# The Importance of Temperate Grasslands in the Global Carbon Cycle

Report prepared by:

Edward Bork, Professor
Faculty of Agricultural, Life, and Environmental Sciences,
University of Alberta

Pascal Badiou, Research Scientist,
Institute for Wetland and Waterfowl Research,
Ducks Unlimited Canada

Ducks Unlimited Canada
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# INTRODUCTION

Grasslands cover between 25 and 40 % of the earth's land surface and contain up to 30% of global soil organic carbon stocks (Brau et al., 2013; Hewins et al., 2015; Wang et al., 2014, WRI 2000). Temperate grasslands of the world cover an estimated 9.0 – 12.5 million $km^2$ or 7.0 – 9.7 % of total land area (White et al., 2000), and are among the most diverse and productive terrestrial biomes (Henwood, 1998). These open ecosystems are dominated by herbaceous vegetation that is maintained by drought, fire and grazing and occur in regions where there is low moisture, cold winters and deep fertile soils (Federal, Provincial and Territorial Governments of Canada. 2010). Within Canada, natural temperate grasslands historically covered 615,000 $km^2$ extending over broad areas of Alberta, Saskatchewan and southern Manitoba with additional small pockets of grassland areas occurring in southern Ontario and in eastern British Columbia.

Western Canada contains vast areas of range and pasture that provide a wide array of benefits for Canadians, including forage for livestock. These provinces contain 96% (~19 M ha) of Canada's rangelands and 82% (~3.5 M ha) of the nation's seeded pasture used by cattle. Across Western Canada, roughly 3.7 M beef cows reside that is more than 80% of the national breeding herd. Grazing resources in this region include a combination of native rangeland, which are areas previously uncultivated and consisting of mosaics of endemic grassland together with various shrub and forest habitats. In Alberta alone, approximately 9 M ha of forage lands are used for grazing, most of which (6.5 M+ ha) is native grassland. The proportional presence of native grassland varies markedly among subregions, ranging from as little as 10% in the Aspen Parkland, to 43% in the Dry Mixedgrass Prairie.

Because grasslands are often targeted for conversion (currently and historically) there is ample opportunity to investigate the role of conservation and restoration of these systems in order to deliver natural cost-effective climate change adaptation and mitigation measures through avoided carbon emissions and enhanced carbon sequestration.

# GRASSLANDS AND THE GLOBAL CARBON CYCLE

## Carbon stocks in Temperate Grasslands:

While it is recognized that temperate grasslands are important for forage and livestock production, native grasslands provide many other environmental goods and services (EG&S), including carbon (C) storage. Rising atmospheric $CO_2$ levels and associated increases in mean temperature have raised substantial interest in developing strategies to biologically sequester C in order to mitigate climate change. Due to growing concerns regarding global climate change, the large amount of land area covered by grasslands as well as the potential for grasslands to sequester carbon, there has been increased interest in the carbon cycling within these systems (White et al., 2000).

The carbon sequestered within temperate grasslands is the difference between the carbon uptake associated with net primary productivity and the carbon emitted through via heterotrophic respiration, harvest, fire and changes in soil organic carbon stocks (Jones and Donnelly, 2004). Soils are particularly important for storing large amounts of C, as it contains nearly three times the C of the atmosphere. Similar to carbon sequestration in other terrestrial ecosystems, sequestration in grassland systems occurs mostly below ground in the soils (Soussana et al., 2004) and is brought about by increasing carbon inputs (Conant, 2010). Perennial grasslands are particularly important sinks for storing C, as up to 97% of soil C is stored belowground, where it remains in a relatively protected form from short-term disturbances such as fire, which otherwise releases C in above-ground vegetation via combustion. This relatively stable soil environment results in substantial accumulations of soil organic matter due to slow carbon tunrnover below ground (Abberton et al., 2010).

