AB NAWMP Peer Review: Critical Review of Five Carbon Reports

An assessment of validity, technical merit, timeliness, relevance and gaps.

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Alfalfa Seed Committee

Conclusion

Both grasslands and wetlands represent massive carbon stores and as a result it is clear that on balance, these ecosystems have contributed to a net uptake of atmospheric carbon since the last ice age. However, once near-steady state levels of carbon sequestration are achieved these ecosystems may fluctuate between net carbon sinks and net carbon emitters. Further research into the impact of vegetation type, alterations in hydrology, grazing management and climate on carbon fluxes should provide insight into how these ecosystems can be managed in a manner so as to make a significant contribution to combatting climate change. With regard to specific project goals of the reports:

- All reports are of a high technical standard and represent the state of knowledge at the time of their preparation. A few additional items that could have been covered are outlined in the GAPS section below, but these gaps do not detract from the spirt of the findings within the reports.
- Work is current and as this is a very active area of science, it is not surprising that there has been additional findings since this point in time. However, these new findings build upon the report and do not detract or refute the fundamental information and recommendations that are in the reports. The reports clearly have technical merit and are scientifically accurate.
- Work is highly relevant to stressing the importance of conservation of both wetland and grassland ecosystems if carbon stocks are to be retained. Again there have been additional findings since this report was undertaken and these could be considered in future studies in this area.

❖ Reports clearly demonstrate the importance of advancing a carbon management strategy for Alberta and provide and partners and stakeholders with the necessary science and suggested tools to benefit wetland and grassland conservation in Alberta and the Prairie Habitat Joint Venture.

❖ Reports are ready for public release.

Science Summary

Wetland ecosystems play a key role in both carbon and nitrogen cycles and deliver a number of important ecosystem services that influence water availability and quality, social aesthetics and biodiversity. Undisturbed they contain vast stores of carbon that are in a balance between ongoing sequestration and emissions in the form of CO_2 and CH_4. Biological formation of methane requires anaerobic conditions as oxygen is toxic to methanogens. Wetlands can transition from anaerobic to aerobic conditions depending on hydrology and thus the emissions of CO_2 and CH_4 can differ based on location, season or even among years. Consequently, describing a wetland as a system of sequestration or emissions can be difficult, but in general wetlands result in net sequestration of carbon if they are left undisturbed. Microbial activity typically declines under anaerobic conditions as anaerobic fermentation generates less energy than aerobic respiration. Fermentation acids can also cause acidification of the environment, creating conditions that are even less-favorable to microbial growth and activity. Under these conditions, the liberation of carbon is impeded and the ecosystem can become a net carbon sink.

Restoration of disturbed wetlands can result in a replenishment of carbon with the time needed to reach pre-disturbance conditions being shorter for mineral wetlands such as marshes (50-150 yr) than for fen and bog peatlands (> 1000 yr). Differences in time required for restoration is also reflective of how biologically active these systems are in terms of capturing carbon through photosynthesis, with less photosynthetically-active ecosystems requiring a longer period to recover. However, with time the amount of carbon stores in less photosynthetic ecosystems can actually exceed those that are more biologically active as a larger portion of the carbon produced is conserved.

Grasslands typically possess less carbon than wetland ecosystems as the rate of carbon recycling is more rapid owing to aerobic conditions. Longer-term carbon in grasslands is stored within the root zone, as above-ground carbon is subject to harvest, grazing and fire. Thus, above-ground carbon tends to be cycled more rapidly than carbon within the root zone. Species composition of the grasslands can also impact carbon deposition within soils with carbon tending to be more stable in deep- as compared to shallow-rooted species. Disturbance of grasslands through cultivation can result in the release of large quantities of soil carbon as reflected by the depletion in the organic matter content of cultivated Canadian prairie soils. Grasslands can help further conserve soil organic matter through the prevention of wind and water erosion and by storage of soil moisture. Rate of recovery of disturbed grasslands depends on climate and moisture conditions, which in turn dictates the balance between carbon capture via photosynthesis and carbon loss via decomposition. Drought or nutrient deficiencies can reduce the photosynthetic capture of carbon and prolong the recovery time. Grazing can impact carbon levels if it alters the botanical composition from deep-rooted to shallow-rooted species. Overgrazing can expose the soil surface, increasing the loss of soil organic matter through wind or water erosion. However, the long-term impacts of grazing on soil carbon levels in undisturbed pastures has been difficult to quantify. It appears that grassland systems move towards a steady state level of carbon, but this equilibrium may be altered by climate change, or long-term grazing pressure. Differences in grazing practices over a season are unlikely to have long-lasting impacts on soil carbon levels.

Reviewer comments

The present series of documents represents an encompassing review of carbon cycling within wetland and grassland ecosystems. The document conclusions are relevant and reflect the present understanding of the value that these systems have as significant carbon stores with the potential to mitigate climate change. Restoration of disturbed grasslands and wetlands could act as a cornerstone for climate change adaptation and mitigation policies. Grasslands are among the most endangered of earth's ecosystems and harbor vast quantities of carbon, with large portions of this already released into the environment as a result of anthropogenic activities. Further development of these regions will undoubtedly add to atmospheric CO_2 levels and radiative warming. Although, generally less-disturbed in the boreal region, a large portion of the wetlands harbor even more carbon than grasslands. These stores may be even more threatened by climate change, a phenomenon that is already being witnessed in the form of increased GHG emissions as a result of thawing of permafrost. Preservation of both grasslands and wetlands should clearly be a central pillar of any climate change mitigation and adaptation policy. Although some of these items were mentioned, some expansion in the following areas could be considered.

Gaps

Boreal wildfires impact on above and below ground carbon.

Wildfires have had a significant impact on both CO_2 and CH_4 emissions in the boreal region in recent history, an outcome that is possibly driven by climate change. In the boreal region these emissions can arise from the combustion of both above- and below-ground carbon. If these fires are linked to drought conditions, drought in itself may be altering hydrology in a manner that is conducive to the greater release of carbon stores as a result of an increase in temperature and aerobic respiration. Evidence of this is already becoming apparent with regard to the thawing of permafrost and the release of carbon in the form of both CO_2 and CH_4.

