration is the rate at which carbon is moved by plants and microbes into the soil and incorporated into existing longer-term carbon pools.

Generally, soil carbon can be classified into three types: labile (or fast) carbon, slow carbon, and (biochemically) recalcitrant carbon (Dugait et al. 2012; Schmidt et al. 2011; Marschner et al. 2008; Hungate et al. 1997; Oades 1988). These types are measured in different ways because of their unique properties (see Belay-Tedla et al. 2009; & Dijkstra et al. 2005 for general examples in grasslands), but generally the amount of recalcitrant carbon increases with depth and is dependent on: a) chemistry of the organic matter, b) mineral content of the soil, c) water availability, d) temperature, e) acidity of soil, f) decomposer and microbial community composition (Dugait et al. 2012; Schmidt et al. 2011).

Figure 1: Examples of soil pits and surrounding vegetation in two different soil types occurring in Lac du Bois protected area near Kamloops British Columbia. Both soil profiles were described on south facing slopes at low elevation (left photo) and upper elevation (right photo). Soils at upper elevations have more above ground plant cover comprised of different plant communities, and these soils are typically darker with more organic content.

Fast carbon occurs mostly near the surface where organic matter is being broken down and carbon is contained in microbial communities. It is constantly being exchanged with the atmosphere and incorporated into progressively more recalcitrant forms of carbon. Labile carbon cycles in and out of this pool in timescale of days to weeks. Recalcitrant carbon is carbon that is almost completely in a mineralized form. It exists in the soil for decades to centuries. The slow form of carbon is intermediate between labile and recalcitrant forms, and is important because it represents a progression between these other two forms. Molecules of slow carbon remain in the slow carbon pool for years or decades. Gains in the storage of carbon in soils may come from identifying and increasing the amount of slow carbon in soils and understanding how and which processes sequester carbon and which processes cause soil carbon to accumulate at a greater rate than those processes that release it (Dugait et al. 2012; Schmidt et al. 2011).

Understanding which management practices increase the incorporation of carbon stored by bacteria and other organic carbon sources into more recalcitrant forms is fundamental to this question. It may be that sequestration of carbon into soil by plants (Figure 1) can only occur on particular grassland types , and certain times of the year, or under certain conditions (e.g., appropriate litter quality, moisture levels). If incorporation of carbon into slow and recalcitrant pools is increased, soil carbon levels can be increased by moving progressively more carbon to slow and recalcitrant forms and thereby increasing residence time in the soil. We have little understanding of how this process operates in different grassland types and under different types of management (Figure 2; Dugait et al. 2012).

By far the largest benefit in terms of carbon storage comes from conservation of soil pools. The first type of conservation initiatives arises from land-use decisions. Conversion of native grassland to urban developments, annual crops (e.g., barley), perennial crops (e.g., hay), tame forage (e.g., crested wheat grass) or restoration of land back to native grassland all have a decreasing impact on soil carbon when compared to the maintenance of native soils and grasslands (Figure 3). Conversion of grazing land to other uses is the single largest threat to soil carbon reserves (Poeplau et al. 2011; Post & Kwon 2008; Guo & Gifford 2002; Conant et al. 2001).

This difference in the ranking of alternative land-use strategies arises from the nature of three distinct pools of carbon in soil, and the fact that increasing levels of soil disturbance will result in release of progressively more carbon to the atmosphere. It is difficult and time consuming to re-establish these carbon pools (especially recalcitrant pools) and this makes it progressively more difficult to restore native soil carbon pools after they have been lost (Conant et al. 2001).

The second type of conservation program impacting soil carbon stores are programs to reduce soil erosion. As soil disappears, largely from poor land management decisions, the carbon it contains also disappears. There is a long history of activities to reduce soil erosion including crop rotation, use of cover crops, planting windbreaks, using erosion barriers, low tillage cropping, contour cropping, perimeter runoff control and other water management activates all contribute to soil conservation as does management of soil to reduce salinization or acidification of soils.

Crop production methods for conserving soil include: managing crop residues, proper tillage, cutting stubble high, direct seeding (zero-till), extended crop rotations, using forage crops, using complementary rotational crops, and using wind and water barriers like: annual crops on summer fallow, annual crop barriers in crop, perennial grass barriers, shelterbelts, strip cropping, cover crops, using green manure, and animal manure. Discussions of how to manage soil erosion are largely beyond the scope of this document, especially because they largely pertain to cropping methods not extensively used in British Columbia, and because these are methods familiar and well developed by both agrologists and farmers.

