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DUCKS UNLIMITED CANADA

BOREAL WETLANDS AND CLIMATE CHANGE

KEY FINDINGS TO SUPPORT THE DEVELOPMENT OF ALBERTA'S CLIMATE CHANGE ADAPTATION STRATEGY |

Contents

Statement of Purpose

Alberta is a signatory to "The Pan-Canadian Framework on Clean Growth and Climate Change (Government of Canada, 2016). The Framework document represents a "*collective plan to grow our economy while reducing emissions and building resilience to adapt to a changing climate*". Alberta's Climate Leadership Plan (https://www.alberta.ca/climate-leadership-plan.aspx) reflects an early and immediate commitment to the actions under the Pan -Canadian Framework focussed on reducing emissions of greenhouse gases (GHGs) or climate change mitigation. An additional component of the Framework considers that "*living natural infrastructure (e.g. constructed/managed wetlands and urban forests) can build the resilience of communities and ecosystems and deliver additional benefits, such as carbon storage and health benefits"*. This infrastructure is often also called "green infrastructure" and is central to both climate change mitigation and adaptation. It is our understandings that strategies to support climate change adaptation are in the early stages of development in Alberta, but that these important programs are developing (*Alberta Climate Change Office pers. com Feb 2017*).

The boreal forest represents an unprecedented conservation opportunity; one that integrates strategic protection of natural areas and the best possible approaches to sustainable management of ecosystems in a working landscape. Nearly 50% of Canada's Western Boreal Forest is considered waterfowl habitat and is used by millions of ducks annually (Prairie Habitat Joint Venture Boreal Implementation Plan 2015-2020). Canada's boreal is second only to the Prairie Parklands in supporting North American waterfowl populations (Prairie Habitat Joint Venture Boreal Implementation Plan 2015-2020) and the western boreal forest in particular is considered a "safety net" when droughts are limiting prairie habitat. Leading conservation scientists have suggested that long term conservation of the boreal forest will depend on implementation of large scale systematic conservation planning (e.g., http://www.beaconsproject.ca/documents) that considers climate change (Stralberg et al., 2015).

Ducks unlimited Canada works in partnership with governments, academia and industry towards establishing protected areas and ensuring sustainable land use through effective policies and best management practices implemented in an adaptive management framework. Researchers have also highlighted the vulnerability of boreal systems to climate change (e.g., Price et al., 2013; Stralberg et al., 2015) and the importance of considering climate change in integrated landscape management, planning for cumulative effects and other systematic conservation planning efforts (e.g., Groves et al., 2012). Ducks Unlimited Canada(DUC) has an interest in highlighting the important role of boreal wetlands, including open water systems, marshes, fens, bogs and swamps, in meeting climate adaptation and mitigation commitments; this in support of our conservation objectives.

This science overview is intended to form the basis for science translation work undertaken by Viresco Consulting on behalf of DUC and AB North American Waterfowl Management Plan (NAWMP). Viresco has been asked to develop a business case for the GOA that integrates wetlands into not only their Climate Leadership Plan but also into a broader vision for ensuring the resilience of Alberta's communities and ecosystems to climate change through adaptation. To that end, we highlight some key pieces of science regarding the role of wetlands in both climate change mitigation and adaptation strategies. This overview will include relevant aspects of carbon management (e.g., sequestration, storage, reducing greenhouse gas (GHG) emissions) to support climate change mitigation and adaptation and will quantify benefits of wetland conservation and management in terms of avoided &reduced emissions.

Introduction

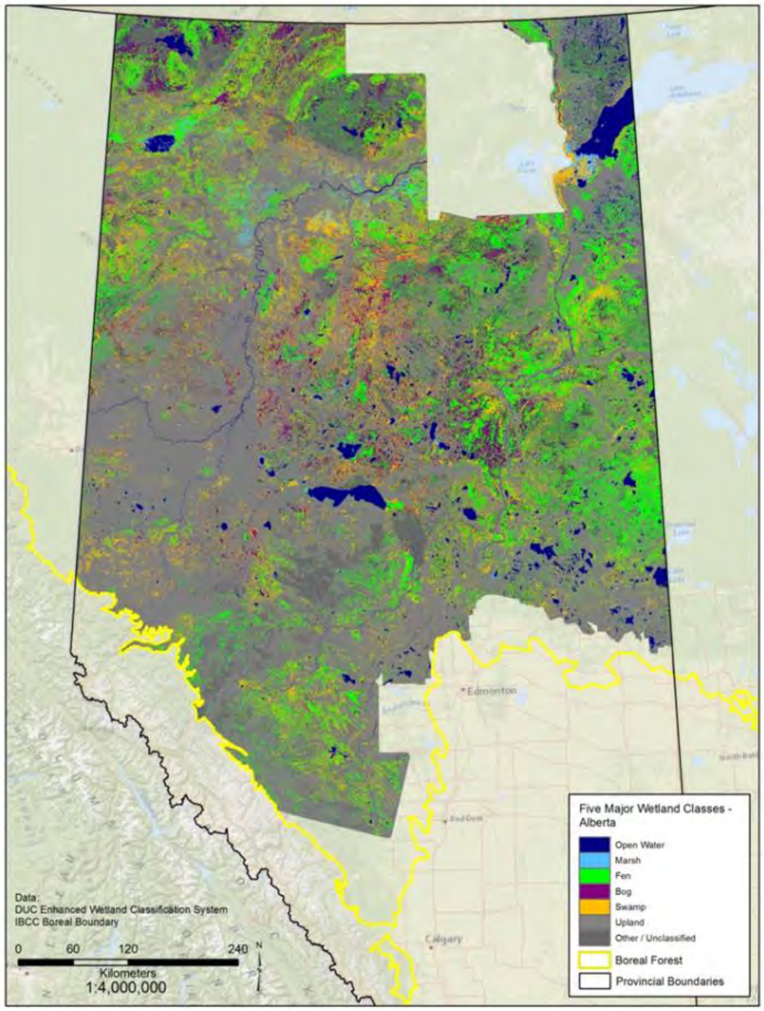
Within Canada, the boreal region is the largest of Canada's ecoregions, covering an estimated 584 million hectares (ha) or 58.5% of Canada's land base (Anielski and Wilson, 2009). Of this area, roughly 20%, or 119 million ha, consists of boreal wetlands including peatlands [1] (Source numbers taken from Badiou report for MB). In Alberta, 70% of Alberta's land base falls within the boreal region and this region is highly dominated by wetlands [2] (Figure 1). As a group, the five major classes of wetlands: bogs, fens, swamps marshes and shallow open water systems comprise approximately 38% of Alberta's boreal landscape (29 million ha; Figure 1). In some parts of boreal Alberta, wetland areas are more extensive (e.g., 485 km^2), covering as much as 85-95% of the land surface (DUC and Western Hydrology Group, 2006).

Wetlands in Alberta and across Canada's boreal zone support an array of ecosystem services such as supplying clean water, groundwater aquifer recharge, absorbing and filtering contaminants, regulating river flows by absorbing and releasing excess water, protecting shorelines from erosion, and serve as habitat for waterfowl, fish, and other biota (Table 1; Anielski and Wilson, 2009; Ketcheson et al., 2016; Kreutzweiser et al., 2013; Webster et al., 2015). Where carbon storage is concerned, peatlands (represented by bogs and fens) make a particularly large contribution. Covering only 3% of the earth's surface they contain one third of the earth's stored carbon. Most (67%) of Alberta's wetlands are treed and 56 % are peatlands as a result Alberta's boreal region also holds substantial stores of carbon (*see below*).

Together this broad suite of ecosystem services is fundamental not only to the ecology of Alberta's boreal but also to social and economic aspects of the communities embedded within it. In the context of a discussion of the role of wetlands in climate change adaptation and mitigation two related issues are central: the management of water and of carbon. This report focusses largely on carbon management. Water management is framed relative to its role in carbon management and the importance of water quantity and quality as an ecosystem service of wetlands is discussed as a co-benefit.

[1] Land saturated with water to promote wetland or aquatic processes poorly drained soils, hydrophytic vegetation various kinds of biological activity (CWCS).

[2] Boreal Plain is synonymous with the Boreal Central Mixedwood Natural Subregion in the provincial ecosystem classification) Schneider et al. 2016.



Wetland Class	Type	% of Boreal Alberta	% of Boreal Alberta Wetlands
Open water	Mineral or Peatland	4.1	10.7
Marsh	Mineral	1.4	3.7
Fen	Peatland	13.9	36.7
Bog	Peatland	7.4	19.4
Swamp	Mineral*	11.2	29.5

Figure 1. Wetland composition by major wetland class (CWCS) in boreal Alberta calculated using Ducks Unlimited Canada Enhanced Wetland Classification. *Some treed swamps may also have peat depths of > 40 cm and may be considered peatlands.

Table 1. Wetlands ecosystem services and climate change mitigations and adaptation options with respect to those services (Adapted from Webster et al. 2013).