Role of the soil and aquatic microbiomes on GHG emissions.

In both aquatic and terrestrial systems, carbon emissions are largely driven by microbiota. In the case of CH_4, emissions represent a balance between the production of CH_4 by methanogens and its oxidation by methanotrophs. Likewise, soil microbial communities are responsible for the emissions of CO_2 from grassland ecosystems. Advancements in genomics and deep sequencing now makes it possible to characterize both the phylogeny of microbial communities as well as their potential metabolic activities within both aquatic and terrestrial ecosystems. Summary papers would have benefited from a description as to how best management practices interact with microbial communities to promote favorable carbon sequestration outcomes.

Role of beavers in hydrology in parkland and boreal wetlands

Beavers play an integral role in the hydrology of parkland and boreal wetlands. Expansion of the beaver population as a result of a reduction in the fur trade has been associated with a significant increase in CH_4 emissions from wetland ecosystems (Whitfield et al. 2015). Beavers tend to heighten water levels, harvest trees and transport waste material into less oxygen-rich environments where more CH_4 may be formed. However, transport of carbon in the form of tree biomass into these anoxic environments may also increase the long term carbon stored in these environments. The impact of beavers on wetland hydrology was not discussed in any of the reports.

More detailed studies on the fate of CH_4 and N_2O and variability in Greenhouse Gas balance in wetland ecosystems.

Studies have shown that there is substantial variation in the carbon balance among different wetland ecosystems, but the specific factors responsible for this variability remain largely unknown. For example, studies on dugouts used for watering livestock have shown that about 50% of these water bodies are net carbon dioxide sinks and about 50% are net carbon emitters (Webb et al. 2019). This variability could arise as a result of different aquatic plant species, chemistry (e.g., pH, SO_4 concentration), temperature, depth and sediment deposition. Further work also needs to focus on the balance between CH_4 production by methanogens and its oxidation by methanotrophs. Likewise, there is emerging information that wetlands and ponds may serve as net N_2O sinks, but the mechanisms for this response remain largely unknown. Further, research on these secondary GHG would also help define if these ecosystems have a net positive or negative impact on the global warming potential.

Economic implications of transition away from fossil fuel-based economy

It seems probable that fossil fuels will be replaced by renewables such as wind, solar and biodigestion at least by 2100 if not earlier. Although this will likely reduce the pressure on Alberta's boreal wetlands it could conceivably increase the pressure on Alberta's grasslands. Wind and solar generation are amendable to southern Alberta owing to its higher and more consistent wind speeds and greater solar radiation. Furthermore, these generation systems also tend to be located in the vicinity of transmission lines where electricity can be easily transported to end users that reside within urban centers. Loss of economic viability and abandonment of the oil sands could preclude future wetland restoration projects, making it unlikely that carbon stores in this region will be reestablished. Oil prices are subject to the pressures of demand and supply as recently demonstrated by oil price war between Russia and Saudi Arabia and the decline in demand as a result of the COVID-19 mediated reduction in travel. Under these conditions it is going to be challenging for companies to justify investment in restoration activities to shareholders. Consequently, the uncertainty in restoration makes preservation a far better option in ensuring sustenance of existing carbon pools.

Silvapasture

There is interest in some areas with regard to the practice of combining grassland and forest production into a combined system that promotes carbon sequestration. Brazil is likely the leading nation in this regard with several silvapasture systems being investigated. This system is more amendable to areas of the world that can produce high-value wood products or trees that have a high growth rate such as eucalyptus. Such systems can reduce the productivity of grass lands if they restrict radiative forcing to the understory. However, they can also conserve soil moisture and provide shade that reduces the incidence of heat stress. Silvapasture approaches in Alberta would be more applicable in the parkland and boreal regions. Such approaches could be investigated from the perspective of carbon sequestration and overall grassland productivity. At this point it is not clear how forestry within these regions could compete with forestry on crown lands or internationally with higher-valued wood products. It is also important to bear in mind that forest encroachment can adversely impact grassland production in boreal and parkland regions.

Food security and Food production.

From a food production perspective, the value of grasslands is gained from their ability to support and maintain ruminants which produce high-quality protein in the form of meat and milk. However, from a food security perspective it is projected that globally we will need to produce enough food to support 9.5 billion people by 2050. This growing demand for food is likely to only increase the pressure to convert grasslands into cropland. We have clearly seen an increased emphasis on the inclusion of plant-based proteins in the human diet as demonstrated by Canada's most recent food guide. These recommendations are often based on the proposition that crop-based protein production systems have a smaller environmental footprint than ruminant production systems. However, most of the modelling used in these assessments fails to assign the carbon lost as a result of the original cultivation or deforestation of the grasslands and forests, respectively. Instead they only explore the carbon footprint associated with an annual cropping year. These analysis also fail to consider potential impact on other ecosystem services such as erosion, water scarcity and quality and biodiversity. The external forces influencing food security needs should be considered in both wetland and grassland conservation initiatives.

Climate change

Climate change could have a significant impact on carbon stores in both grasslands and wetlands. Conversion from the anoxic conditions that favor the production of CH_4 to the aerobic conditions which favor organic matter decomposition and CO_2 emission is often mediated through evaporation and drought. Likewise, increased warming can reduce the duration of ice cover on lakes and wetlands, an outcome that is hypothesized to convert these ecosystems from net CO_2 emitters into net CO_2 sinks (Finlay et al. 2015). Increased temperature, precipitation and atmospheric CO_2 levels can also lead to enhanced photosynthesis. If photosynthesized organic matter is not subject to decomposition, the CO_2 capture can contribute to carbon stores in lake and wetland bottoms as well as soil. Consequently, future estimates of carbon stocks in grasslands and wetlands in Alberta should also consider the potential impacts of climate change.