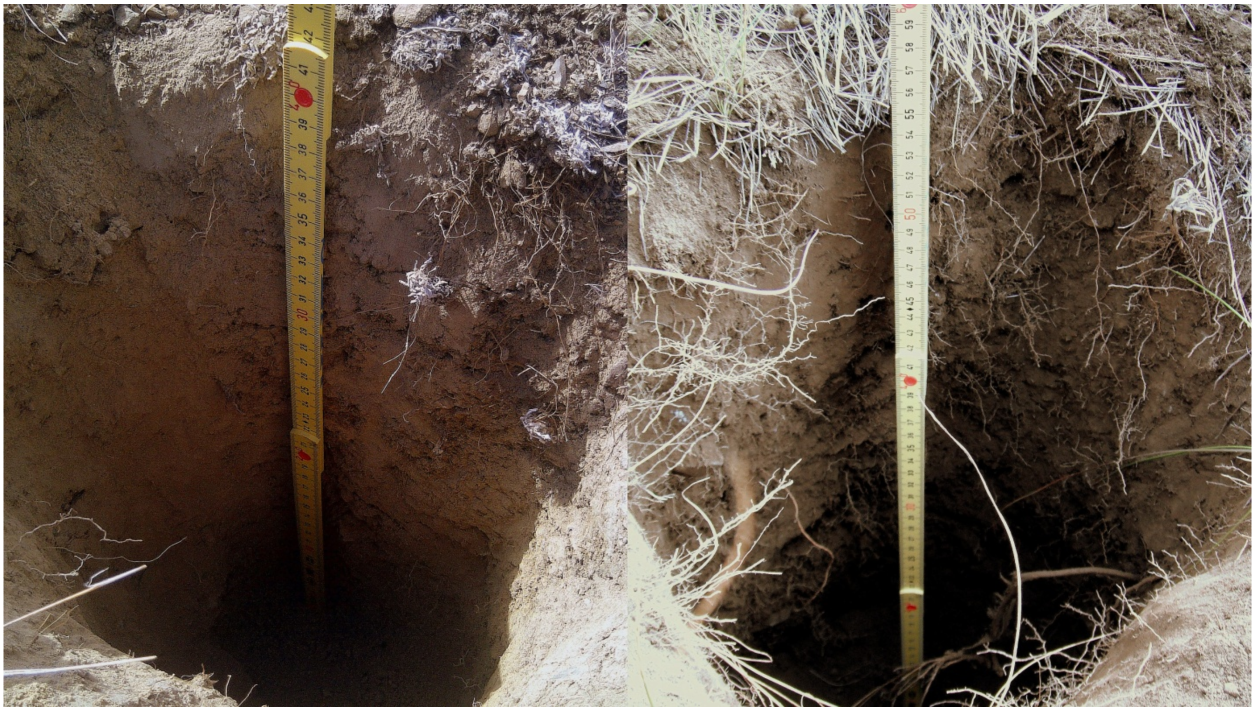

Figure 2:Examples of soil pits and surrounding vegetation in two different soil types occurring in Lac du Bois protected area near Kamloops British Columbia. Both soil profiles were described on south facing slopes at low elevation (left photo) and upper elevation (right photo). Soils at upper elevations have developed deeper, more textured soils as they occur in areas with abundant plant growth and more abundant rainfall.

5.1 Soil Carbon Conservation

The positive relationship between soil carbon conservation, and grassland forage production are obvious. Preventing the conversion of land to commercial or residential development will benefit the amount of rangelands available for livestock production and thus increase forage potential. Preventing conversion to other agricultural practices, like greenhouses and annual crops will also increase the area available for forage and will substantially increase soil carbon conservation. It is less certain how shifts to tame forage or uses like orchard or berry cropping systems will impact carbon pools however it is likely that similar to grain crops, natural grasslands store more carbon than orchards or berry cropping. Restoring areas to native rangelands, and converting marginal cropland to perennial forage crops, will start to increase carbon pools over other land management activities, and this will increase the forage available for livestock production (Post & Kwon 2008; Guo & Gilford 2002; Knops & Tilman 2000; Burke et al. 1995; Dormaar & Smoliak 1985).

Carbon Soil Sequestration

If carbon capture and ecological restoration is the objective, every effort should be made to conserve and especially restore areas to native rangelands as this is the primary benefit to forage, carbon, water, and biodiversity. In this type of PES program the additionality, or added benefit comes from the land management decision made by the landowner (i.e., not to convert grasslands to urban development, annual crops, or other intense use). There are currently mechanisms to pay ranchers for this type of management (e.g., agreement of sale between Frolek Cattle Company and The Nature Conservancy of Canada near Kamloops BC).

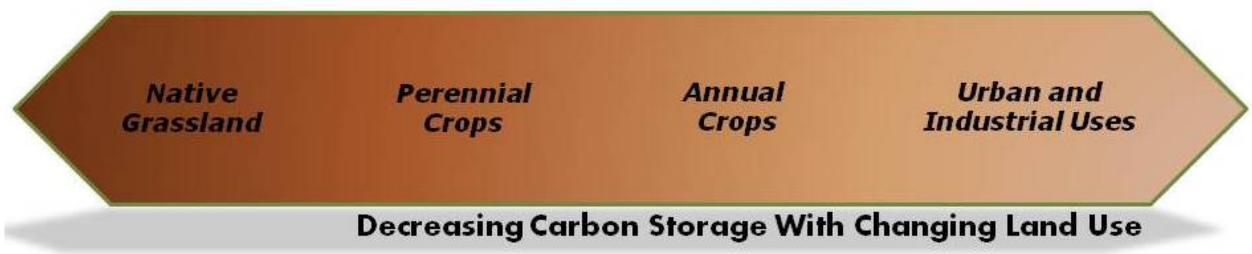

Figure 3: Gradient showing the relative amount of carbon stored in soils of different land uses. Although the amount of temperature, water, and nutrients available to plants along with grazing history and type of plants growing on a site determine the amount of carbon storage, by far the largest impact to carbon stores is the reduction in the amount of carbon stored in lands with progressively more human influence. Native grasslands store the most carbon.

Apart from the amount of land in forage production (i.e., quantity of forage), soil carbon management can be associated with quality of rangeland producing forage. Areas with abundant high quality forage often store and likely sequester large amounts of soil carbon (Conant & Paustain 2002; Conant et al. 2001), reduces wind and water erosion of soils (Follett et al. 2001), enhances water infiltration and soil moisture in arid and semi-arid grasslands (Unger et al. 1991), can lead to increased biodiversity (Bekessy & Wintle 2008).