Service	Role of Wetland	Climate Change Mitigation Options	Climate Change Adaptation Options
Provisioning			
Fibre and fuel/energy	Treed peatlands for forestry (and swamps); peat mining for peat moss products and bioenergy	Promote economic and policy instruments that encourage sustainable forest management practices, carbon storage/sequestration, and reduction in fossil fuel use (Bhatti et al. 2003)	Develop and promote practices to increase the rate of recovery
Food	Used as food for people (e.g., fish) and domestic animals, fur, and medicine	Protect large carbon banks like peatlands from drainage, fire, and land-use change (Bhatti et al. 2003) including conversion (*e.g.,* by promoting BMP[3]s that maintain wetlands).	Prevent the conversion of peatlands (e.g., agriculture), establish wetland rich protected areas
Fresh water	Public and industrial water supply may be obtained from wetlands[4]	Protect water tables and ensuring the natural hydrology of wetland systems is maintained *(e.g.,* by promoting/developing BMPs that maintain hydrology of wetlands).	Maintain wetlands as green infrastructure; Avoid or minimize disturbance to wetlands; ensure wetland areas are restored where they have been lost
Regulating services			
Climate regulation	Regulation of greenhouse gases, regulation of climatic processes	Protect large carbon banks like peatlands from drainage, fire, and land-use change; (Bhatti et al. 2003)	Manage forest fire risk; Maintain wetlands as green infrastructure

[3] BMPs: Best Management Practices

[4] E.g. as reservoirs draining peatlands; peatlands lost as freshwater source when drained for agriculture or forestry; water quality compromised by waste disposal or landfill; flooding of wetlands during reservoir creation lead to methyl mercury production (Webster et al. 2013)

Water regulation	Water storage, groundwater recharge, and discharge	Protect water tables and ensuring the natural hydrology of wetland systems is maintained *(e.g.,* by promoting/developing BMPs that maintain hydrology of wetlands).	Maintain wetlands as green infrastructure
Water purification and waste treatment	Retention, recovery, and removal of excess nutrients and pollutants		Maintain wetlands as green infrastructure
Erosion protection	Wetland vegetation protecting the underlying soils from erosion		Maintain wetlands and riparian areas as green infrastructure
Cultural Services			
Recreational and aesthetic	Opportunities for recreation and tourism; appreciation of nature		Maintain wetlands as green infrastructure
Spiritual and inspirational	Personal feelings and well-being; religious significance		Same as above
Educational	Opportunities for education, training, and research		Promote the value of wetlands and the ecosystem services they provide through education and training programs
Supporting services			
Soil formation	Accumulation of organic matter	Protect large carbon banks like peatlands from drainage, fire, and land-use change; (Bhatti et al. 2003)	Avoiding or minimizing disturbance to wetlands; ensuring wetland areas are restored where they have been lost
Nutrient cycling	Storage, recycling, processing, and acquisition of nutrients	Same as above	
*Biodiversity??	Habitats for species* including SARA species (i.e., woodland caribou, wood bison, yellow rail etc.)	Same as above	

Boreal wetlands and the global carbon cycle

How much carbon is stored in Alberta's wetlands?

Total carbon (C) storage in boreal wetlands can only be estimated, resulting in a range of values driven by both uncertainties in average bulk density and mean peat depth (Frolking and Roulet, 2007; Turunen et al., 2002). Following a method used for Manitoba (DUC 2016) Alberta's boreal wetlands are estimated to store between 11.5-13 billion metric tons of carbon (Table 2), below ground. Although in boreal wetlands the majority of carbon is stored below ground, treed systems and those with thick moss cover also store large amounts of carbon above ground (Kurz et al., 2013).

Table 2. Organic soil carbon content estimates for each of the 5 major wetland classes

		Peatlands of Canada Data		Vitt et al 2000	
	Area (ha x10^3)	**Organic Soil Carbon Density** (t/ha)	**Total Organic Soil Carbon** (t x 10^6)	**Organic Soil Carbon Density** (t/ha)	**Total Organic Soil Carbon** (t x 10^6)
Open Water	1,641	289	474	289	474
Marsh	567	289	164	289	164
Fen	5,623	1123	6,314	1,344	7,555
Bog	2,969	1109	3,294	1,254	3,723
Swamp*	4,523	289	1,308	289	1,308
Total	**15,323**		**11,553**		**13,223**

**below ground carbon storage in swamps is not well measured and table values are likely underestimates.*

Why do boreal wetlands accumulate carbon?

Organic soils occur in areas with climates that favor accumulation of organic matter (*i.e.,* cool and waterlogged) under low oxygen conditions (Tubiello et al., 2016); carbon accumulates because rates of decomposition of the vegetation are very low. Over thousands of years, the low decomposition rate results in a build-up of organic matter and, as a result, accumulated carbon storage (Mitsch and Gosselink, 2015).

Boreal peatlands (here bogs/fens) have been found to accumulate between 20-200 cm of depth every 1000 years with rates of 29 g/m^2 /year considered a reasonable average (Table 2; Gorham, 1991). On the other hand, relative to peatlands, mineral wetlands are typically thought to contain substantially lower amounts of carbon because decomposition rates are sufficiently high to avoid peat accumulation. However, in some swamp types (e.g., conifer swamps) peat accumulation may occur resulting in peat depths > 40 cm. Carbon storage in sediments of open water and marsh systems within the Boreal region have not been well assessed but are known to vary with catchment area, surficial geology, and depth (Squires et al., 2006). Despite lower sequestration rates in peatlands, the abundance of these in boreal Alberta combined with slow decomposition rates result in substantial carbon stores.

Table 3. Carbon sequestration rates by wetland type (adapted from Mitsch and Gosslink 2015 pg 569)

Wetland Type	Sequestration g-C/m²/year	Source
Boreal peatlands (i.e., bogs & fens)	29±13 (n=8)	Mitsch et al., 2013
	15-26	Turunen et al., 2002; Yu, 2012
	19 -20	Boville et al. 1983;Armentano and Menges 1986; Wieder 2001
Natural marshes (temperate)	83 (based on avg sedimentation rates of 2 mm/yr	Euliss et al. 2006
Natural open water wetland (*boreal -marsh or pond within peatland)*	40-180	Squires et al. 2006
Restored flow through temperate riverine marshes	181-193 (10 years old) 219-267 (15 years old)	Anderson and Mitsch 2008 Bernal and Mitsch,2013a
Restored marsh (Prairie Pothole Region/semi-permanently flooded)	305 (>10 years old)	
Swamps	Not available	Not available

Sequestration rates may vary substantially within and among sites depending on variability in factors controlling rates of decomposition and productivity. For example, studies have found that boreal peatlands may switch between source and sink functions among years (Lafleur et al., 1997 in Wieder 2001; Wieder 2001) and among wetlands. A pattern that holds true even among those wetlands in close proximity to one another and within the same class (Waddington et al., 2010). As a result, regional or global assessments of carbon balance are quite understandably confounded by this variability which challenges any efforts to scale up (Wieder, 2001). These challenges suggest a precautionary approach to managing wetlands in boreal systems aimed at maintaining natural process that will be beneficial.

Using the values in Table 3and the areas of wetland tabulated in the DUC Enhanced Wetland Classification, a coarse estimate of the current annual carbon sequestration capacity of Alberta's undisturbed peatlands (bogs and fens) is 2.5 million metric tons/year (range 1.3-3.6). The overall sequestration capacity of marshes in the boreal appears much less (0.5 million metric tons) because this class of wetlands makes up a relatively small proportion of Alberta's boreal landscape. However, the amount of carbon sequestered by this wetland class alone is the equivalent of offsetting annual emissions from ~530,000[5] thousand cars. This class is also often a restoration target for efforts directed at peatlands (Rooney et al. 2011 see below). However, at this time we do not have complete understanding of the trade-offs in carbon storage with respect to boreal wetlands of different classes through succession and as a result of restoration.

[5] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Sequestration rates for swamps are poorly quantified and their contributions have been omitted from this calculation. Given that swamps account for 30% of Alberta's wetlands (an additional 4.5 million ha and the second most abundant wetland class) our calculation is expected to be very conservative.

Wetlands and other greenhouse gases

Wetlands are the world's largest source of natural methane (CH_4; Turetsky et al. 2014) and are estimated to emit about 20-25% of current global methane emissions (Mitsch and Gosslink 2015). Methane emissions are of concern because CH_4 is 25x more powerful a greenhouse gas than CO_2 (Bridgham et al., 2006; Mitsch and Gosselink, 2015). However, wetlands at northern latitudes account for only about 7% of total annual CH_4 emissions, despite their large geographic extent (calculated from Table 17.2 pg 571, Mitsch and Gosslink, 2015). Local conditions such as hydrology, vegetation, and climate can cause CH_4 emissions to vary by several orders of magnitude both within and among wetlands (Turetsky et al., 2014) challenging our ability to make large scale generalizations (Anas et al., 2015)**.** However, evaluating CH_4 emissions from a wetland classification perspective, a general rule of thumb is that bogs <fens<swamps<marshes (Mitsch and Gosselink, 2015). For example, CH_4 emissions from fens are generally higher than from bogs due to higher water tables and a greater abundance of vascular plant species with aerenchymous tissue (Turetsky et al., 2014).

In any case, fens and bogs often appear to be assessed or reported together under the more general classification of peatlands. For example, Moore and Roulet (1995) found that CH_4 emissions from Canada's peatlands were generally less than 7.5g C/m^2/year depending on a combination of soil temperature, water table position. A recent study by Mitsch et al., (2013) used CH_4 emissions ranging between 1.5 and 55.2 g C/m^2/year to assess the net carbon accumulation potential for boreal peatlands. These numbers suggest that for the most part undisturbed northern peatlands act as net carbon sinks with a resulting cooling effect on the atmosphere (e.g., Ramsar 2016). However, when incorporating the CO2 sequestration and CH4 emissions estimates from Mitsch et al., (2013) for boreal peatlands into the GHG perturbation model presented in Neubauer (2014) we calculate that the radiative switchover time for these systems is in excess of 1200 years.

Marshes (intact) of temperate areas such as Alberta's prairies emit between 40-75 g/C/m^2/year (Mitsch and Gosselink, 2015). A similar estimate is reasonable for marshes in boreal systems (Badiou pers com.). These wetland types are not well studied in the boreal and represent a much smaller proportion (Figure1) of the landscape than peatlands. However, when boreal peatlands are disturbed they may, especially early in succession, be replaced through restoration by mineral based systems (Timoney, 2015), thus highlighting the importance of quantifying carbon sequestering values of mineral systems in boreal landscapes. Further, swamps as a major wetland class, are poorly assessed in this context and estimates for these systems are also inaccurate. Treed swamps may have values similar to those in treed peatlands while shrub swamps might be more comparable to marshes in expected emissions.