Carbon offsets

Since the preparation of the report, progress has been made on the "Grasslands Avoided Conversion Project" under the direction of the Climate Action Reserve. This program rewards producers for the conservation of grasslands, with a total of 10 sites presently participating (6-Colorado, 3-Oregon, 1-Montana) with offsets (74,000) having been issued to five of the sites representing around 40,000 acres. Most projects are managed through an aggregator. To be eligible, these land must have been grassland for the past 10 years (30 years more desirable) and cannot have more than 10% tree cover. In the case of transition from cropland to grassland, this program would likely miss a large portion of the period where carbon sequestration rates were at a maximum. Land must be able to be legally converted to cropland and should have a value that would be 40-100% higher than if it is retained as grassland. Offsets are discounted if conversion value is less than 100%. Factors such as land use suitability, irrigation etc. are also considered. Land considered of very low quality is not eligible to the program. Implementation and returns from these programs typically require 18 to 24 months and payments are predicted to be between $25 to $50 per acre. However, these estimates are linked to market and legislative forces that may influence the price of carbon. The price of carbon is also dependent on overall economic stability and the impact of factors such as the recent collapse in global markets as a result of Covid-19 are unknown. However, it is also important to realize that there presently are no official Canadian offset protocols in place for programs in either grassland or wetlands so any developed protocols would represent an accomplishment.

Carbon offset programs can be complicated and some programs require substantial collection of data for auditing and verification purposes. Some programs involve discounts in returns based on land type, use and management practices. For example, real or perceived over-grazing could result in substantial offset discounts. It is not clear if adaptive grazing would be considered acceptable. Some of these discounts could impact the ability of producers to derive value from the land. All of these programs are also influenced by external factors such as carbon pricing, unforeseen market forces and the willingness of off setters to continue to pay. Many of these programs are in the early emergence stage and their long term sustainability is presently unknown. As additional positive ecosystem services practices such as promotion of biodiversity or preservation of wetlands are enacted, it may be possible to obtain multiple offsets from the same designated land area.

In addition, the industry need to be aware of competing carbon offset practices such as deep carbon burial and other carbon capture approaches such as microalgae production. Some of these approaches may be more amendable to linkages with large emitters such as the oil industry. They also may be seen as establishing new infrastructure and creating identifiable employment that may offer more apparent political returns.

Importance of Freshwater Mineral Soil Wetlands in the Global Carbon Cycle

Freshwater mineral soil wetlands (FWMSW) account for about 12% of the total wetland area in Canada and are amongst the most disturbed of Canada's wet lands with a loss of about 20 million ha. The oxygen-limited nature of these wetlands reduces the decomposition of organic and leads to the accumulation of carbon. Caron densities in these environments are typically in the range of 175.1 to 205 Mg C ha^{-1}.   These environments are also frequently rich in aquatic and terrestrial diversity and represent an ecosystem that is more biologically active due to carbon cycling as compared to fens or bogs. Disturbed FWMSW are also more amendable to restoration than are bogs and peatlands and sequester at least three times (270-305 g C m^{-2} yr^{-1}) the carbon of restored grassland ecosystems (43-94 g C m^{-2} yr^{-1}). Restoration may be achieved in as little as 50 to 150 years, unlike the thousands of years that are estimated to be required to restore peatlands to a natural state.

In addition to the release of CO_2 from organic matter decomposition, anaerobic niches within FWMSW can contribute to the production of CH_4 which has a global warming potential that is 28 times that of CO_2 as estimated by AR5.   However, CH_4 also has a half-life of only 12 years as compared to several hundred years for CO_2, resulting in some scientists advocating for the adoption of the GWP* which considers the fate of both long- and short-lived greenhouse gases (Cain et al. 2019).   Emissions of CH_4 from these systems depends on the presence of anaerobic environments within FWMSW as well as the oxidation of CH_4 by methanotrophs. Changes in water levels as a result of drainage, drought or flooding can alter carbon cycling as environments transition from anoxic to aerobic conditions (Zhou et al. 2019). Transitions between these systems could be impacted by future climate change as a result of high precipitation of drought.

Other factors such as nutrient run off in the form of nitrogen or phosphorus can alter biological systems leading to anoxic conditions as a result of algae blooms or the release of the GHG N_2O which has a GWP that is 265 times that of CO_2 (AR5). Increased nutrient loads into FWMSW can enhance microbial activity, accelerating the rate of organic matter decomposition and leading to enhanced CH_4 and N_2O production (Davidson et al. 2018). The production of N_2O can be accelerated in N fertilizer enters these water bodies and is an impetuous to ensure that application of N fertilizer does not exceed crop requirements.

FWMSW are among the most damaged wetlands in Canada as they are often associated with agricultural regions and subject to drainage for cropping and forage production. Installation of tile drainage systems is often seen as one of the first steps in towards improving the productivity of cultivated land. The loss or FWMSW continues to occur at an estimated loss of about 11,000 ha per year with about 7% of GHG emissions arising as a result of this continued conversion.

Fire could be a natural component of FWMSW ecosystems, particularly in grasslands where fires are often frequent. Prescribed burning has been advocated as a method of eradicating invasive species, but is likely to be of limited value in fire-adapted ecosystems or where hydrology fluctuates dramatically. Such practices are also likely to be of limited value in altering GHG emissions and could result in a loss of carbon from the system, particularly during times of drought. FWMSW may also help suppress the severity of fires due their ability to act as a fire break, as well as increase the humidity and cooling of surrounding areas.

Harvesting of wetland ecosystems may have some value in terms of the removal of invasive species, but could also result in damage to wetland habitat as a result of the roads needed to remove harvested goods and their impact on local hydrology. The capital costs associated with harvest from wetlands are unlikely to be competitive with alternative means of biomass production in cropping systems. There is some evidence that harvesting may reduce CH_4 and N_2O emissions from FWMSW, possibly as a result of increased soil temperatures, reduced moisture levels and enhance CH_4 oxidation as a result of the removal of vegetative material (Li et al. 2019 Figure 1).   Such responses are likely to be regionally, seasonally and vegetation-type dependent.