The primary mechanism that both carbon and forage potential is managed on rangeland is through livestock management. From the perspective of soil carbon, this method of increasing soil carbon storage seeks to either maintain or increase sequestration by promoting suitable plant communities and their growth. Thus, grazing management that promotes diverse native grasslands with abundant forage and appropriate amounts of litter generally results in deep dark soils associated with increased soil carbon sequestration (Figures 1 & 2). Overgrazing will cause shifts in the composition of plant communities (i.e., species identity and vigour plants) that reduce both forage potential and carbon sequestration (Conant & Paustian 2002). The additionality of these PES programs comes from change in management action associated with grazing, not the land-use decision that serves as the baseline condition when programs are aimed at the conservation of existing carbon pools.

6.0 Baselines and Additionality

Additionality is the added benefit gained in the ecosystem service by a change in some action and it arises from measuring the change in some ecosystem service (or its proxy) from a baseline condition (Johnson et al. 2012; de Groot et al. 2010; Daily et al. 2009). In this case either: a) a land-use decision; or b) a change in grazing practice. The monetary benefit that is provided by the PES program is the difference between the measurements that were made by maintaining the current practices, and the measurements made of the ecosystem service after the practice has changed. Baselines can be achieving a desired goal (e.g., a 5% increase in soil carbon over 5 years), or baselines can be not seeing a corresponding loss (e.g., sequestration was maintained at 90% of previous levels, while surrounding land-uses degraded grasslands). Baselines for conservation and sequestration methods of soil carbon management differ substantially, and the explicit definition of these baselines will govern what benefits (or losses) are associated with the PES program.

Baselines for conservation efforts would be associated with not converting land into an alternative low carbon land management practice. One example of this would be to show benefit by restoring an area used for annual crops or tame pasture to native grasslands, another would be to preserve land from urban or commercial development. Landowners would have to prove either restoration occurred, or land conversion was avoided through land covenants or other such methods. Baselines associated with sequestration may be more difficult to directly measure, but could possibly be easier to relate to ranchers since many of the mechanisms to prevent conversion of land to low carbon – low forage alternatives are already in place.

Baselines for sequestration related to native range would show benefit from altering grazing management. For products formerly sold on the Chicago Carbon Exchange, this was the creation and applications of a grazing management regime (Chicago Model) that: a) differed from current practice used to manage livestock, b) produced healthy productive plant communities, and c) incorporated a drought response to reduce stocking rates in these years (see Harrower et al. 2012 for further discussion). The amount of soil carbon benefit under the Chicago Model was estimated based on region of United States that the grazing lands occurred on, and consisted of a flat rate that conservatively estimated carbon gains from a changed grazing regime. Grazing plans were 5-year management plans that specify the number of cattle, length of time, and time of year animals are on the range. The application of similar 5-year grazing management plans could work in British Columbia, but both the flat rate approach and the payment mechanism should be tailored local needs.

British Columbia is highly mountainous and has extremely varied and complex ecosystems that differ widely between regions and even within ranches. The baselines used on the Chicago Model would not apply here, although the structure of their program may. This the use of proxy measures by the Chicago Model to estimate the value gained by a change in practice to an ecosystem service is widely used (e.g., Raudsepp-Hearne et al. 2010; Egoh et al. 2008; Naidoo et al. 2008) and applicable in British Columbia, However, we can likely provide better estimates of soil carbon gains by using specific local measures, and tailoring altered grazing practices to local conditions on an individual ranch or in a particular region.

Smaller-scale estimates suited to the grassland types that occur in British Columbia will likely provide better returns and more flexibility to local ranch operations.

Grazing management plans can be altered to achieve additionality by increasing grazing on grassland types that benefit from grazing and reducing grazing on more sensitive areas. These sensitive areas often produce limited forage and cattle may lose weight while occupying these pastures. Alternatively, sensitive areas may simple receive more rest, in a rest rotation system, than grasslands that benefit from grazing. In these ways, local estimates of how carbon is influenced by grassland type and management practice can allow a better trade-off between the need to raise livestock and the need to increase carbon sequestration. This trade-off may become beneficial to both livestock and carbon production because of the ability of individual ranches to spatially and temporally manage grazing to promote both services. Thus, a carbon management scheme needs to be built up from individual ranches, to regions, and eventually provincial scales; not vise versa. The flexibility to tailor grazing management must remain with the rancher.

We can remotely estimate PES benefit by grassland types through large-scale ecosystem mapping developed by using products and methods similar to those used in the forest industry (see pilot in Harrower et al. 2012 for the Thompson-Nicola), and verify and improve these estimates using more intensive work on individual ranches (Figure 4). Thus, additionality is measured by estimating the increase in soil carbon that occurs when grazing practices are changed, and measured by up-scaling estimates of how this occurs on focal areas to regional grassland types. The intensive monitoring at focal ranches informs regional grassland forage quality and carbon sequestration inventories, and thereby reduces the needs to monitor intensively at every ranch. Grazing management that increases soil carbon will likely be the same practices that promotes forage production since healthy diverse grassland plant communities are likely to be the ones that sequester the largest amount of carbon below ground, and in some grassland types this sequestration below ground can be promoted by grazing livestock. Thus, developing baselines for each grassland type by region is a key goal of ongoing scientific investigations.