In these systems, the production of methane is an anaerobic process and occurs only in the saturated zone of a wetland or in local anaerobic microenvironments (Turetsky et al., 2014). As a result, altering the hydrology of these systems can significantly alter their CH_4 emissions. Maintaining the natural hydrology of all boreal wetland types which are highly interconnected to drainage features such as creeks and rivers and their associated riverine/riparian wetlands will also minimize CH_4 emissions (Mitsch and Gosselink, 2015; Turetsky et al., 2014).

When do boreal wetlands release carbon?

Hydrology of wetlands, especially peatlands, drives carbon sequestration and release via its influence on gas diffusion rates, redox status, nutrient availability and cycling, and vegetation species composition and diversity (Holden, 2005). Model simulations developed by Mitsch et al., (2013) suggest that wetlands sequestering CO_2 with intact natural hydrology are good for climate because they will almost without exception, be net sinks. While undisturbed northern peatlands have and are for the most part, currently acting as net carbon sinks (Wieder, 2001), there are exceptions. Natural disturbances such as fire may also result in carbon loss stored above ground in trees and moss with below ground losses dependant on the severity of the fire and moisture conditions (Thompson et al., 2014; Waddington et al., 2010). For example, the Fort McMurray fire made headlines for its carbon emissions, 72% of which are estimated to have resulted from the combustion of wetlands; amounting to approximately 6.9 billion metric tons of carbon (CFS unpublished data). Flooding can also result in large outputs of dissolved organic carbon (DOC) in water, accelerate peat decomposition and affect methane and therefore carbon dioxide fluxes to the atmosphere (Schindler et al 1998; DUC 2006). One substantial management challenge will be maintaining carbon stocks in peatlands; wetlands which are known to be particularly sensitive to changes in climate (Petrone et al. 2011). Even if, hypothetically speaking, sequestration stopped today, we would need to manage these carbon stocks very carefully to avoid massive losses of carbon to the atmosphere.

Since controls on the carbon balance are a result of complex relationships among vegetation, landscape position and hydrology (Petrone et al., 2011) , these relationships are vulnerable to changes that can result in a conversion of boreal wetlands from net sinks to net sources of carbon (Wieder, 2001; Ramsar 2016). Examples of such changes include large scale impacts such increased fire frequency and severity predicted as a result of climate change, local anthropogenic impacts as a result of improper road placement/construction that alter natural hydrological processes (Forman and Alexander, 1998; Gillies, 2011; Tague and Band, 2001), wetland loss such as by draining wetlands for agricultural purposes (Acreman and McCartney, 2009; Environment Canada, 2013)or for peat extraction (Acreman and McCartney 2009). We discuss some of these impacts in greater detail below.

Take Home Messages

- The carbon balance in Alberta's boreal wetlands regardless of wetland class is the result of complex relationships among vegetation, landscape position and hydrology; relationships that are vulnerable to disturbances that may lead to boreal wetlands acting as net sources of carbon rather than net sinks (Wieder, 2001; Ramsar 2016).
- Intact Boreal wetlands are both net carbon and radiative sinks.
- A precautionary approach to managing wetlands aimed at maintaining natural process in boreal wetlands will be beneficial to ensuring CH_4 emissions are minimized maintaining the current role of wetlands on the landscape as mainly carbon sinks (Mitsch and Gosselink, 2015; Turetsky et al., 2014).
- Due to the radiative switchover time estimated for boreal peatlands (in excess of 1200 years), development of these systems should be avoided where possible.

Impacts of climate change on boreal wetlands

Wetlands and boreal forests are among those ecosystems expected to be most affected by climate change (Bhatti, 2003; Price et al., 2013). Boreal Alberta is expected to experience increased precipitation and warmer temperatures as a result of climate change. Recent climate modelling work suggests the western boreal zone including Alberta, will become much drier drawing into question the ability of this landscape to continue to support forests (Hogg, 1994; Price et al., 2013; Schneider et al., 2016) and some have suggested water resources are also likely to suffer large impacts (Baldocchi et al. 2000 *in* Price et al. 2013). That is, increases in precipitation in the boreal plain are not expected to make up for the expected concurrent increases in temperature resulting in higher rates of evapotranspiration. In addition, changes in precipitation coupled to changes in temperature driving regional evapotranspiration will alter the seasonality and amount of water available to vegetation(Price et al., 2013).

As a result of these changes in climate, bioclimatic envelope models based on accepted climate scenarios predict that virtually all of the climate space currently occupied by the Boreal Plain will be replaced by climates currently associated with Parkland and Fescue Grassland ecosystems (Schneider et al., 2016). That is, the climates that typically maintain boreal plain ecosystems are expected to shift northward and climate in the southern extent is expected to be similar to that associated with parkland, aspen forest and grasslands (e.g., Schneider et al. 2016). Although, peatlands in a substantial portion of northeastern Alberta are predicted to be severely affected by climate change (Tarnocai, 2006), some authors expect transitions as a result of climate change may be slower in areas with a high proportion of peatlands (e.g., Schneider et al., 2016). Feedbacks within peatlands that minimize water losses during dry conditions may also slow the rate or alter the trajectory of some of these changes (Schneider et al., 2016). Recommendations are that overall, although these transitions may be inevitable, they may be further slowed and social and economic impacts reduced through climate change mitigation and adaptation strategies (e.g., Lempriere et al., 2008).

Wildfires are currently one of the largest natural disturbances affecting boreal forests. Both the frequency and severity of forest fires is expected to increase with climate change (Price et al. 2013). Hydrological feedbacks inherent to peatlands in particular are believed to be important for controlling vulnerability to disturbances such as wildfire (Waddington et al. 2015; Johnstone et al. 2010). Under most fire weather conditions fire frequency and deep burning are inhibited by thick wet soils, low evapotranspiration and water retained in mosses (especially Sphagnum) and hydrologic feedbacks (Waddington et al., 2015). These negative feedback processes within peatlands support the retention of large volumes of water on the landscape and as a result these systems are also considered inherently resilient to climatic fluctuations (Schneider et al., 2016; Waddington et al., 2015). Large water bodies (such as lakes) surrounded by large amounts of water (such as wetland complexes) have also been found to influence fire patterns by acting as fire breaks (e.g., Nielsen et al., 2016). Drying as a result of climate change has the potential to alter these historic patterns.

Although the expected rate of change is currently a matter of debate and under study, there is agreement that wetland responses to climate change will largely be mediated by changes in the water table (Turetsky et al., 2011; Gong et al., 2012; Sherwood et al., 2013; Kettridge et al., 2015). Thus, management strategies that wherever and whenever possible, focus on maintaining the water table will be important.

Take home messages

- Altered disturbance, nutrient and moisture regimes and subsequent changes in species composition will affect the future carbon balance of boreal systems (Bhatti et al. 2013) including those in Alberta.

- Net C releases to the atmosphere as a result of the lost capacity of these systems to sequester carbon are likely - especially where conversion of peatlands to other purposes occurs (e.g., agriculture, oil sands etc.; Wieder, 2001; Rooney et al., 2011).
- Given the importance of the water table in mediating effects of climate change, ensuring wetlands are conserved and water tables protected (i.e., natural hydrology is maintained) will be a fundamental component of both adaptation and mitigation strategies.
- Alberta will want to ensure strong climate mitigation and adaptation strategies are in place to alleviate potential effects of climate change in the boreal including potential reductions in water availability and increases in fire frequency. In terms of GHG management, the maintenance of large stores of C in undisturbed peatlands should be a priority[6] (International Peatland Society).
- *"Research aimed at improving peatland inventories and enhancing our understanding of the links between climate, hydrology, ecology, permafrost degradation, fire regimes and GHG balances will improve our knowledge of the state of current peat resources and predict the fate of this important store of carbon" (* International Peatland Society). DUC would extend this statement to all wetland classes.
- Further degradation and loss of peat ecosystems, regardless of their location, could seriously hamper climate change mitigation and adaptation efforts and the achievement of the Paris Agreement

Wetland loss and functional impairment in boreal Alberta & implications for GHG emissions and carbon sequestration

Wetlands are considered dynamic systems: variable across the landscape and through time (Acreman and McCartney 2009). Wetlands are affected by two principle anthropogenic disturbance mechanisms: functional impairment and loss. Functional impairment is a term sometimes used to suggest loss of biological function or integrity and may be defined as *"the condition in which human activities have caused an ecosystem to exceed its normal range of variation in structure or function"* (Timoney, 2015). Functional impairment can occur as a result of hydrologic impacts at local or catchment scales (Acreman and McCartney, 2009). Hydrologic impacts are possible as a result of road placement and/or construction that alters ecohydrological processes (Forman and Alexander, 1998; Petrone, 2012). Function can also be impaired as a result of changes in water quality such as through contamination (e.g., pipeline breaks, oil spills), erosion and changes in land use (e.g., agriculture). Wetland loss can occur as a result of long term hydrologic impairment or by physical removal such as by draining (*e.g.,* for agricultural or for peat extraction) or cultivation. We first discuss and attempt to quantify wetland loss in boreal Alberta and follow-up with some examples of functional impairment.