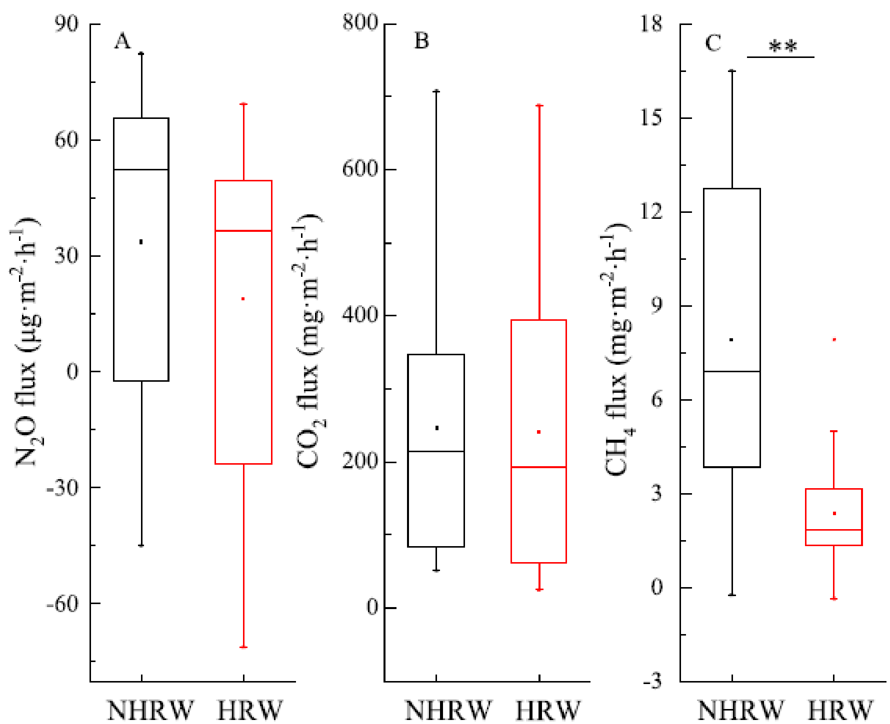

Fig. 1. N_2O (A), CO_2 (B) and CH_4 (C) flux during the year in NHRW (not-harvested) and HRW (harvested). Significant differences between NHRW and HRW are marked **indicates significance at $P < 0.01$, otherwise no significance was found. Boxplots show upper and lower quartile, median (black line), smallest, and largest value (bars). Abbreviations: NHRW, wetland without harvesting; HRW, wetland with harvesting. (Liu et al. 2019).

In addition to implications for GHG emissions, sustenance of FWMSW plays an important role in flood control, erosion prevention and as habitat for a range of aquatic species and waterfowl. These “pot hole” sources can also serve as an important water source for both grazing livestock and wildlife. Harvesting of aquatic plants in these areas is likely to have unintended impacts on biodiversity.

Boreal Wetlands and Climate Change - Summary.

Boreal wetlands store vast quantities of carbon, particularly in boreal peatlands, and are an important ecosystems for the sustenance of waterfowl and other terrestrial and aquatic species. This region constitutes Canada's largest ecoregion at an estimated 584 million ha and accounts for 70% of Alberta's land base. Of this region about 38% consists of wetland ecosystems including bogs, fens, swamps, marshes and shallow open water. These regions are also subject to the impacts of climate change as has been suggested by the droughts and uncontrollable wildfires that have occurred in these regions in recent years. These ecosystems are fundamental to both carbon and water management frameworks. These regions have been subject to alteration by oil and gas, mining, forestry and to some extent agricultural developments. In general agriculture and urbanization have had less of an impact on carbon dynamics than in grassland ecosystems. However, transition to agriculture land is occurring in boreal transition zone and such pressures are likely to increase as global demand for food increases.

Uncertainties with regard to estimates of carbon stores in boreal wetlands are high as very few direct measurements of carbon stores or sequestration have been undertaken. Regional differences in the depth of peat within these wetlands can have a dramatic impact on estimates of the amount of carbon stored per ha. Deposition of significant quantities of carbon can require centuries with accumulation of 20-200 cm over a period of 1000 years at a sequestration rate of 2.5 million metric tons per year. Consequently, once disturbed, restoration of these systems to their natural state is virtually unachievable. As a result, preservation is the best strategy to ensuring these carbon stores are intact. These boreal wetlands can also produce substantial quantities of CH_4 with the rate of release being correlated with the degree of microbial activity within the wetland type marshes > swamps > fens > bogs, but spatial variation may exist even within a single wetland.

Fire can play a significant role in the carbon balance within boreal wetlands, particularly when times of drought lower moisture levels within peatlands to the point that they can become flammable. Under these conditions below-ground peat fires can potentially release stored carbon for months and are extremely difficult to extinguish. These fires may also alter the stability of permafrost, resulting in additional secondary emissions after the fire event (Figure 2; Gibson et al. 2018). Although CH_4 has a higher GWP than CO_2, the dynamics of fire, drainage and other hydrological impacts does not assure that these systems will be net carbon sinks even if CH_4 emissions are curtailed.