To develop baselines, we need to better understand how the size of the three soil pools and the rate of sequestration into these pools changes with grassland type and grazing management. The amount of resources (i.e., temperature, water and nutrients) that occur at a location, along with the sites historical use and disturbance, all combine to determine what type of grassland will occur at a location. In British Columbia, the Biogeoclimatic Classification System (BEC) does a good job of delineating one level of grassland classification. Bunchgrass, Ponderosa pine, and Interior Douglass Fir BEC Zones distinguish basic large scale grassland types with bunchgrass and Ponderosa pine zones encompassing mostly middle and lower grasslands, and dry interior Douglas fir sites occupying areas typically described as upper grasslands. Furthermore, BEC zones can be subdivide based on site characteristics using detailed site descriptions (Lee 2012), and variants tailored to specific regions. By linking estimates of carbon in liable, slow, and recalcitrant pools by BEC site series and variant we can have spatially explicit soil carbon mapping for all rangelands. Subsequently linking this to grazing management practices, developed through this adaptive management program, will allow better quantification of both forage production and carbon storage and sequestration throughout British Columbia. These data are essential for the creation of a PES program in the province, and making these data publically available will help both local and regional management and development programs.

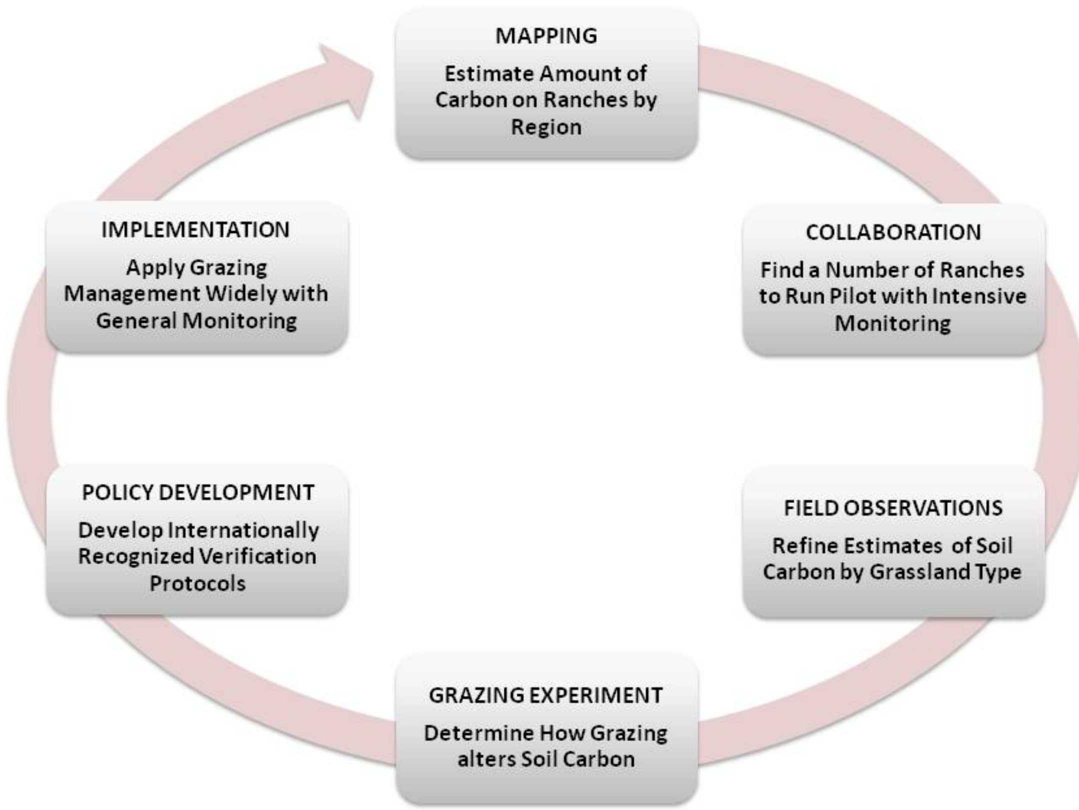

Figure 4: Outline of basic steps to developing a Payment for Ecosystem Services (PES) program for soil carbon on British Columbia rangelands. Portions of this program are already in place where pilot projects have begun to estimate soil carbon potential in regional areas (Harrower et al 2012), develop collaboration with ranches in particular regions (GCC), perform field observation of how historical grazing and grassland type influence soil carbon pools (TRU), however, control experimentation on how grazing management influences soil carbon in different grassland types and key policy develop programs are still required.

For the purposes, of mapping soil carbon over large areas, Harrower et al. (2012) described 15 grassland types base on elevation local topography (aspect and slope position), and these groupings roughly correspond to site characteristics measured in the field and match the biogeoclimatic site series classifications (Harrower et al. 2012; Lee 2012). The size of soil carbon pools and sequestration values should map almost directly to a classification scheme using topography and biogeoclimatic subzone to define grassland types. For example, and north facing slope on the top of a hill near the forest boundary, will likely store and sequester less carbon than a lower slope south facing site nearer the valley bottom.

These sites will also have widely varying forage potential and plant communities (Lee 2012). Data are readily available to delineate both topography and biogeoclimatic subzone so the creation of base maps can be easily accomplished. By linking these base maps to soil carbon measurements we can provide early estimates of the spatial distribution of carbon in British Columbia relative to different grassland types.

Foresters in British Columbia already use concept similar called 'site index' to describe the potential of a location to grow trees, I propose a similar method focused on a locations potential to produce forage and sequester carbon. Continuing experimentation with different grazing practices on different grassland types throughout the province will allow ranchers to tailor management practices and managers to monitor and improve estimates of forage production and soil carbon benefit. Again, mapping the incorporation and storage of carbon into the three soil pools will likely also provide detailed mapping and monitor of how forage production improves with good grazing management.