Wetland Loss in Boreal Alberta

The exact area and number of wetlands lost in Alberta's boreal region has not yet been formally quantified however, most sources indicate overall wetland loss has not been as high in boreal Alberta as in the settled prairie and parkland regions (*e.g.,* Watmough et al. 2007). The settled portion of Alberta (i.e., the white zone) has lost approximately 63% of its wetland area since settlement (Watmough and

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[6] http://www.peatsociety.org/peatlands-and-peat/peatlands-and-climate-change

Schmoll, 2007). On the other hand, a conservative estimate of overall wetland loss[7] in Boreal Alberta is an average of 5.5 % across the five major wetland classes (DUC *unpub. analyses*). However, a closer look shows that wetland loss at the scale of the boreal plain may not be as extensive as that in prairie and parkland areas, this region of Alberta has not been immune to permanent wetland loss and widespread industrial activities potentially resulting in long term degradation (Figure 3; Photo Panel). Wetlands in Alberta's boreal region have been directly affected by anthropogenic disturbance though a range of activities resulting in permanent (or very long term) loss of wetlands (e.g., well pads, oil sands mining, roads etc.).

Some regions within the boreal plain have also seen greater proportional losses than others (e.g., Rooney et al., 2016). For example, Timoney (2015, pg. 2) state that northeastern Alberta has become a "global hotspot for habitat loss"; a statement which extends to wetlands (e.g., Rooney et al. 2016). Areas of the boreal plain that are within Alberta's white zone have also experienced extensive wetland loss in conjunction with agricultural expansion (PHJV Implementation Plan, 2015). More recently, areas of the green zone are also experiencing high rates wetland loss through conversion of crown land dispositions to both industrial and agricultural land uses. These examples are discussed in turn below (also see Appendix 1).

Working Examples

Estimates of wetland loss due to Oil sands

Oil sands deposits accessible by open-pit surface mining cover approximately 475,000[8] ha of boreal Alberta, 99% of which is already leased (*source* in Rooney et al., 2016. Development in the Mineable Oil Sands Area (MOSA see Figure 2) is a substantial portion of Alberta's economic growth but also contributes the largest proportion of Alberta's GHG emissions(Alberta Government presentation to DUC Feb 2017) and as a result Alberta is the largest emitter in Canada(https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=18F3BB9C-1). Approximately75% of the disturbed area is surface mines or settling ponds, with lesser area existing as roads, infrastructure and reclaimed areas. Approximately 50 % of these areas are peatlands most of which are fens (90 %) with peat thicknesses ranging between one and five meters (Ketcheson et al., 2016). This area also has a substantial biological carbon footprint, releasing carbon stored in vegetation, soil and peat as the resource is extracted. Extensive land cover changes are expected to eventually cover 167,044 ha as a result of the 10 mines that currently have government approval to operate. Rooney et al. (2016) first quantified land cover changes including wetlands as a result of oils sands mining in northeastern Alberta and estimated subsequent effects on carbon storage and sequestration. DUC recently conducted a similar analysis using the 2014 ABMI human footprint. As of 2014, the net footprint in the MOSA as of 2014 covered 119,221 ha (Figure 2). Although each effort used different wetland classification systems and scales, overall results are quite similar with a net loss of peatlands was estimated at between 28,000 and 31,000 ha's excluding pipelines, roads, seismic lines, and other infrastructure that support mine

[7] Alberta Biodiversity Monitoring Institute (ABMI) human footprint intersected with DUC- EWC. EWC does not classify wetland in large fires and includes substantial area classified as "anthropogenic" and "agriculture" not included in this analysis

[8] DUC 2016 calculation is 489,103 ha

development (Rooney et al. 2016; Figure 2; DUC estimates Table 3). As of 2014, the ABMI human footprint indicated loss or functional impairment could be as high as 58,451 ha for wetlands alone; approximately 28 % of the original wetland area but not including what has been or will eventually be reclaimed (Rooney et al. 2016, DUC unpub analyses).

None of the closure plans call for the restoration of lost peatlands and since these plans are not independently evaluated, success of reclamation procedures is uncertain (Rooney et al., 2016). Reclamation will result in the largescale conversion of wetlands to upland forest largely at the expense of peatlands (Rooney et al. 2011). Wetlands are expected to be restricted to areas between hills and surrounding end pit lakes. A relatively dry climate, where evapotranspiration exceeds precipitation will limit the formation of wetlands in this landscape (Devito et al; Rooney et al; Price et al). Although recreating fen-type hydrology post-mining landscapes is possible and successful examples do exist (Price *et al.* unpub results; Stryker et al. unpub results), a minimum 2:1 upland to peatland ratio is required so that uplands may supply adequate seepage to maintain peat wetness thus the area of fens lost (estimated at 35,00 ha so far) can never be replaced (Price et al, 2009; Rooney et al. 2011).

Table 4. Wetland composition area lost or disturbed within the MOSA, Northeastern Alberta[9].

	Total Wetland Area (ha)1948	Area Disturbed (ha) 2014	% Wetland Disturbed or Lost
Open Water	11,598	534	12
Marsh	1,613	246	28
Bog	13,236	3,225	25
Fen	141,624	35,998	30
Swamp	80,769	18,450	35
Total	248,839	58,452	28

Simply draining one hectare of boreal peatland releases an estimated 1603 metric tons of stored carbon (5877 metric tons of CO2 equivalents) (Rooney et al., 2016) the equivalent of 3711 barrels of oil. They estimated that carbon storage loss caused by peatland conversion could be equivalent to 7-y worth of carbon emissions by mining and upgrading in Alberta (at 2010 levels).

Estimates of wetland loss due to human footprint as of 2014 account for 58,452 ha or about 30% of wetlands in MOSA. Oil sands removal requires large open pit mines in Northern Alberta result in large-scale removal of the surficial landscape, extending 100 m into the earth (DUC, 2008; Ketcheson et al., 2016). Applying the carbon content values form Table 2 to areas calculated in Table 4. Accounting for only below ground carbon as of 2014, 49 million metric tons had been removed to accommodate surface mines or settling ponds The implications for carbon storage and carbon sequestration were also conservatively assessed by Rooney et al., (2016) resulting in a similar range in values of between 11.4-47.3 million metric tonnes of carbon.

[9] Calculated using historical imagery including air photos predevelopment Landsat imagery and wetland classification and the 2014 ABMI human footprint.

Additional research is needed to assess potential future trends in biological carbon emissions from oil sands mining, and to evaluate biological carbon emissions associated with in situ oil sands development. *In situ* development, although not requiring the removal of soil, has the potential to cause a larger cumulative footprint due to the greater extent of subsurface bitumen deposits (DUC 2008).

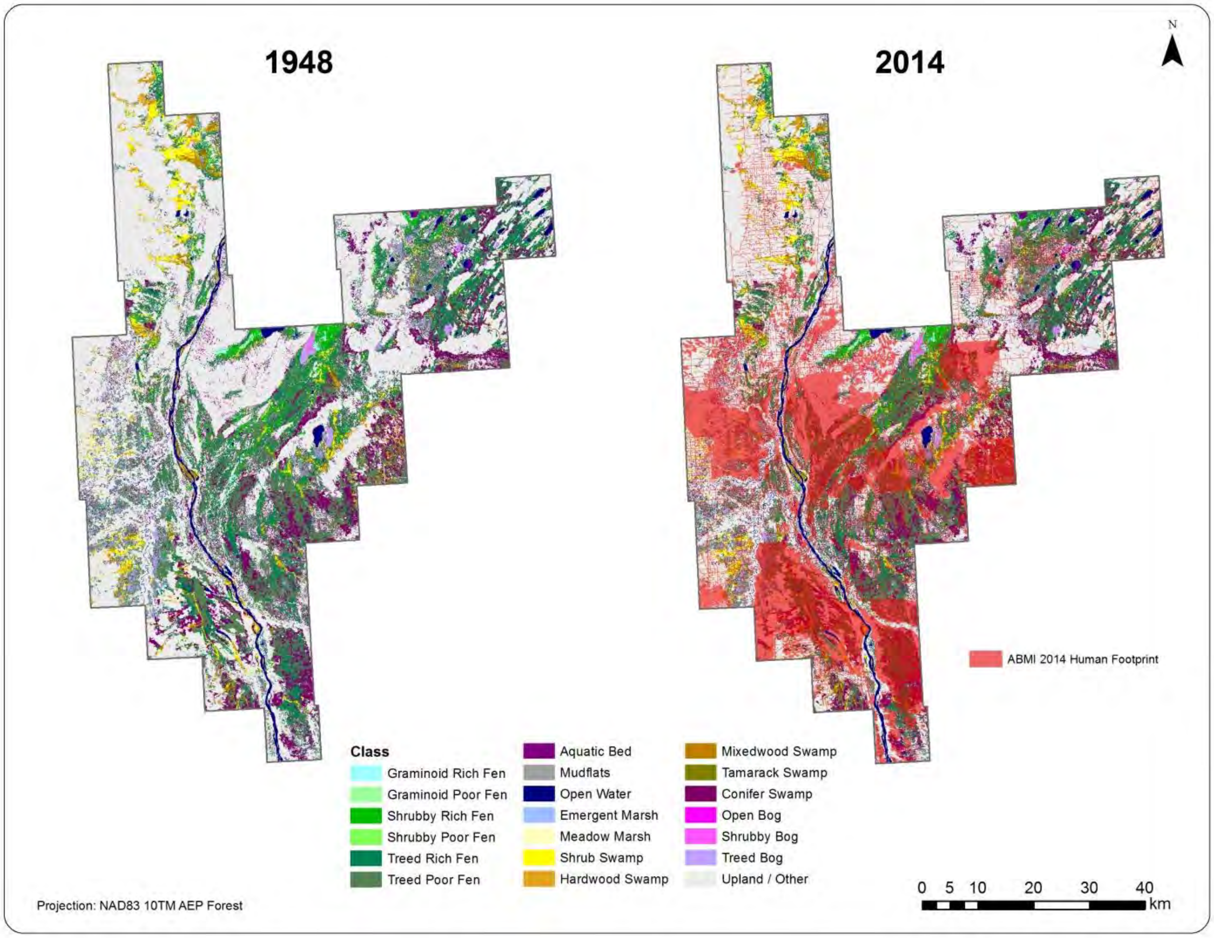

Figure 2. Wetland composition (DUC EWC) of Oil Sands Mineable Lease Area (northeastern Alberta) in 1948 (Pre-mining development) and extent of human footprint today (ABMI 2014).