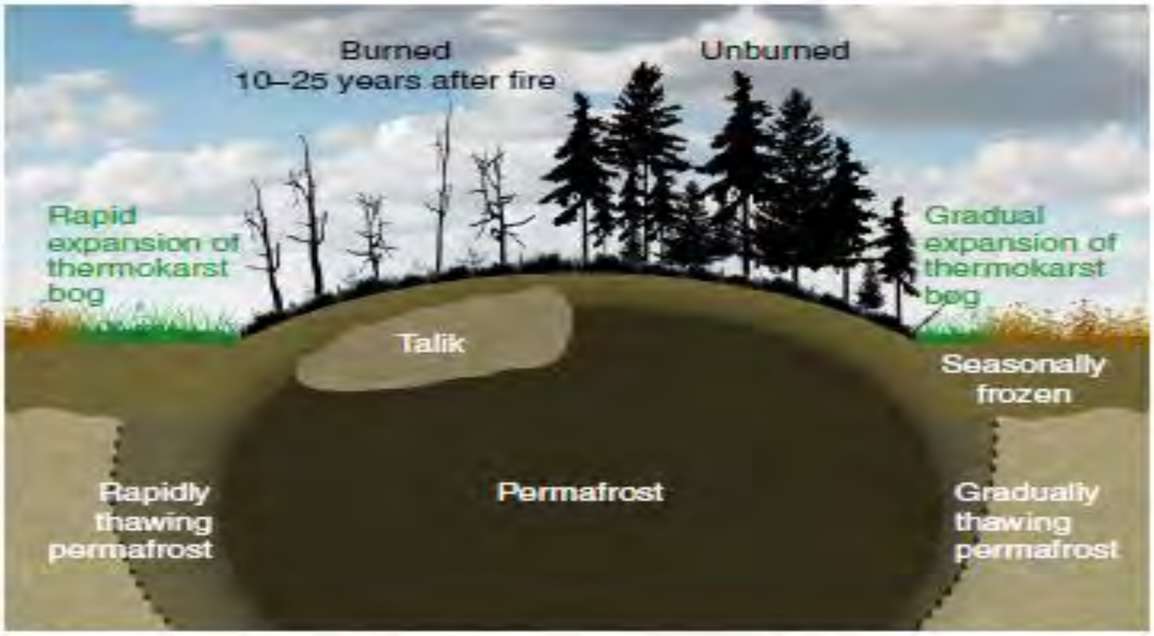

Fig. 2 Simplified illustration of soil thermal states for peat profiles along transects from thermokarst bogs to peat plateaus, within and outside historical burn areas. Taliks are continuously thawed soil layers between the permafrost and the seasonally frozen layers

Gibson et. al. 2018

Climate change will could also have a direct impact on Alberta's boreal wetlands as a result of increased temperatures and a reduction in moisture content, possibly resulting in a transition towards parkland habitat characterized by aspen forest and grassland. This transition could result in further carbon release as a result of the decomposition of stored organic matter. Presently, boreal wetlands are among the least disturbed of Alberta's wetland ecosystems, but this could rapidly change if agriculture or urbanization were to expand into these regions as a result of a transition to an ecosystem that was more amendable to agricultural practices. Restoration of these areas to peatlands is impractical and will result in the formation of upland forest, with some restoration of wetlands in low lying areas to mineral wetlands. There are few BMP with regard to ensuring that boreal wetlands retain their status as a net carbon sink, preservation is the best approach to ensuring that carbon stores are retained, but even this practice may not be sufficient if climate change driven hydrological changes limit the quantity or quality of water that is required to maintain these ecosystems.

Presently there are no approved boreal wetland carbon-reduction protocols approved in Canada. A number of protocols have been approved in the United States, most of which revolve around the restoration of previously disturbed wetlands. Many of these protocols are also being driven by the need to reduce nutrient flow into surface waters, improve flood control and enhance ecosystem services. Protocols that offer multifaceted benefits are more likely to be adopted and implemented by end users. Developing economic and policy instruments that encourage the preservation of boreal wetlands are likely to be the most effective tools.

The importance of temperate grasslands in the global carbon cycle.

In Canada, temperate grasslands cover about 615,000 km^2 and is amongst the most biologically diverse ecosystem in Canada. A large portion of this forage land in the western prairies supports the Canadian beef cow herd through both grazing and as a source of conserved forage. In Alberta, there is about 9 million ha of forage land, of which about 72% is native grassland. Cattle have largely replaced the role of bison within this ecosystem although herd sizes and grazing practices differ from pre-European buffalo herds. Above ground carbon in grasslands is more labile than below ground carbon and is subject to recycling via fire, herbivory and senescence and decomposition. In grasslands, as much as 97% of the carbon is stored below ground (50-200 tonnes per ha), an amount that differs with root depth and development as compared to that above ground (3-12 tonnes). Most of the below ground carbon is within the top 30 to 90 cm of the soil profile. Grasslands may also contain inorganic carbon that may be of lithogenic or pedogenic origin. Decomposition rates of carbon differ within grasslands, with root and humate carbon being longer lived than carbon in labile carbohydrates or proteins. Lignified carbohydrates can also contribute to the formation of a surface mulches which conserve moisture, reduce erosion and enhance soil biodiversity.

Grasslands are among the most threatened ecosystems on earth with an estimated 70% already converted to agricultural cropland and urbanized areas. Grassland conversion in Canada continues and land use change as a result of this conversion has been responsible for a recent increase in Canada's agricultural GHG emissions (Figure 3).