Worldwide, 10-30% of organic C is thought to be stored in grasslands, with temperate grasslands, covering 8% of grasslands worldwide, projected to contain 300 Gt of C. In addition to organic C, grasslands may contain substantial pools of inorganic C as well, including in comparison to areas converted to other land uses (Bork et al., unpublished data). Grasslands are particularly adept at building C in soil due to the high biomass allocation of grasslands to root growth (e.g., up to 85%+ root mass allocation), which through progressive root development and turnover, leads to high C accumulation over time. In addition, due to the absence of cultivation, grasslands accumulate substantial amounts of C at the surface of the mineral soil in an overlying mulch layer (Bork et al., unpublished data), which in higher rainfall areas, can become a well-developed soil layer. Globally, on average, grasslands store between 100-300 metric tonnes of carbon per hectare (White et al., 2000). Temperate grasslands in Canada store between 50 – 200 tonnes of organic carbon per ha in soils, and an additional 3 – 12 tonnes of carbon per ha in plant biomass and litter (Bremer 2008). This is comparable to the range of 84-110 tonnes of carbon per ha estimated for Canadian grassland soils (0-30 cm) by Bhatti et al., (2002) using the carbon budget model of the Canadian Forest Sector (CBM-CFS2). While this is significantly less compared to carbon stores found in northern peatlands, the vast extent of grasslands makes them one of the most important terrestrial carbon stores on our planet. Within the province of Alberta alone, it is estimated that the carbon stock contained in the 7 million ha of temperate grasslands is roughly equivalent to 3 times the total annual greenhouse emissions from all of Canada (Bremer 2008).

## The impact of temperate grassland conversion on carbon stores and GHG emissions

In terms of terrestrial ecosystems, temperate grasslands represents one of earth's major biomes and are one of the most imperilled ecosystems on the planet with little of their historical extent remaining in a natural state (Henwood, 1998). According to Hoekstra et al., (2005) among terrestrial biomes temperate grasslands present a substantial biome crisis due to their high degree of conversion (45.8%) and the fact that they have the highest conservation risk index (CRI>10, calculated as the ratio of percent habitat converted to percent habitat protected). In North America, temperate grassland loss has been extensive with roughly between 65 – 70% of original grassland extend converted to other uses, primarily agricultural cropland (Henwood, 2010). The majority of grassland conversion occurred between the 1880s and 1930s as populations and the area of cropland worked by producers in the three Prairie Provinces grew rapidly (Wilms et al., 2011). However, grassland conversion in North America continues at an alarming rate. Between 2009 and 2015 more than 21 million hectares of grasslands were converted to cropland (cumulatively), with some of the highest annual loss rates reported for temperate grasslands in the Canadian Prairies (2.78% between 2014-15; [WWF, 2016; Gage et al., 2016]).

The single greatest impact of disturbance on C stores in grasslands is land use change, with cultivation leading to a 30-50% reduction in C stores worldwide (Burke et al. 1995). In the central grassland region of the United States, Burke et al., (1991) estimated that 8 to 20 tonnes of carbon per hectare had been lost since settlement as a result of grassland conversion to cropland. Experiments in Alberta show that a change from native grassland to continuous wheat cropping led to the release of 1.7 t C/ha/year for the first four years, with this rate of C loss decreasing to 0.32 t C/ha/year for the next 9 years (Wang et al. 2010). The combination of increased aeration and soil temperatures leads to increases in soil organic matter degradation, and therefore net C release over time. Similar results have been observed in the comparison of various agroforestry systems across north central Alberta, where silvopastures comprised of a mix of aspen forest and perennial grassland led to greater soil C stores (Baah-Acheamfour et al. 2014, 2015), lower $CO_2$ loss, increased $CH_4$ and $N_2O$ uptake, and most importantly, reduced global warming potential (Baah-Acheamfour et al. 2016), relative to agroforestry systems where one of the embedded land uses consisted of annual cropland.

The extent of C loss also varies across agroclimatic zones, with grassland conversion to cropland in the Mixedgrass Prairie and Foothills Fescue leading to a decline in C concentrations of 41% and 30%, respectively (Whalen et al. 2003). Moreover, studies assessing changes in soil properties following the natural recovery of native grassland on areas previously cropped indicate that prairie soils have limited recovery, with Mixedgrass soils failing to recover more than 50 years after undergoing revegetation (Smoliak and Dormaar, 1985). These results highlight the long-term opportunity cost associated with land use conversion on ecosystem properties, including soil OM and associated C. More recent studies indicate that croplands have reduced soil health properties such as lower soil aggregation and soil moisture retention during drought, thereby increasing the susceptibility of these communities to perturbations, including drought (Hebb et al., in press).

While the conversion of native grassland into tame forage such as alfalfa, smooth brome, or crested wheatgrass leads to greater C than cropland, observed reductions in C concentration relative to grassland are still notable, declining 32% and 20% in the Mixedgrass and Foothills, respectively (Whalen et al. 2003). Reduced soil C in crested wheatgrass stands of the Mixedgrass have been attributed to large declines in root mass, and associated reductions in soil organic matter accumulation (Dormaar et al. 1994). Soil health under these conditions is greater than that within croplands, but remains below that of native grassland (Hebb et al., in press).