Wetland loss due to agricultural conversion

In Canada, 85% of wetland loss is attributable to agriculture through activities such as draining, filling, cultivation, consolidation (references in Wrubleski and Ross, 2011)and in the case of treed wetlands-clearing. Wetland loss attributable to conversion of the forested landscape to agriculture in the boreal transition zone (i.e., where boreal intersects with Alberta's white zone) is largely unquantified and has not been fully monitored (but see Watmough et al., 2007). However, it is thought to be as prevalent as in parkland and prairie regions. Anecdotal evidence reveals large scale wetland area conversions and drainage have occurred or are ongoing along with various upland habitat alterations (e.g., clearing resulting in deforestation) with potential impacts on any remaining wetlands (see Figure 3; Watmough et al., 2007; Morissette et al., unpublished data; DUC unpublished data; Appendix 1).

For example, in the La Crete area of Alberta wetland loss between 2005 and 2016 may be as high as 80 % (Appendix 1 Figures 1a&b), the majority of which were marshes, already the least abundant wetland class in AB. In areas that have not experienced outright wetland loss, functional impairment (as defined above) due to high nutrient inputs and/or grazing has also occurred and these impacts are much more difficult to quantify. At a broader scale, implications are that catchment hydrology in these areas is likely also compromised (Acreman and McCartney, 2009).

Take Home Messages

- Wetland loss in the boreal may represent a smaller proportion of the landscape than losses experienced in either Prairie or Parkland ecosystems. However, the boreal is experiencing extensive expansion of industrial activity. In the oils sands region wetland loss approaches 30%. In areas experiencing agricultural intensification regional estimates of losses between 60-80% are not unreasonable. Small wetlands, easily drained, cleared or cultivated are especially vulnerable.
- Wetland loss results in reduced carbon storage and sequestration on the land base. The capability of the land base compensate for carbon emissions from anthropogenic sources is also reduced.
- Researchers are predicting that success in restoration of peatlands at a scale required to replace systems lost thus far (i.e., as a result of oil and gas exploration) is unlikely. However, some regulatory requirements in place for restoring well pads and are part of reclamation plans in the oil sands.

Wetland functional impairment: potential effects of industry disturbance on carbon

Functional impairment of Alberta's wetlands has not been quantified at the scale of the boreal. While the human footprint accounts for only about 5% of the overall area of boreal wetlands, linear features such as roads, seismic lines and pipelines also potentially result in medium and long term changes in the hydrology and ecology of Alberta's boreal wetlands. As with wetland loss, some areas in Alberta's boreal are more affected than others, however densities of linear features exceeding 8 km/km^2 are not uncommon.

Known effects of hydrologic impairment on carbon

Practices that interfere with hydrology resulting in changes in water levels can have an impact on carbon stores in wetlands. For example, drainage for cultivation, peat extraction or to increase forest productivity (past practice in AB) can turn organic soils such as those in peatlands into a significant source of GHGs (Tubiello et al., 2016). Previously waterlogged soils become exposed to oxygen and carbon stocks previously resistant to decay can be lost. Drainage causes oxidation of the organic material subsequently releasing CO_2 and N_2O often for several decades (Bhatti et al., 2003; Tubiello et al., 2016) Draining a hectare of boreal peatland is estimated to release between 387 and 1603 metric tons of stored carbon (1417-5877 metric tons of CO2 equivalents) (Rooney et al., 2016) the equivalent of between 895-3711 barrels of oil.

Peatlands are generally considered carbon sequestering systems and activities that influence the function of these systems can influence the carbon/methane balance (Petrone et al. 2005). Effects of hydrologic interference from roads or infrastructure that impounds or diverts water depend on the type of hyrdrologic regime, nutrient status and vegetation structure of the system being studied (Miller et al., 2015; Minkinnen et al. 1999; Strack et al., COSIA poster 2017). For example, Miller et al., (2015) quantified the effects of multi-decadal drying on fens and found that water loss due to diverted water and drainage resulted in increased tree biomass for treed fen sites and increased shrub biomass in a shrub fen (e.g., Miller et al. 2015). Changes in the functional composition of the understorey were also apparent (Miller et al., 2015). Authors thought that the water table might recede even further because of resulting feedbacks among soil drying, increased tree biomass and the increase in evapotranspiration and canopy interception (Miller et al. 2015). Several studies have shown that increased tree biomass may drive and amplify drying (i.e., drop the water table even further) caused by drainage and or blocked flow. Changing vegetation structure will also change biomass and subsequently carbon storage. Net effects on the carbon balance are currently unclear.

Altering the hydrologic regime and lowering the water table can also influence fire behavior which is in part regulated by the quantity and quality of available fuel (Kettridge et al., 2015; Miller et al., 2015; Thompson et al., 2014). Sphagnum which forms hummocks inhibits burning due to its ability to retain moisture (Thompson et al., 2014). In drought or following disruption of hydrology when Sphagnum cover may be replaced by feathermosses, the resulting loss in surface soil moisture can increase risk of surface ignition and deep burning of peat (Miller et al., 2015; Waddington et al., 2012). Likewise, when the water table in sedge fens is lower due to drought or hydrologic impairment, thick sedge beds previously wet may now become important fuel sources (Thompson pers com.)

When peatlands are harvested they have higher rates of CO_2 emissions than similar but undisturbed peatlands (Bhatti et al., 2003; Waddington and Price, 2000) a pattern that likely also applies to swamps where peat accumulation exceeds 40 cm. Evapotranspiration is reduced due to removal of vegetation and peat becomes oxygenated due to removal of the surface peat layers, lowering of the water table resulting in a release of carbon

Effects on peatlands (or treed swamps with >40 cm of peat) of clearing or drainage can include subsidence due to dewatering and compaction (Turchenek, 1990). Clearing and drainage of organic soils not for immediate agricultural use is not recommended because of increased fire hazard (Turchenek 1990). Additional impacts such as increased runoff and reduced water quality (particulates and pH) may occur before a seedbed can be established. When wetlands are drained the capacity of landscapes to deal with excess nutrients is also reduced; increased nitrogen and phosphorous in runoff waters is common (Turchenek 1990). Harvesting adjacent to peatlands may also result in hydrologic changes to these systems and could alter carbon storage function of these systems (Plach et al., 2016).

The Intergovernmental Panel on Climate Change (IPCC) defines radiative forcing as ''*an externally imposed perturbation in the radiative energy budget of the Earth's climate system*" (Ramaswamy et al. 2001 *in* Bridgham et al., 2006). Thus, carbon fluxes in unperturbed wetlands are important only in establishing a baseline condition while changes from baseline conditions in fluxes are those that constitute a radiative forcing that will negatively impact climate change (Bridgham et al., 2006). Based on this definition, activities that impair the capacity of wetlands to sequester carbon at current rates are considered positive radiative forcings, and exacerbate effects of climate change. For example, the lost sequestration capacity and oxidation of the soil carbon pool in drained wetlands are both considered positive radiative forcings (Bridgham et al., 2006). Given the sensitivity of carbon sequestering processes in wetlands to changes in hydrology and subsequent changes in vegetation composition, these activities will include any that result in changes to the water table (e.g., drainage, blocking flow), the flooding regime (e.g., dams) and/ or result in increased oxidation of the soil carbon pool (e.g., drainage, excavation, compaction).

Take Home Messages

- A precautionary approach is strongly recommended to identify characteristics of activities that may cause functional impairment of wetlands and reduce their ability to sequester carbon. Altering hydrologic functions in particular can result in a cascade of effects on the ability of boreal wetlands to sequester carbon potentially resulting in a net release of GHGs to the atmosphere.
- Altering the hydrologic regime and lowering the water table can also influence fire behavior. These relationships are not currently factored into mitigation and adaptation strategies related to fire.
- Industrial and agricultural sectors should implement Best Management Practices (BMPs) when planning for development and during installation of infrastructure and equipment. Proper planning will capitalize on opportunities to avoid wetlands in the first place and minimize impacts where avoidance is not possible.
- There are few recognized and tested BMPs in place to ensure functional capacity of wetlands relative to GHGs and including carbon accumulation is maintained (e.g., Gillies, 2011; Graf, 2009). As a result, it will be especially important for techniques that are currently at the forefront of testing and research to be implemented subject to adaptive management and ongoing monitoring. An adaptive management framework will ensure the most effective methods are widely available and development of new knowledge and continual improvement occur quickly (Ketcheson et al., 2016).

Agricultural clearing, draining wetlands

Roads and well pad- wetland loss and changes in hydrology (note: contamination due to spill also)

Agricultural clearing and drainange - wetland loss

Roads- changes in hydrology

Active draining of wetlands

Road altering hydrology

Figure 3. Examples of Wetland loss, alteration and functional impairment (e.g. hydrologic) in Alberta's boreal forest region (Photos DUC)

Restoration and reclamation

As mentioned above, it can be argued that there are very few examples of successful restoration of peatlands to date (Graf, 2009; Rooney et al., 2016; Timoney, 2015). Often reclamation efforts for wetlands result in establishment of upland vegetation (Graf, 2009; Rooney and Bayley, 2011) or wetlands of a different type (e.g., peatland restored to marsh type wetland; Timoney 2015). When hydrology is restored where infrastructure and other practices have resulted in blockage of flow (e.g., improved road crossings), more rapid recovery is expected once the hydrologic connectivity and the water table have returned to normal. However, activities that result in substantial disturbance to the water regulating layer of (e.g. through horticultural peat extraction) peatlands increases the level of effort required to restore the site due to effects on the water balance (Graf 2009, Petrone 2005). However, water management and selective plant reintroduction may accelerate recovery (Timoney, 2015; Rooney and Bayley2011; Rochefort and Lode, 2006). Recent and emerging research provide examples where appropriate successional trajectories have been re-established following well pad reclamation techniques (Cobbaert et al., 2004) however, long term success of these techniques in the face of climate change is uncertain. Furthermore, these recently developed techniques are not, to our knowledge, being widely implemented. However, prescriptive approaches are unlikely to be as helpful as general guidance or expert consultations because each site must be assessed and a plan made to accommodate unique challenges (e.g., Price et al., 2003; Schrautzer et al., 2013).