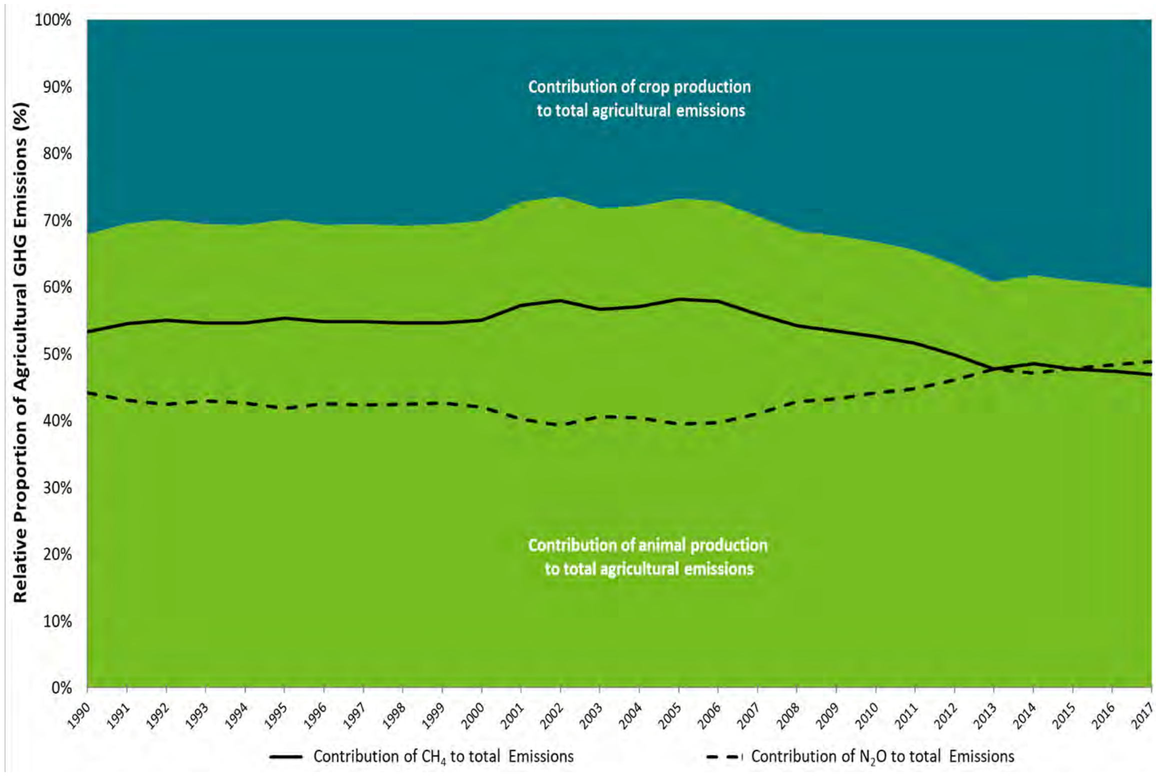

Fig. 3. Contribution of livestock vs crop production to Canada's agricultural GHG emissions. Note that emissions from crop production have increase since 2007 due to conversion of grasslands to croplands and an increase in the amount of N fertilizer used for crop production.

Land conversion has been shown to result in a loss of 1.7 t C ha^{-1} yr^{-1} with the magnitude of release declining with time, likely reflecting the earlier release of the most labile carbon fraction. As these changes in carbon dynamics is largely related to the soil and rhizosphere microbiome it is logical that this changes would correlate with alterations in the enzymatic activity within soil. Further research is required to elucidate the extent to which these changes in enzyme activity are mediated by prokaryotic, eukaryotic organisms and the host plant. Conversion from cropland back to grassland can reverse the process and promote carbon sequestration, but it may require decades for carbon levels to return to pre-disturbance quantities. If deep-rooted species are replaced by shallow-rooted species, carbon in below-ground stores may never fully recover, but sequestration will undoubtedly occur over the recovery period. Carbon sequestration within a given year will be influenced by factors such as growing degree days, moisture levels and grazing pressure.

Increases in carbon sequestration can be achieved through either an increase in the deposition of organic biomass or by a reduction in the rate of decomposition. The amount of carbon sequestered differs with soil depth, soil type and with the botanical species that is established. In general, most soil carbon measurements have been restricted to the top 30 cm of the soil profile. Measurements within a given area can be highly variable based on topography, degree of soil coverage and exposure to either wind or water erosion. Past work has suggested that grazing likely has little effects on carbon sequestration. However, this conclusion may have arisen due to challenges associated with estimating grazing intensity and the duration at which this intensity was applied to a given grassland. In these systems it is important to differentiate between carbon storage and carbon sequestration. Grasslands always store considerable quantities of carbon, which will be released upon disturbance through cultivation. Short term differences in carbon sequestration could reflect changes in yearly or seasonal differences in biomass accumulation or decomposition. Thus, true carbon sequestration can only be assessed with long-term continuous and consistent measurements under similar grassland management strategies. An adequate duration for these measurements still in undefined, but in some grassland ecosystems this could require a measurement period in excess of a century. Some of the estimates of carbon sequestration of grasslands have been modelled, but there are a number of assumptions in such models that have not been verified by direct experimentation.

Perhaps some of the most convincing data to date with regard to grazing enhancing carbon sequestration was recently reported by Bork et al. (2020) using sites in the temperate grasslands of Saskatchewan. This study involved 32 paddocks that were stocked for periods ranging from 7 – 27 years in the mixed-grass prairie region of Saskatchewan. Increasing the stocking rate from 0.49 to 2.3 times over recommended levels increased soil organic carbon from 24.7 to 57.4 tonnes ha^{-1}. This increase was associated with an increase in the abundance of introduced plant species (Kentucky Blue grass) and an overall decline in range condition (Fig. 4). However, carbon deposits may differ with depth as well as by the degree of lability of the carbon within the grazing system. Carbon that is less labile is more likely to avoid decomposition and contribute to carbon stores. Variation in the deposition of feces within the pasture can also influence carbon distribution within the pasture and fecal matter tends to be composed of the more recalcitrant carbon fraction.