Current studies are also underway to assess the mechanisms associated with C cycling in grasslands, including the role of enzymes and their impact on C, N and P cycling (Chuan et al, unpublished data). Preliminary studies using both controlled experimental defoliation (Hewins et al., 2016) and field studies (Hewins et al. 2015) suggest that the enzyme activity associated with the cycling of C and soil macronutrients is altered by ongoing disturbances such as defoliation, and may help explain where, when and how grazing changes grassland C stores. This process may also be augmented by changes in plant species composition arising from grazing. For example, grazing induced increases in grazing tolerant plant species such as bluegrass may alter C accumulation, particularly as this species has been shown to have relatively rapid litter mass loss under field conditions (Chuan et al., unpublished data).

## Carbon sequestration and GHG emissions in temperate grasslands

The capacity of temperate grasslands to sequester carbon is finite (Abberton et al., 2010), and prior to rapid European settlement the grassland ecosystems of the Canadian Prairies were likely under a grazer-induced equilibrium (Wang et al., 2014). As described above, stocks of carbon stored in temperate grasslands of the Canadian Prairie were greatly reduced because of grassland conversion/cultivation of annual crops. This has resulted in an estimated loss in cropland areas (formerly temperate grasslands for the most part) of 1Pg of soil organic carbon out of a total of 4.3 Pg (Lynch et al., 2005). Due to this fact there is a significant potential to increase soil organic carbon stocks through enhanced biological sequestration in temperate grassland regions. The main mechanisms to enhance carbon sequestration in temperate grassland is through the conversion of arable land to permanent cover/natural grassland and through the management of these systems (Soussana et al., 2004). Of these two mechanisms, conversion of arable land to permanent cover/natural grassland provides the greatest potential for enhancing carbon sequestration per unit area. On the other hand, there may be more potential to sequester carbon cumulatively via grassland management due the large land base available for such activities. The enhanced carbon sequestration achieved through these mechanisms is due to the increased amount of C biomass added to the soil and/or the reduction of organic C losses from the soil relative to the preceding management system (Boehm et al., 2004).

Measured and modeled rates of carbon sequestration in temperate grasslands range from 0 to more than 8 Mg C per ha according to Jonnes and Donnelly (2004). A summary of empirical research on soil organic carbon change for conversion of annual crops to perennial cover conducted by Éco Resources Carbonne (2011) found that rates in the Canadian Prairies ranged from 0.23 to 1.40 Mg C/ha/yr, and that rates in Ontario and Quebec ranged from 0.22 to 1.07 Mg C/ha/yr. In terms of cumulative soil organic carbon stock changes, Boehm et al., (2004) found that conversion of cropland to permanent cover resulted in a change of 18 Mg C/ha for the

Brown soil zone to 66 Mg C/ha for the Black and Gray soil zones of the Canadian Prairies using the Century model. Similarly, conversion of arable land to natural grasslands is estimated to increase soil organic carbon stocks by 25 Mg C/ha (Soussana et al., 2004), with annual sequestration rates of 0.8 Mg C/ha/yr (IPCC 2000). Within the Canadian Prairies, conversion from annual croplands to natural grasslands results in carbon sequestration rates between 0 and 0.94 Mg C/ha/yr, with most studies finding that this land use change results in enhanced carbon sink capacity and sequestration rates generally above 0.4 Mg C/ha/yr (Éco Resources Carbonne, 2011). Cumulative change in carbon stocks as a result of conversion of croplands to permanent grass cover is in the order of 2 Mg C/ha to 65 Mg C/ha depending on the soil column depth examined and the geographic and the type of grass mix seeded (Wang et al., 2014).

Under existing management conditions, temperate grasslands are generally considered to be functioning as carbon sinks (Jones and Donnelly, 2004) and it has been estimated that grazing and management of grasslands can sequester 0.5 Mg C/ha/yr (IPCC 2000). A recent summary of long-term studies of soil organic carbon stock change in the Canadian Prairies conducted by Wang et al., (2014) concluded that in recent decades managed temperate grasslands sequestered a total of 5.64 Mg of C/ha on average at an estimated rate of 0.19 Mg C/ha/yr. This same study found that carbon sequestration in managed temperate grasslands of the Canadian Prairies varied as a function of soil type (0.22 Mg C/ha/yr – Black soil zone, 0.14 Mg C/ha/yr - Brown soil zone, and 0.09 Mg C/ha/yr – Dark brown soil zone) and the three main grass associations (0.05 Mg C/ha/yr – dry mixed grasses, 0.22 Mg C/ha/yr – fescue grasses, and 0.16 Mg C/ha/yr – mixed grasses), but that grazing intensity had little impact on soil sequestration rates. Lastly, Lynch et al., (2005) found that management of Canadian prairie region grazing lands (11.5 Mha) could increase soil organic carbon by approximately 0.465 million Mg C/yr, similar to emissions from agricultural soils in Canada at that time (0.485 million Mg C/yr).