Wetland reclamation research has focussed heavily on establishing mineral wetlands (especially marshes) because successful restoration of peatlands may be unlikely and marshes represent a reasonable alternative restoration target (Rooney and Bayley 2011; Timoney, 2015). Mineral wetlands are much more productive relative to peatlands and therefore take up more carbon per unit area on an annual basis, however, the flip side is that they likely also emit methane (Badiou *pers. comm.*). There are very few studies that have examined carbon storage rates in boreal open water and mineral systems. However, one study (Squires et al., 2006) estimated long term carbon burial at 31 g/m^2 and more recent rates at 40-180 g C/ m^2/year suggesting at minimum, they should be neutral relative to climate change while providing a broad suite of other ecosystem services.

Success of restoration of peatlands on a scale such as the oil sands is currently deemed unlikely (Timoney, 2015) and expected to be very costly. Even, smaller scale restorations to assist regeneration of linear features in wetlands located in important caribou areas, although successful, has proven to be challenging and costly (Clare et al., 2011). As a result, it will be especially important for techniques that are currently at the forefront of testing and research to be subject to adaptive management and ongoing monitoring to ensure rapid assimilation of new knowledge and continual improvement (Ketcheson et al., 2016).

Take home messages

- Given prediction under climate change scenarios is that restoration is going to become more difficult and therefore more expensive, management efforts should capitalize on opportunities to avoid wetlands and minimize impacts wherever possible (also recommended in Clare et al., 2011)
- Reclamation efforts should be focussed on restoring wetlands to wetlands rather than other vegetation types. Wherever possible objectives should be focussed on restoration to the pre-disturbance wetland type or class.

- Research into successful restoration techniques for peatlands is gaining ground and it does appear that functioning fens can be developed and techniques for restoring seismic lines in wetlands seem to be successful (CFS work; COSIA meetings). However, restoration efforts are more costly than simply avoiding or minimizing impacts by implementing BMPs to mitigate potential impacts wherever possible (Clare et al., 2011).
- Where restoration techniques are available for wetlands these should be implemented. Additionally, ongoing efforts to improve efficacy of restoration techniques will be valuable and BMPs need to be developed, tested and implemented as soon as they become available. A diverse "toolbox" based on thorough understanding of hydrology and wetland ecology will increase success of BMPs and mangers to properly assess individual scenarios.

Boreal Wetlands 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. Following an invitation from the United Nations Framework Convention on Climate Change (UNFCCC) to "undertake further methodological work on wetlands, focusing on the rewetting and restoration of peatland, with a view to filling in the gaps in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, the IPCC developed the *2013 Supplement to the IPCC Guidelines on National Greenhouse Gas Inventories: Wetlands*. This supplement provides nation-level guidance on inventorying methods for soil organic carbon (SOC) and GHG sinks and sources from various wetland types, including those associated with organic soil wetlands (peatlands) and freshwater mineral soil wetlands.

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. The 3 tiers of approaches to estimate SOC stock and stock changes most amenable to application on boreal wetlands are described in Chapter 2 of the 2013 Supplement for "Drained Inland Organic Soils", Chapter 3 for "Rewetted Organic Soils", and Chapter 5 for "Inland Wetland Mineral Soils". Currently, at the national scale in Canada, stock changes associated with boreal wetlands 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. However, for the purpose of reporting and in line with the land categories as defined in IPCC (2006), the Wetlands category is restricted to those wetlands that are not already in the Forest Land, Cropland or Grassland categories (ECCC 2017). As result stock changes and emissions associated with only two types of managed wetlands that pontentially occur in boreal regions are reported on: 1) peatland drained for peat extraction, and 2) flooded land (large hydroelectric reservoirs). There is no corresponding area estimate of wetlands within the other major land use categories in Canada (Cropland, Forest Land, Grassland, and Settlements). Therefore, we currently know very little regarding how boreal wetland carbon stocks and GHG emissions have been altered in response to land use changes and how thes have in turn influence GHG emissions at the national scale. This will likely change in the near futre given the updated guidance provided by the 2013 Wetlands Supplement developed by the IPCC.

Due to the fact that wetlands and in particular boreal peatlands are among the planets most important carbon stores, conversion of these ecosystems has the potential to release significant amounts of carbon. Furthermore, land use after conversion typically has higher GHG emissions. Subsequnetly, there is ample opportunity for quantifiable reductions associated with boreal wetland activities, in particular those associated with peatlands. To date activities for which protocols have been developed have focused on the avoided conversion of peatlands, and the rewetting of drained peatlands. 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) and are either directly applicable or potentially applicable to boreal wetlands:

- ACR – Restoration of California Deltaic and Coastal Wetlands
- ACR – Restoration of Degraded Wetlands of the Mississippi Delta
- ACR – Pocossin Wetland Restoration (under eview)
- VCS VM0004 – Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0
- VCS VM0009 - Methodology for Avoided Ecosystem Conversion
- VCS VM0027 – Methodology for Rewetting Drained Tropical Peatlands, v1.0

Currently there are no approved boreal wetland (for mineral soil wetlands or peatlands) protocols for use in Canada. While boreal wetlands can comprise a substantial portion of the landscape they should be consider as part of the larger forest landscape. This would suggest that much more needs to be done in terms of reporting on changes in carbon stocks and GHG emissions for these ecosystems within the managed and unmanged forest landscape of Canada.

Boreal Forests and Wetlands in Climate Adaptation and Mitigation Strategies: recommendations from science

Boreal ecosystems regulate weather and climate directly via transpiration cooling and albedo effects (Oke 1978; Barnett et al. 2005 in Kurz et al. 2013) and indirectly via carbon sequestration (Webster and McLaughlin 2014; Kurz et al. 2013) and thru freshwater inputs to the Arctic Ocean (Bates et al. 2008 in Kurz et al. 2013). The consensus is that northern peatlands currently acts as carbon sinks and have a cooling effect on the atmosphere. As discussed, land use and climate change could alter this balance. However, carbon storage and sequestration are not the only values at risk from these changes.

Changes to global climate and hydrologic cycles also may also impact boreal water resources (Price et al. 2013). Climate models predict that changes in temperature and precipitation are likely to continue affecting the partitioning of water between evapotranspiration and runoff as well as the amount of water stored in glaciers, snowpack, lakes, wetlands, soils, and groundwater (Ireson et al., 2015, Price et al. 2013). Extreme weather events such as drought and floods, reduced winter ice coverage and changes in the seasonality of flow regimes are predicted to be among the key impacts of climate change on the water cycle (NRTEE 2010). These impacts are in addition to impacts from industrial and agricultural land uses.

In the pan Canadian Framework, the Federal, **provincial (including AB)**, and territorial governments have agreed to "*partner to invest in traditional and natural infrastructure that reduces disaster risks and protects Canadian communities from climate-related hazards such as flooding and wildfires*". Green infrastructure (e.g. Earth Institute 2011 Columbia University) is a term that is common in the climate change adaptation and mitigation literature. Green infrastructure is defined in various ways and some definitions are more comprehensive than others. In Ontario, green infrastructure is defined "as the natural vegetative systems and green technologies that collectively provide society with a multitude of economic, environmental and social benefits (http://greeninfrastructureontario.org/)." Alberta's definition is narrower in scope and to date encompasses only technologies that benefit Alberta's economy while reducing GHG emissions (presentation to DUC-AB Climate Change Office 2107).

Climate change will pose many challenges to sustainably managing Alberta's boreal region. Challenges related to carbon management include managing carbon pools and fluxes, quantifying carbon stocks and estimating carbon sources and sinks, developing methods for exploiting opportunities for carbon sequestration and associated credits all while maintaining its ecological integrity and the economic benefits this region provides (Bhatti et al., 2003; Helbig et al., 2016; Ketcheson et al., 2016)

The Alberta government has also identified several anticipated negative impacts of climate change on Alberta's agriculture and forestry sectors, infrastructure, the availability of energy and water resources and considered the financial implications of increased natural disasters (https://www.alberta.ca/climate-change-alberta.aspx). There is an opportunity now to align mitigation and adaptation objectives to maintain ecosystem services provided by wetlands (Table 1) and to ensure implementation of a no regrets strategy for achieving the most favorable socio-economic and ecological outcomes possible for Albertans.