Following from the concept of a site index (i.e., or potential of a site to store carbon and produce forage) we can map the potential to store carbon at relatively small scales to provide estimates of current carbon pools, and potential benefits gained from management actions (Harrower et al. 2012). These crude estimates can be added up over large areas to determine how, for example, land-use change could alter the distribution of carbon store resulting from urban development, agriculture land conversion or other activities that diminish the capacity of soil to store carbon (Harrower et al. 2012) . Similar exercises have be accomplished with regards to the loss of grasslands to urban encroachment (GCC 2004), and it would not be difficult to find the potential loss of carbon resulting from these land use changes, either retroactively or into the future. The Natural Capital project, out of Stanford University (www.naturalcapitalproject.org), provide good and improving methods to make these estimates and incorporate them into land-use planning decisions. Additionally, the calculation of a grassland site index can be improved over time by refining estimates with data (the current approach) and by increasing the complexity of the calculation used to determine this index (i.e., a better understanding of turnover between carbon pools). For example, I currently propose using only topography and BEC subzone, but adding disturbance history, current plant community, potential natural community, soil type, projected rainfall and other variables could increase the complexity of the site index model and may improve estimates. However, at the initial stages of a PES program development our simple model is sufficient, but future incorporation of new data is essential.

The basic mapping exercises I suggest values can be summed for individual ranches, farms, regional districts, forest districts, watersheds, or regions allowing local groups improve decision making. This investment will promote development and agricultural activities throughout the province. Pilot programs to manage PES are already being established by some groups (e.g., East Kootenay regional planning for PES program, and South Okanagan conservation planning), but adding a soil carbon – forage production component would help. Although soil sequestration benefits on individual parcels of land may be small, aggregation of these benefits over larger areas and over more years (e.g., 5-year timeframes) promises to provide substantial benefits to both forage production, carbon storage, water availability and quality, and biodiversity. Adding carbon benefits to individuals ranches may seem to have little absolute benefit. However, if a program was applied over a regional district, like the East

Kootenay, and the benefit from each individual parcel, surrounding protected area, and forest was combined the benefits may be substantial and provide returns not realized by applying the program on individual ranches alone. But, the detailed coordination of these programs would be required to realize emergent benefits from simply managing rangeland soil carbon and rangeland forage production together on multiple land parcels (Figure 5).

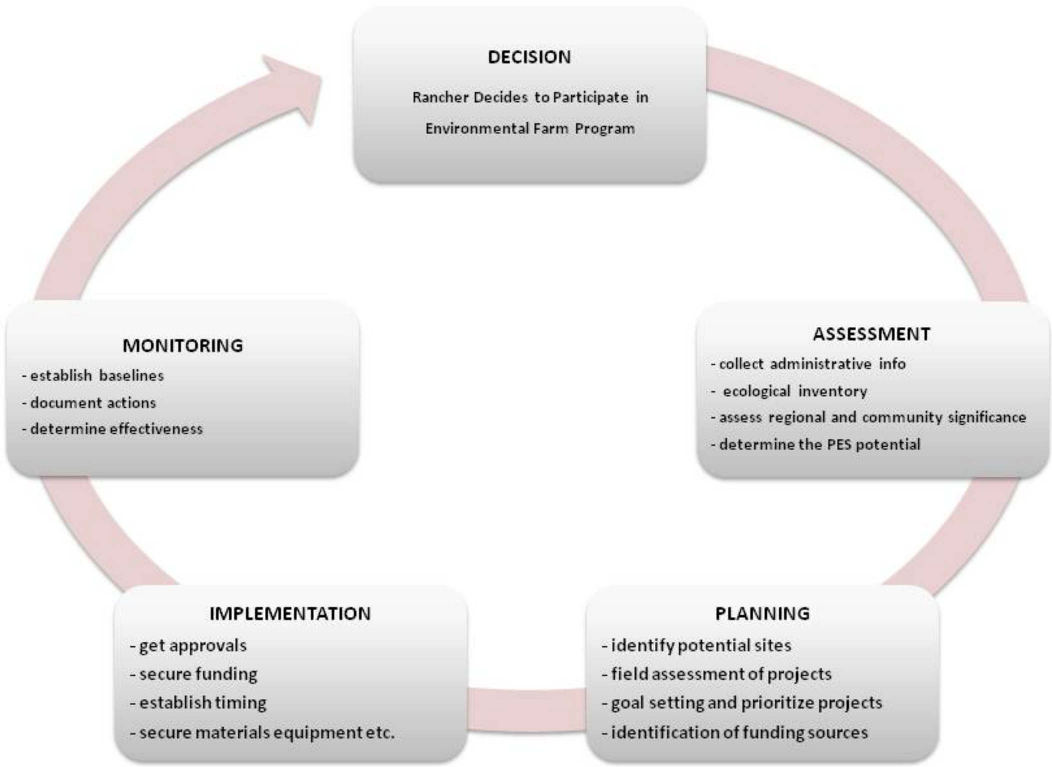

Figure 5: Outline of how the Environment Farm Plan program would work to develop Payment for Ecosystem Services (PES) programs on individual ranches. Individual ranches would use Farm Advisors supplied by AgCorp to help develop the program and reduce the administrative workload to ranchers. How a PES program would differ from the current Environmental Farm program would be through the incorporation of monitoring programs that feed information of how projects impacted ecosystems functions and the incorporation of this knowledge into new and existing projects. Examples of ecosystem functions include: forage production, soil carbon sequestration, water quality, flood control, or provision of biodiversity.