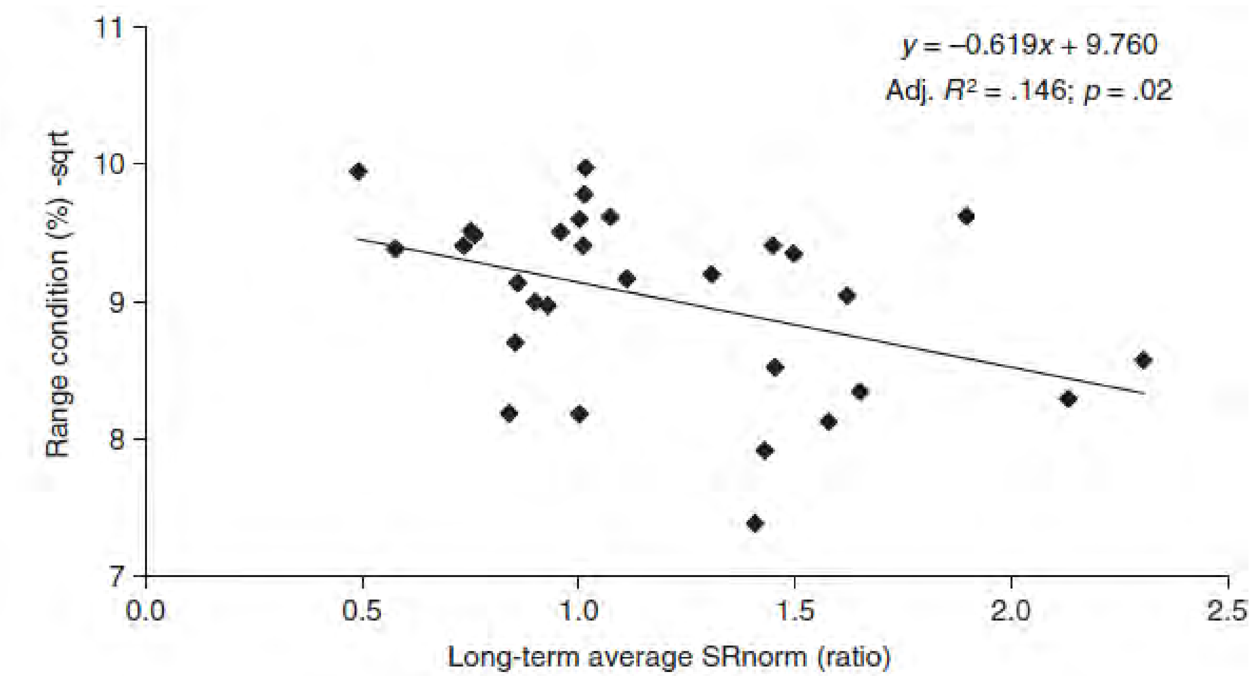

Fig. 4. Relationship between range condition and long term normalized cattle stocking rate across study sites (Bork et al. 2020).

Increased stocking density was associated with an accumulation of soil carbon, despite the decline in range condition (Fig. 5). Changes in soil carbon were largely driven by an increase in soil organic carbon as inorganic carbon stayed relatively constant. Decline in range condition was associated with the invasive Kentucky Blue grass with increases in carbon being apparent even at the 60 cm depth even though the root depth of this invasive species does not exceed 10 cm. These responses are likely to be soil- and location-dependent as a second recent study in Northern temperate grasslands found that stocking rates had minimal impact on peak above or below ground biomass, but did confirm that introduced plant species can have a positive impact on pasture productivity and soil carbon (Bork et al. 2019).

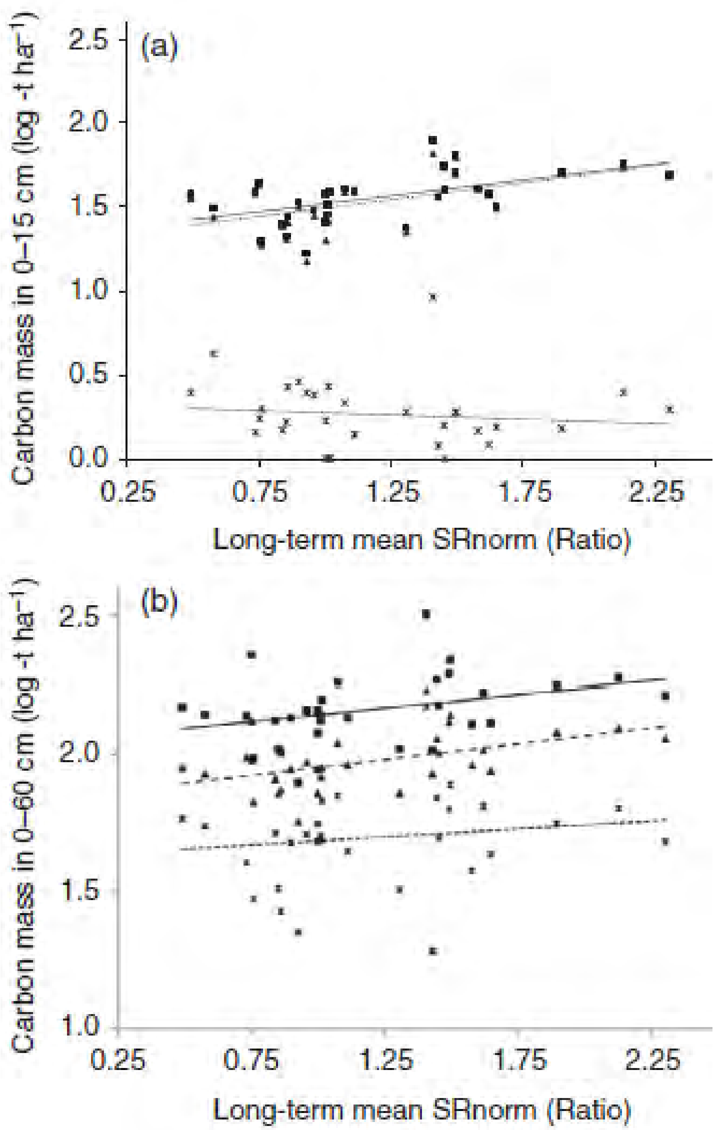

Fig. 5. Changes in total carbon, soil organic and inorganic carbon in 0 to 15 cm and 0 to 60 cm depths in relation to normalized stocking rates. Increases in soil organic carbon is believed to be associated with invasive Kentucky Blue Grass (Bork et al. 2020).

Grasslands deliver more ecosystem services than simply serving as a carbon store. They provide habitat to some of Canada's most prominent species at risk. They host an array of grassland bird species, many of which have dramatically declined in numbers as a result of conversion of grasslands to cropland. Grassland play an important role in avoiding water scarcity and improving water quality. Grasslands are often the site of infiltration of water into ground water systems and prairie pot holes serve as an important water source for wildlife and migrating bird populations. Endangered grassland ecosystems should be valued based on the entire suite of ecosystems services that they deliver to society.

Wetlands and Grasslands as Carbon Management Tools and Business Case

Alberta's grasslands and wetlands could play a key role in meeting Canada's commitments under the Pan-Canadian Framework on Clean Growth and Climate Change and the Alberta Climate Leadership Plan. Programs such as the Green Infrastructure Fund could provide capital to support carbon conservation and refurbishment programs. Given the difficulty of reestablishing wetlands and restoring grasslands, these funds may conserve more soil carbon if they are used to conserve existing carbon reserves as opposed to the remediation of damaged systems. Furthermore, assigning financial responsibility of the recovery of damaged wetlands and grasslands to those organizations responsible for the original land use change would theoretically further increase overall wetland and grassland carbon stores.