In order to understand the net effect of grasslands and grassland management on atmospheric radiative forcing it is important to account for the emissions of other greenhouse gases such as $CH_4$ and $N_2O$. In particular, $N_2O$ accounts for the majority of GHG emissions from agricultural soils and makes up about 37% of Canada's GHG emissions from agriculture (ECCC 2017). Cumulative $N_2O$ emissions from natural and managed temperate grasslands are generally significantly lower than those from cropland, suggesting that conversion of cropland to perennial cover and/or native grasses can potentially contribute to meaningful GHG reductions in the agricultural sector (Grant et al., 2004; Gelfand et al., 2016).

$CH_4$ also contributes significantly to Canada's total agricultural GHG emissions, but these emissions are for the most part associated with enteric fermentation and manure management. In fact, undisturbed grassland soils are often consumers of $CH_4$ and act as a sink for $CH_4$ (Braun et al., 2013). However, even when accounting for $CH_4$ emissions via enteric fermentation, as well as other carbon losses and transfers associated with fire, animal product export, manure additions, as well as leaching and erosion of organic carbon, Senepati et al., (2014) found that a frequently grazed sown grassland was a net sink and sequestered 1.41 Mg C/ha/yr.

While there is not an extensive number of studies that have examined the net sink potential of grasslands and perennial cover there are two studies that clearly demonstrate that these systems or net sinks even after accounting for $CH_4$ and $N_2O$ emissions. Using the Canadian Economic and Emissions Model for Agriculture (CEEMA), Boehm et al., (2004) found that carbon sequestration rates in Canada were higher for conversion of cropland to perennial cover and adoption of improved grazing management on grasslands, relative to conversion between conventional tillage and zero-tillage. Accounting for the $N_2O$ and $CH_4$ emissions associated with these activities (conversion to perennial cover and grazing management) reduced carbon sequestration by 40-50% but still resulted in a net sink. Similarly, Soussana et al., (2007) conducted a full accounting of GHG emissions from temperate grasslands in Europe under various management scenarios and found that accounting for $N_2O$ and $CH_4$ emissions resulted in an offset of approximately 19% of carbon sequestration but still produced a net $CO_2$ sink.

## GRASSLAND CARBON STOCK MONITORING AND PROTOCOLS

As a result of the number of carbon offset programs developed internationally, there has been increased emphasis on developing guidelines and requirements for carbon offset programs and greenhouse gas (GHG) emissions reporting associated with land use change. At the request of the United Nations Framework Convention on Climate Change (UNFCCC), the IPCC (2003) developed a report on "Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF). This report provides nation-level guidance for estimating, measuring, monitoring and reporting on carbon stock changes and greenhouse gas emissions from LULUCF activities, including those resulting from the conversion/management of grasslands as well as the conversion of cropland to grassland. The IPCC's Guidelines for National GHG Inventories identifies three tiers of methodological approaches for determining GHG emissions and removal estimates for Agriculture, Forestry and Other Land Use (AFOLU) activities. The three tiers are hierarchical in terms of complexity and accuracy; Tier 1 methodologies are the simplest and Tier 3 methodologies are the most complex. Methodological approaches are selected based on available information; the IPCC recommends higher tiered approaches to be used where possible to increase GHG emission and removal estimate accuracy. Stock changes associated with grasslands are currently accounted for in Canada's national inventory reporting of GHG sinks and sources under the Land Use, Land-Use Change and Forestry Sector. Grasslands remaining grasslands and grasslands converted to cropland are currently captured in this national scale reporting but lands converted to grasslands are not.