As coordinated programs are developed better baselines for each grassland type, and assessments how grazing management impacts sequestration on each type will be developed. Organizing these methods by region will allow ranchers to tailor their activities for the specific type of operation they are (i.e., large northern or Cariboo ranches, versus smaller operations in the South Okanagan). By continuing to collect data on how grassland types and management practices influence soil carbon sequestration and forage production we can continually feed data back into refining the program at large. These data drive adaptive management programs aimed at determining the amount of carbon sequestered by grassland type and incorporate this directly back into carbon estimates improving the accuracy of site index estimates and allowing ranchers to develop better grazing management programs. Programs to refine forage production and carbon sequestration estimates can then be used in land-use decision making frameworks to determine how the future costs of removing forage land from production, say for urban development, or costs associated with altered stocking rates impacts ranchers. In this way baseline mapping exercises could provide significant benefit both to inventory of rangelands, but also to scientific investigations of soil carbon storage and sequestration. The entire process should improve provincial forage production, raise the profile of the ranching industry, and generally improve rangeland health.

7.0 Management and Monitoring Issues

An effective monitoring program for forage production and soil carbon (along with other ecosystem services) will have these essential components:

1) Measurements, of forage production and the values of carbon stored in three distinct soil carbon pools and how the residence time of carbon in each pools differs between grassland types.
2) Ecosystem Mapping, to provide and inventory of grassland types on rangeland and upscale estimates of stores in each pool and potential sequestration rates calculated from residence times to regional and provincial levels.
3) Experimental trials, to provide data on how stocking rates and turnout times influence both forage production and the incorporation of each carbon into each carbon pool in different grassland types.
4) Land-use mapping, to estimate how land-use change and grazing management can change the size of carbon pools on different ranches and in different regions.
5) Verified Carbon Standard (VCS) protocols, to ensure that the programs that are being developed in British Columbia will meet and be accepted by international bodies and donors.
6) Adaptive management trails, to incorporate forage production and soil carbon programs into PES programs aimed at providing payments for water, carbon, and biodiversity through the Environmental Farm Plan, and ensure that information garnered from the development and use of the program are incorporated into future activities.

One goal of ongoing work on PES programs in British Columbia is to integrate ongoing work by the BC Agriculture Council, Environmental Farm Program, the Ecosystem Services Initiative (ESI), and Grasslands Conservation Council (GCC) into a coherent PES program for the agricultural industry and diverse ecosystems of British Columbia. A PES program must be: a) scientifically credible, b) legitimate and responsive to the needs of farmers and ranchers to ensure their participation, c) be transparent to funders, ranchers, and the general public; and d) time and cost effectives for both administrators and ranchers. To accomplish this the GCC is proceeding with a three step process:

1) The GCC has supported and is continuing to work on pilot projects to test and show the proof that our concept works (e.g., Harrower et al 2012).
2) The GCC is supporting Thompson Rivers University (TRU) researchers in their scientific investigations at five focal ranches across the province to better understand the link between management practices and ecosystem functions on rangelands.
3) The Ecosystem Services Initiative (ESI) is working to establish the policies and procedures that will help implement, administer, and fund a PES program aimed at providing producers (i.e., farmers, ranchers, etc.) money for managing for beneficial ecosystem services.

The joint program at the GCC and TRU will not only provide valuable data on how grazing influences carbon on different grassland types, but begin to let an emerging PES program move from an action-based to function-based payment scheme (Banerjee et al. 2013). It will do this by identifying baselines, refining and adjusting targets for functioning different grassland types, and establishing what types of traditional and innovative grazing practices improve ecosystem function. Under this program ecosystem functions will be measured as plant growth, carbon sequestration, and plant species identity and these can be directly equated with ecosystem services like forage production, greenhouse gas emission reductions, and biodiversity conservation. Linking ecosystem services and their proxy measures directly to improvement in ecosystem functions is an essential step in reducing scientific uncertainty and ensuring legitimacy in this program.

With regard to synergies between forage production and soil carbon management, it is likely that management for soil carbon (and other ecosystem services) will be complementary and when designed and implemented properly should place little additional work on the rancher. There are direct synergies between soil carbon, water quality and soil moisture which collectively provide a rich environment for increasing biodiversity and forage production. These programs promise to substantially alter revenue sources on ranches and thus should be explored. A forage production – soil carbon management program or a full scale PES program should (and likely will) be developed by producers and implemented by AgCorp through the Environmental Farm Plan program using methods similar to those existing for Biodiversity management. ESI is actively working with AgCorp towards this goal.

This means individual ranchers can have mapping, assessment, and decision making tools provided to them through the help of that program and a Farm Advisor; a program already in place. What is needed is support in developing the products to support this process in a PES program framework. Guidebooks providing methods to increase forage production in different grassland types, to facilitate carbon sequestration in various regions of the province, and mapping to assist in assessment and decision making by ranchers on individual ranches is essential. Only with these tools can test cases begin and show how this type of management can benefit ranchers, the ranching industry, and the environment.