Land use change is the foundation for the anthropomorphic emissions associated with alteration in grassland and wetland ecosystems and is a key component in Canada's national inventory system. Alterations of these systems should consider the loss of future carbon sequestration in addition to the loss of previously-stored carbon. It is also important to consider that carbon storage, capture and sequestration should be considered as separate functions and that carbon is only one of the ecosystem services provided by these environments. If wetlands are established, such as when dugouts are established as a water source, the carbon emissions associated with wetland construction should also be considered in the estimation of the carbon balance. Ultimately, all positive ecosystem services of these environments such as contributions to water quality and biodiversity should be part of an overall ecosystem offset protocol. The role of these ecosystems in climate change through providing a cooling or humidifying effect should also be considered.

A number of approaches to encourage the preservation and restoration of grassland and wetland ecosystems have been considered. These include policy and legislation, frameworks and strategies, carbon pricing and offsets, conservation and stewardship tools and incentive-based programs. All of these approaches are subject to changes in both political and economic forces and the ability to ensure sustenance of these stores for in perpetuity is questionable. It is clear that a combination of government and NGO programs is likely to be the most effective approach achieve both carbon sequestration and delivery of other ecosystem services. Offset values from Alberta's grasslands and wetlands have a predicted estimated value of $2.5 billion per year, but as per any offset, buyers must be willing to pay the projected price for value to be realized. The stability of this value given the current economic uncertainty is certainly at significant risk.

There are a number of federal, provincial and private programs that are targeted at conservation and restoration of grasslands and wetlands. It is clear that greater coordination among these programs is required to reduce costs associated with data collection, auditing and verification practices. Coordination of some of these activities could reduce overall administrative costs avoid duplication of activities and improve project outcomes. Such an approach would also minimize trade-offs in terms of benefits and detriments to various ecosystem services. A systems evaluation approach is needed to ensure that there are not unintended negative consequences in policy or offset approaches to carbon management.

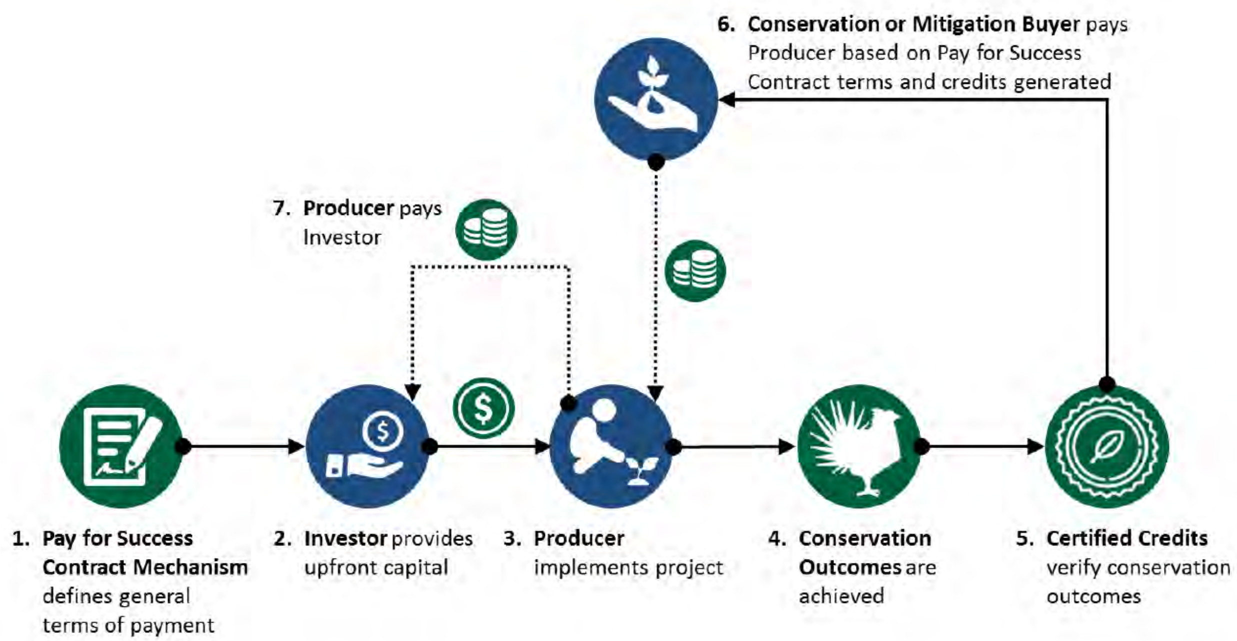

Fig. 6 Carbon offset program with a full delivery system.

A number of approaches are proposed in the development of carbon offset protocols, but the basic components of this approach are outlined in Figure 6. These systems do require investment in personnel that undertake processes such as investment, verification, aggregation, and purchase and dissemination. The producer also participates in these programs with the anticipation of making a profit as opposed to simply covering operational costs. Ensuring that the buyer has a stable and definable market for the associated offsets is also a key component to the success of this strategy. Although numerous approaches to achieving the goals of a grassland and wetland offset program have been devised, very few project have actually been initiated.

It appears that the most advanced of these programs is associated with the climate action reserve which has active programs in the United States in Colorado (6), Oregon (3) and Montana (2). Grasslands that have been established for a period of 30 years are considered with around 1 credit awarded for each conserved acre. Factors such as the pressure to convert grass- or wetlands into cultivated lands is also considered with the credit value increasing with lands that are more favorable for cultivation. Buffer credits are also required as insurance against the loss of carbon stores by natural processes such as fire. Most contracts mandate that grasslands projects occur over a 100 year time period. Credits awarded to compliance projects are generally more valuable than those arising from volunteer sources. Typically 18 to 24 months is required to initiate projects. Lands much be properly managed in terms of grazing pressure, and if the land is sold the terms of the agreement are applied to the sold land, obligating the purchaser to honor the contract commitments. Given the present adoption level, it appears that additional incentives may be required to encourage widespread participation in these programs.

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