Due to the fact that grasslands are efficient at storing carbon, conversion of grasslands releases significant amounts of carbon, land use after conversion typically has higher GHG emissions, and conversion pressure is high with relatively little barriers to prevent conversion, there is ample opportunity for quantifiable reductions associated with grassland activities. To date grassland activities for which protocols have been developed have focused on the avoided conversion of grasslands, the conversion of marginal croplands to grasslands, and compost additions to grazed grasslands to enhance carbon sequestration. The following protocols have already been approved for use by the American Carbon Registry (ACR), Climate Action Reserve (CAR), Chicago Climate Exchange (CCX), and the Verified Carbon Standard (VCS):

- ACR – Avoided Conversion of Grasslands and Shrublands to Crop Production
- ACR – Compost Additions to Grazed Grasslands
- ACR – Grazing Land and Livestock Management
- CAR - Avoided Grassland Conversion Protocol
- CCX - Continuous Conservation Tillage and Conversion to Grassland Soil Carbon Sequestration Offset Project Protocol
- CCX - Sustainably Managed Rangeland Soil Carbon Sequestration Offset Project Protocol
- VCS VM0009 - Methodology for Avoided Ecosystem Conversion
- VCS VM0017 - Adoption of Sustainable Agricultural Land Management
- VCS VM0021 - Soil Carbon Quantification Methodology
- VCS VM0026 - Methodology for Sustainable Grassland Management
- VCS VM0032 - Methodology for the Adoption of Sustainable Grasslands through Adjusted Management of Fire and Grazing

Currently there are no approved grasslands protocols for use in Canada, however ÉcoResources Carbonne (2011) has prepared a "Conversion to Native Grasslands Offset Project Protocol Frasmework" for application in Canada. Additionally, the Climate Action Reserve has been retained by the governments of Ontario and Quebec to adapt offset protocols to be used under their cap and trade system. One of the preliminary protocols identified for adaptation is a grasslands protocol.

## CO-BENEFITS ASSOCIATED WITH GRASSLAND CONSERVATION AND RESTORATION:

Grassland conservation and restoration provide many other co-benefits that more traditional carbon offset methodologies do not. Additionally, some of the co-benefits associated with grassland restoration and conservation will help mitigate some of the impacts predicted to occur as a result of climate change. For example, droughts and flooding are both predicted to worsen in the future as a result of anthropogenic climate change. Grasslands, have the potential to moderate extreme drought and flood conditions and can help keep water on the land when it is scarce by sustaining base flows in stream. Conversely, under extreme snowmelt and precipitation conditions grasslands can store water and reduce runoff and erosion because they have higher infiltration rates and deeper root systems relative to conventional crops planted in the Canadian Prairies. Grasslands also provide a number of other ecosystem services such as nutrient cycling, waste treatment, soil formation, refugium function, and recreational opportunities. A recent study by Kullshreshtha et al., (2015) evaluating the ecosystem services associated with grasslands in Manitoba estimated the socio-economic value of these systems at $0.7 billion to $2.5 billion annually. This is equivalent to a value of between $292 and $1,050 per hectare per year. This is within the range of other grassland ecosystem service valuations by Costanza et al., (1997) and de Groot et al., (2012).

## CONCLUSIONS AND RECOMMENDATIONS:

Temperate grasslands play a major role in the global carbon cycle due to their high rates of productivity, enhanced carbon sequestration rates and geographical extent. However, conversion and/or degradation of intact wetland ecosystems can result in significant losses of soil organic carbon, resulting in these systems becoming net radiative sources. Conversely, conversion of marginal croplands to grasslands as well as management of grasslands/grazing lands can provide significant opportunities for carbon sequestration. In addition to the carbon benefits associated with temperate grasslands and their management these systems provide a host of other valuable ecosystem services that benefit society. As result, grasslands and grassland management offer a no regrets solution when used to achieve emissions reductions.

Currently, Canada is reporting on carbon stock changes associated with grasslands as part of it national inventory of GHG sinks and sources. However, these current estimates do not include carbon stock changes associated with grazing management on grasslands and does not report on stock changes with conversions from cropland to perennial cover or grasslands. Including these in future reporting would help refine and make more precise Canada's reporting on GHG sinks and sources associated with these land use changes.

Based on the fact that numerous protocols have already been developed that can be used for determining emissions reductions associated with grasslands and their management, jurisdictions in Canada looking at employing biological carbon sequestration should move to assess and adopt these protocols for use. Other protocols should also be examined to include the role GHG emissions associated with grassland conversion. For example, if a proponent is claiming GHG emissions reductions associated with an existing protocol but is converting grasslands to cropland or another use with a higher GHG footprint this should either be debited from the credits claimed or potentially render the proponent ineligible to participate in the market. This type of full accounting will ensure that credits claimed will achieve net reductions in GHG emissions.

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