Wetlands and Climate Change Mitigation

Here climate change mitigation refers to efforts to reduce or prevent emission of greenhouse gases. (UNEP). Wetlands are potentially instrumental in climate change mitigation strategies (e.g., green infrastructure) and are a natural low cost carbon capture alternative. Some options that have been suggested include:

1. **Protecting large carbon banks** like peatlands from drainage, fire, and land-use change; (Bhatti et al. 2003). Fire and insect protection activities have a strong impact on the carbon sequestration and storage of forested landscapes. Protecting the forest from fire and insects can temporarily preserve the carbon stocks in boreal forests (Bhatti et al., 2013) including that held in treed wetlands. Although in a disturbance adapted system such as boreal forests, natural disturbances such as fire are inevitable, **understanding and considering the role of wetlands in fire management can assist with fire management and suppression efforts** (Waddington et al., 2012;Thompson pers. comm.). Wetlands may also help mitigate the impacts of forest fires on adjacent uplands and assist with regeneration following disturbance (Kettridge et al., 2015; Hokansen 2014).
2. **Minimizing or avoiding disturbance in boreal wetlands will leave Alberta well positioned to avoid further emissions.** This recommendation is on pace with international approaches. For example, in 2015, the Nordic Council of Ministers committed to preserving the region's peatlands. Almost half of Nordic countries' peatlands have been lost, and this ecosystem

degradation contributes 25% of their total carbon emissions. (http://www.ramsar.org/news/mother-nature-vs-climate-change)

3. **Developing an inventory of and monitoring for carbon stocks in biomass, soils, peatlands, and lakes** (e.g., predictive maps of carbon stocks; Bhatti et al. 2003). Understanding carbon stocks associated with different wetland types may also assist with efforts to report carbon emissions associated with forest fires in areas with a large proportion of wetlands (Waddington pers. comm.). Knowledge gaps relative to the carbon storage of open water wetlands exist however, recent work in boreal lakes (Anas et al., 2015) suggest this contribution is considerable.
4. **Developing incentives to deter land owners from draining wetlands in the boreal region.** Implications for carbon loss due to drained peatlands to serve the agricultural sector are very large, additionaly wetlands on private land have historically been vulnerable to drainage.
5. **Promoting economic and policy instruments that support carbon storage/sequestration** by encouraging sustainable forest management practices, reducing cumulative effects, eliminating draining of wetlands, ensuring restoration is successful and reducing fossil fuel use (e.g., Bhatti et al. 2003, Lemprière et al., 2013 International Peatland Society 2017). Also, the GOA is in a position to stop the practice of transferring large public owned areas to new agricultural areas. That is, vacant crown lands should not be converted to agricultural dispositions/sales especially for lands which are rich in wetland type and extent.
6. **Ensuring that implementation of the wetland policy in the white and green zone supports conservation objectives will be important to reducing or offsetting GHG emissions.**
7. **Protecting water tables and ensuring the natural hydrology of wetland systems is maintained and, where it is compromised, restored**. Ensuring development, testing, implementation of best management practices (BMPs) for avoiding or minimizing disturbances to wetlands will support this option.

Wetlands and Climate Adaptation Strategies (*i.e.,* resiliency)

Adaptation strategies or options involve making adjustments in decisions, activities, and thinking because of observed or expected changes in climate, in order to reduce harm or take advantage of new opportunities government of Canada (UNEP). As a result, maintaining the resiliency of Alberta's boreal forests and especially wetland ecosystems is a fundamental piece of climate adaptation strategies. Climate change will bring with it higher levels of uncertainty around extreme water events (i.e., resulting droughts or floods) and natural disturbance events (e.g., forest fires, insect outbreaks etc.). Therefore, it will be important to have strategies in place to ensure the resiliency of Alberta's boreal communities and minimize the risks and costs associated with these fluctuations. A number of adaptation options are possible:

1. **Implement Climate Mitigation Options.** Climate mitigation options (as described above) contribute to climate adaptation by reducing climate change impacts (Gauthier et al. 2014)**.**
2. **Protect and maintain wetland hydrology.** Because of the role wetlands play/ecosystem services (e.g., flood storage, storm damage prevention, water quality, habitat protection, water supply protection) wetlands provide it will be particularly important to manage hydrologic systems to minimize climate impacts. Hydrology of wetlands is important for water resource management,

flooding and stream water quality (Holden 2005). Minor changes in climate or peatland management can result in dramatic changes to flood magnitude and frequency and water quality (Holden, 2005). For example, if 10% - 20% of watershed is wetland/lake a 60% reduction in peak flow of big storm events can be expected (Kolka, 2013). Similarly, peatlands can be small percentage of watershed, but produce 50% of streamflow (Kolka, 2013) and are key systems storing moisture in times of drought. Though not necessarily capable of maintaining municipal water supplies (Holden et al., 2005) this storage is accessible to forested parts of the landscape and fundamental to sustainably managed forests and managing forest fire risks. Alberta will need to plan for extreme water events (*i.e.,* droughts and floods) and for avoiding wetlands when placing infrastructure

3. **Invest in retaining Green infrastructure provided by wetlands.** In the Pan Canadian Framework, the Federal, provincial, and territorial governments have agreed to "p*artner to invest in traditional and natural infrastructure that reduces disaster risks and protects Canadian communities from climate-related hazards such as flooding and wildfires*".
4. **Consider cost of replacing lost services and function as a result of the loss of green infrastructure provided by wetland ecosystems.** At this time whether restoration of peatlands will be successful in the face of climate change has not been fully determined.
5. **Reduce stressors on boreal wetlands through avoidance and minimization** (e.g., Gauthier et al., 2014). Minimizing or avoiding disturbance in boreal wetlands will leave Alberta well positioned to avoid further emissions.
6. **Support Wetland Education, Training and Awareness**.
   a.) Activities to raise awareness of industrial land users of the importance of protecting wetlands/minimize impacts are an important adaptation strategy. (*e.g.,* set up good/best practices demonstration projects to share expertise and innovation and develop management guidance).
   b.) Communicate the societal benefits of wetlands including peatlands in terms of ecosystem services and the costs arising from damaged wetlands (Ramsar 2016).
   c.) Promote the role of peatlands rewetting/restoration in reaching national and international policy targets, especially for climate regulation, water quality and biodiversity conservation (Ramsar 2016).
7. **Strategically restore wetlands and associated function** Wetland objectives embedded in regional plans (*e.g.,* land use plans including WPAC Watershed Plans, Land Use Framework, Biodiversity Management Frameworks etc.) should ensure wetland loss is stemmed and some level of net restoration (e.g., linear features, well pads, etc.) is achieved. while ensuring any new techniques applied are tested and monitored within an adaptive management framework (Ketcheson et al. 2016; Ramsar 2016).
8. **Strengthen links between science and policy** to ensure that policy objectives are data based, clear and quantifiable (Ramsar 2016). This recommendation is supported by **investing in research and monitoring** to support evidence-based decision making.

These adaptation actions will also support Alberta's commitments to "work in partnership with Indigenous communities to address climate change impacts, including repeated and severe climate impacts related to flooding, forest fires, and failures of winter roads" (Pan Canadian Framework 2016)

Benefits of Managing for Carbon and Wetland Conservation: The Win-Win

- **Value of Ecosystem Services.** Although many systems can be considered in green infrastructure frameworks (e.g., urban forests, green roofs and walls) wetlands, watercourses and their associated riparian areas (these are also often wetlands), are frequently a critical component of green infrastructure strategies. From an ecosystem services perspective, these services are also very valuable when intact and costly or impossible to replace when disrupted. The total annual nonmarket value of Canada's boreal ecosystems services has been estimated at $703 billion and boreal wetlands are generating approximately 73% of this value with the ecosystem services(Table 1) they provide (Anielski and Wilson 2009); The service of sequestering carbon was the single most valuable of these, with an estimated value of $401.9 billion per annum followed by 77 billion for flood control and water filtering of peatlands only and an additional 3.4 billion for flood control, water filtering and biodiversity value of non- peatland wetlands (Anielski and Wilson 2009). Applying the estimates generated for peatlands at the national level by Anielski and Wilson (2009) to boreal wetlands in Alberta yields a value in excess of $41 billion per annum for stored carbon alone. Strategies to avoid and or minimize changes to the functions (see Table 1) of these important ecosystems will benefit Alberta's resilience to climate change impacts and reduce eventual costs of replacing these services when the consequences of their loss become apparent.
- **Water quantity and quality** - Boreal wetlands linkages to water quality and quantity. Canadians and Albertans value their water resources. In fact, 61.6 % of Canadians ranked freshwater ahead of forests, agriculture, oil and fisheries as the country's most important resource (Nanos 2009 in Webster et al., 2015). Water security issues have a high profile and wetlands play a crucial role in hydrologic function of the landscape. When wetlands are drained the capacity of landscapes to deal with excess nutrients is also reduced- increased nitrogen & phosphorus in runoff waters is common (Turchenek 1990, DUC?). Additionally, quality and quantity of water resources has received much attention with respect to quality of life in Alberta's indigenous communities; in this context green infrastructure becomes particularly critical. The estimated value of water filtration, supply and flood control for boreal AB is $15 billion (applying values from Anielski and Wilson 2009).
- **Biodiversity Conservation.** Wetland associated species are among those most at risk in boreal Alberta including SARA listed species such as Yellow Rail, Rusty Blackbird, Olive-sided Flycatcher, and caribou. Reducing footprint of linear disturbances such as seismic lines will not only reduce greenhouse gas emissions but will also benefit wetland dependent wildlife currently thought to be negatively affected by increased fragmentation and loss in wetlands.
  Additionally, where industrial wetlands (*e.g.,* engineered wetlands) are in place or restoration is occurring, there are several additional biodiversity concerns including reduced richness of native plants associated with wetlands, elevated richness and cover of weeds, reduced vegetation biomass and less wetland area (Timoney, 2015). Presence of contaminants and salts in water and sediments also has implications for use of these areas by wildlife and the capability of these systems to support resilient food webs (Timoney 2015)
- **Managing to retain ecosystem function--**Properly managed forest ecosystems can become carbon sinks and continue to meet the timber, fiber, and energy needs of society(Bhatti et al., 2003; Kurz et al., 2013; Man et al., 2013). Wetlands are an important part of management strategies. While climate change brings with it great uncertainty, it is clear that the forest/land managers will influence carbon stock changes by their management actions (Bhatti et al. 2013). Wetlands are an important piece of sustainably managed forests-assisting with forest regeneration, supporting productivity and influential in fire management efforts (Schneider et

al. 2016, Waddington et al. 2015). Wetland conservation can not only assist with reducing uncertainty within Alberta's forest industry, but also support the social license of all industries who operate on this land base.