Box 2: Examples of environmental and economic benefits gained from managing for ecosystem service on rangelands		
Management Action	**Environmental Benefits**	**Economic Benefits**
Low To Moderate Grazing Intensity	- Stimulate plant growth on some sites - Control over-dominance of species	- improved forage quality and quantity, better weight gain by cattle - improved soil development - better drought resistance
Reduced Overgrazing	- Improved plant community composition - Reduced invisibility by weeds - Increased soil production - Increased plant growth - Better retention of rare and beneficial plant species	- improved forage quality and quantity, better weight gain by cattle - improved soil development - better drought resistance
Increased Rest In Rest-Rotation Grazing System	- Increased litter amounts and quality - Promotion of plant growth and diversity - Increased habitat for insectivores small mammals and birds - improved soil carbon	- improved forage quality and quantity, better weight gain by cattle - improved soil development - better drought resistance - better pest control of grasshoppers and other detrimental insects by bird and small mammals
Spring-Fall-Rest Grazing Rotations	- Promotion of forage production - Increase plant diversity - Increased habitat for insectivores small mammals and birds - improved soil carbon	- improved forage quality and quantity, better weight gain by cattle - improved soil development - better drought resistance - better pest control of grasshoppers and other detrimental insects by bird and small mammals
Fence Cattle From Water Sources	- Reduced erosion - Reduced trampling of aquatic vegetation - Better downstream water quality - Improved flood control - More water retention through drought/dry periods	- better soil retention - biodiversity protection through improved habitat for aquatic insects, plants, and birds; PES - less hauling water during drought - improved insect pest control by birds
Planting Riparian Vegetation	- Improved water quality - Reduced soil erosion - Promotion of wildlife habitat - Increased habitat for insectivores birds	- better soil retention - biodiversity protection through improved habitat for aquatic insects, plants, and birds; PES - less hauling water during drought - improved insect pest control by birds

One way to deal with managing multiple ecosystem services, like forage production and carbon storage, is through either stacking or bundling PES together (Banerjee et al. 2013). Stacking can allow payments for each service from separate markets, and bundling would pay for activates that pay for multiple services at the same time. For example, you can stack payments for forage production and carbon sequestration together. Since a grazing management activity is only a single action by the rancher but that action produces multiple benefits to ecosystem services. Grazing management may promote diverse healthy plant communities improving both forage production and soil carbon sequestration. Ranchers may receive financial benefit from both these services effectively stacking payments for two services produced by one action on top of each other. Bundling ecosystem services is similar to stacking. Bundling is when multiple ecosystem services are managed together, generally with different management actions, but the process of managing both together provides added benefit. In rangelands, you could see added benefit in managing increased water resources and managing for increased forage production at the same time. When bundling multiple services together the rancher received more monetary benefit than if they managed each individually. The most effective way to manage ecosystem services is by managing multiple services together through stacking and bundling processes. Management for forage production and soil carbon resources is fantastic way to increase benefits to the rancher by managing multiple service together.

8.0 Conclusion

In this report I have explored synergies between forage production and soil carbon management in British Columbia and outlined the structure and data gaps required to develop such a program. It appears that ongoing projects to develop PES in British Columbia will continue, and soil carbon on rangeland is an important, but likely currently underdeveloped, component of those programs. Development of a PES program for soil carbon is a large and complicated process because not only are methods to assess and monitor sequestration on different grassland types not well developed but the governance structure of such a program is still uncertain. However, moving forward with a soil carbon program in British Columbia promises to provide significant benefits to forage production both by inventorying areas under production, ranking their importance, and assessing the impact of their loss to alternative land uses. This process will help develop methods that will improve forage production and soil carbon sequestration simultaneously. There seems to be few negative consequences to forage production associated with the implementation of PES programs aimed at rangeland soil carbon and such programs may provide valuable new income streams, provide inventory and management benefits to improve forage production, and raise the profile and support for the ranching industry in general. By reducing land conversion, and improving support for good grazing management both ranches and society also get the added benefit of improved rangeland health.

9.0 References:

Asner GP, AJ Elmore, LP Olander, RE Martin, & AT Harris. 2004. Grazing systems, ecosystem responses, and global change. Annu. Re. Envrion. Resour., 29: 261-299.

Banerjee S, S Secchi, J Fargione, S Polasky, & S Kraft. 2013. How to sell ecosystem services: a guide for designing new markets. Frontiers in Ecology and the Environment, 11(6): 297-304.

Belay-Tedla A, X Zhou, B Su, SW You. 2009. Labile, recalcitrant, and microbial carbon and nitrogen pools of a tallgrass prairie soil in the US Great Plains subjected to experimental warming and clipping. Soil Biology and Biochemistry, 41(1): 110-116.

Bekessy SA, & BA Wintle. 2008. Using carbon investment to grow the biodiversity bank. Conservation. Biology, 22: 510–513.

Burke IC, WK Lauenroth, & DP Coffin. 1995. Soil organic matter recovery in semi-arid grasslands: implications for the conservation reserve program. Ecol. Appl., 5: 793-801.

Conant RT, & K Paustian (2002). Potential soil carbon sequestration in overgrazed grassland ecosystems. Global Biogeochemical Cycles, 16(4): 1143.

Conant RT, K Paustian, & ET Elliott. 2001. Grassland management and conversation into grassland: effects on soil carbon. Ecological Applications, 11: 343–355.

Daily GC, S Polasky, J Goldstein, PM Kareiva, HA Mooney, L Pejchar, TH Ricketts, J Salzman, & R Shallenberger. 2009. Ecosystem Services in Decision Making: Time to Deliver. Frontiers in Ecology and Environment, 7(1): 21-28.

Dormaar JF, & S Smoliak. 1985. Recovery of vegetative cover and soil organic matter during revegetation of abandoned farmland in a semi-arid climate. J. Range Manage., 38: 487-491.

Dijkstra FA, SE Hobbie, PB Reich, & JMH Knops. 2005. Divergent effects of elevated CO_2, N fertilization, and plant diversity on soil C and N dynamics in a grassland field experiment. Plant and Soil, 272: 41-52.

Dungait JAJ, DW Hopkins, AS Gregory, & AP Whitmore. 2012. Soil organic matter turnover is governed by accessibility not recalcitrance. Global Change Biology, 18(6): 1781-1796.

Egoh B, B Reyers, M Rouget, DM Richardson, DC Le Maitre, & AS van Jaarsveld. 2008. Mapping ecosystem services for planning and management. Agriculture, Ecosystems, & Environment, 127: 135-140.

Follett RF, JM Kimble, & R Lal eds. 2001. The potential of US grazing lands to sequester carbon and mitigate the greenhouse effect. Boca Raton, USA, CRC Press LLC.

de Groot RS, R Alkemade, L Braat, L Hein, & L Willemen. 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, and decision making. Ecological Complexity, 7: 260-272.

[GCC] Grasslands Conservation Council of British Columbia. 2004. BC Grasslands Mapping Project: A conservation risk Assessment final Report.

Guo LB, & RM Gifford. 2002. Soil carbon stocks and land use change: a meta analysis. Global Change Biology, 8(4): 345-360.

Harrower WL, C Carlyle, P deKoning, L Fraser. 2012. Managing rangelands for carbon: assessing the viability of carbon offset markets for British Columbia ranchers. prepared for The Grasslands Conservation Council of British Columbia and Habitat Conservation Trust Fund.

Hungate BA, EA Holland, RB Jackson FS Chapin III, HA Mooney, & CB Field. 1997. The fate of carbon in grasslands under carbon dioxide enrichment. Nature, 388: 576-579.

Johnson KA, S Polasky, E Nelson, & D Pennington. 2012. Uncertainty in ecosystem services valuation and implication for assessing land use tradeoffs: an agricultural case study in Minnesota River Basin. Ecological Economics, 79: 71-79.

Knops JMH, & D Tilman. 2000. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. Ecology, 81: 88-98.

Lee RN. 2011. Plant community relationships to soil properties and topography in a southern interior BC grassland: a refinement. MSc Thesis. University of British Columbia. Vancouver Canada.

Leibig MA, JR Gross, SL Kronberg, JD Hanson, AB Frank, & RL Phillips. 2005. Soil response to long-term grazing in the northern Great Plains of N. America. Ag. Ecosys. Environ., 115: 270-276.

Li C, X Hao, BH Ellert, WD Willms, M Zhao, & G Han. 2012. Changes in soil C, N and P with long-term (58 years) cattle grazing on rough fescue grassland. J. Plant Nutr. Soil Sci., 175: 339-344.

Mapfumo E, NA Naeth, VS Baron, AC Dick, & DS Chanasyk. 2002. Grazing impacts on litter and roots: annual versus perennial forages. J. Range Manage., 55: 16-22.

Marschner B, S Brodowski, A Dreves, G Gleixner, A Gude, PM Grootes, U Hammer, A Heim, G Jandl, R Ji, K Kaiser, K Kalbitz, C Kramer, P Leinweber, J Rethemeyer, A Schaffer, MWISchmidt, L Schwark, & GLB Wiesneberg. 2008. How relevant is recalcitrance for the stabilization of organic matter in soils? J. of Plant Nutrition and Soil Science, 171(1) 91-110.

Naeth MA, DS Chanasyk, RL Rothwell, & AW Bailey. 1991. Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems. J. Range Manage., 44: 7-12.

Naidoo R, A Balmford, R Costanza, B Fisher, RE Green B Lehner, TR Malcolm & TH Ricketts. 2008. Global mapping of ecosystem services and conservation priorities. Proc. Natl. Acad. Sci., 105: 9495–9500

Oades JM. 1988. The retention of organic matter in soils. Biogeochemistry. 5(1) 35-70.

Pineiro G, JM Paruelo, M Oesterheld, & EG Jabbagy. 2010. Pathways of grazing effects on soil organic carbon and nitrogen. Rangel. Ecol. Manage., 63: 109-119.

Poeplau C, A Don, L Vesterdal, J Leifeld, B van Wesemael, J Schumacher, & A Gensior. 2011. Temporal dynamics of soil organic carbon after land-use change in the temperature zone - carbon response functions as a model approach. Global Change Biology, 17: 2415-2427.

Post WM, & KC Kwon. 2008. Soil carbon sequestration and land-use change: processes and potential. Global Change Biology, 6(3) 317-327.

Reeder JD, & GE Schuman. 2002. Influence of livestock grazing on C sequestration in semi-arid mixedgrass and shortgrass rangelands. Environ. Poll., 116:457-463.

Raudsepp-Jearne, C, GD Peterson, & EM Bennett. 2010. Ecosystem services bundles for analyzing tradeoffs in diverse landscapes. PNAS, 107(11): 5242-5247.

Schmidt MWI, MS Torn, S Abiven, T Dittmar, G Guggenberger, IA Janssens, M Kleber, I Kogel-Knabner, J Lehmann, DAC Manning P Nannipieri, DP Rasse, S Weiner, & SE Trumbore 2011. Persistence of soil organic matter as an ecosystem property. Nature, 478: 49-56.

Schuman GE, JD Reeder, JT Manley, RH Hart, & WA Manley. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. Environ. Poll. 116: 391-396.

Smoliak S, JF Dormaar, & A Johnston. 1972. Long-term grazing effects on Stipa-Bouteloua prairie soils. J. Range Manage. 25: 246-250.

Swinton SM, F Lupi, GP Robertson, & SK Hamilton. 2007. Ecosystem services and agriculture: cultivating agricultural ecosystem services for diverse benefits. Ecological Economics, 64(2): 245-252.

Unger PW, BA Stewart, JF Parr, & RP Singh. 1991. Residue management and tillage methods for conserving soil and water in semi-arid regions. Soil Tillage Res., 20: 219–24