Conclusions and Recommendations

The boreal forest is the world's largest and most important forest carbon storehouse (Anielski and Wilson 2009), but its ability to continue storing carbon depends on future land management practices (Rooney et al. 2011). An effective climate change policy MUST include a strategy to stem further wetland loss and functional impairment. Bearing in mind that draining just one hectare of boreal wetland releases between 895 and 5877 metric tons of CO_2 equivalents, equal to the annual emissions of between 216 and 1267 cars, we must carefully examine land use planning and development processes and decisions in terms of the climate impacts of wetland loss in particular. Alberta's Wetland Policy should continue to emphasize avoidance as its implementation priority and minimization where avoidance is not possible. Additionally, research and monitoring to determine appropriate thresholds for disturbance of wetlands in land use planning should be supported. This should include the completion of boreal wetland inventories and carbon stock assessments of the various boreal wetland types. Furthermore, given the large potential stock changes associated with conversion of boreal wetlands and the expansive nature of the Boreal landscape there is ample opportunity to develop and implement an avoided conversion of peatland/wetland protocol. Lastly, based on the fact that boreal wetlands are important carbon stores and at the same time one of the most important biological sources of CH_4 to the atmosphere, a better accounting of changes to these systems and implcations for carbon stocks and GHG emissions is required at the provincial and national scale in order to represent Canada's GHG emissions and reductions as accurately as possible

There is a role for several government departments in ensuring this important policy is upheld including Agriculture and Forestry, Environment and Parks and the Alberta Energy Regulator. Protecting wetlands through carefully selected protected areas, implementing avoidance and minimizing strategies and restoring wetlands that have been lost yields a triple bottom line of benefits: increased resiliency to effects of climate change, maintaining a full suite of values, functions and services and support to a carbon management strategy (sequestration, emission reduction and long term storage).

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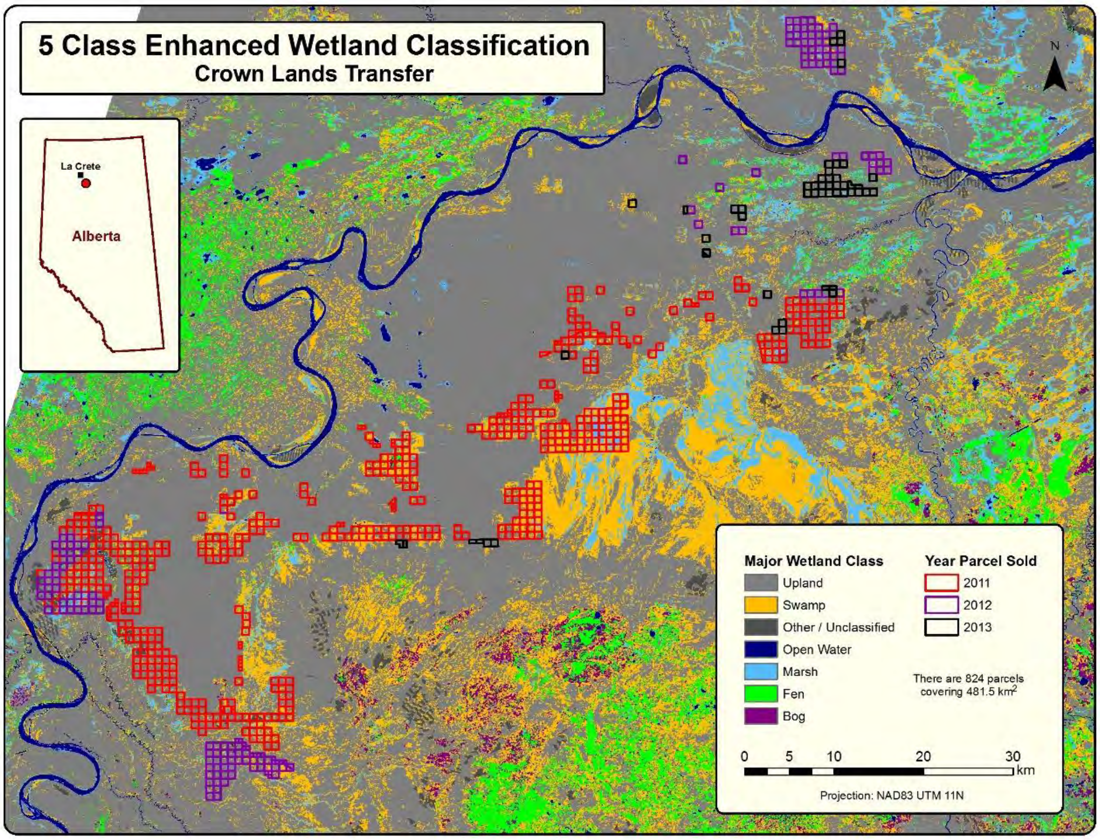
Appendices

Appendix 1 Crown Land transfer and associated wetland classification. Risk of wetland increases with conversion of crown land forested parcels purchased to support agriculture.



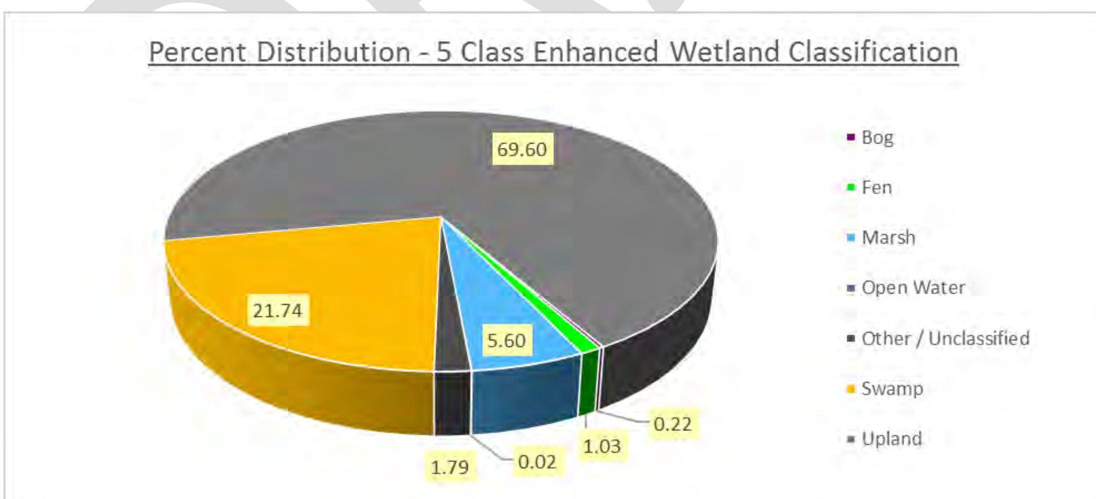
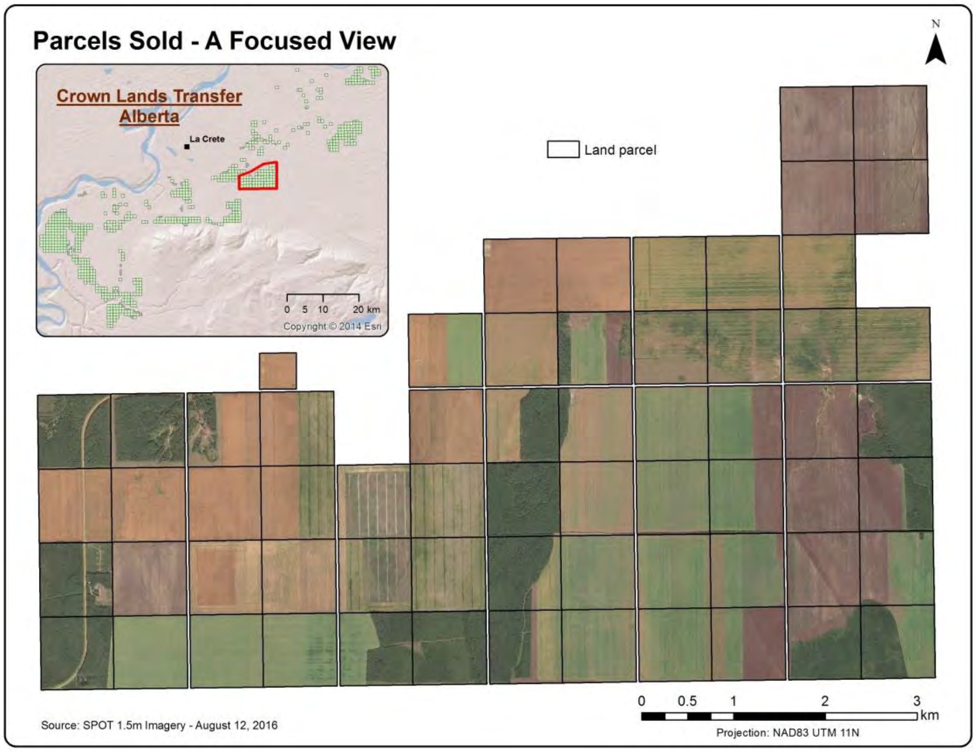


Figure 1 a.


Parcels Sold - A Focused View
N
Crown Lands Transfer
Alberta
La Crete
0 5 10 20 km
Copyright © 2014 Esri
Land parcel
Source: SPOT 1.5m Imagery - August 12, 2016
0 0.5 1 2 3
km
Projection: NAD83 UTM 11N

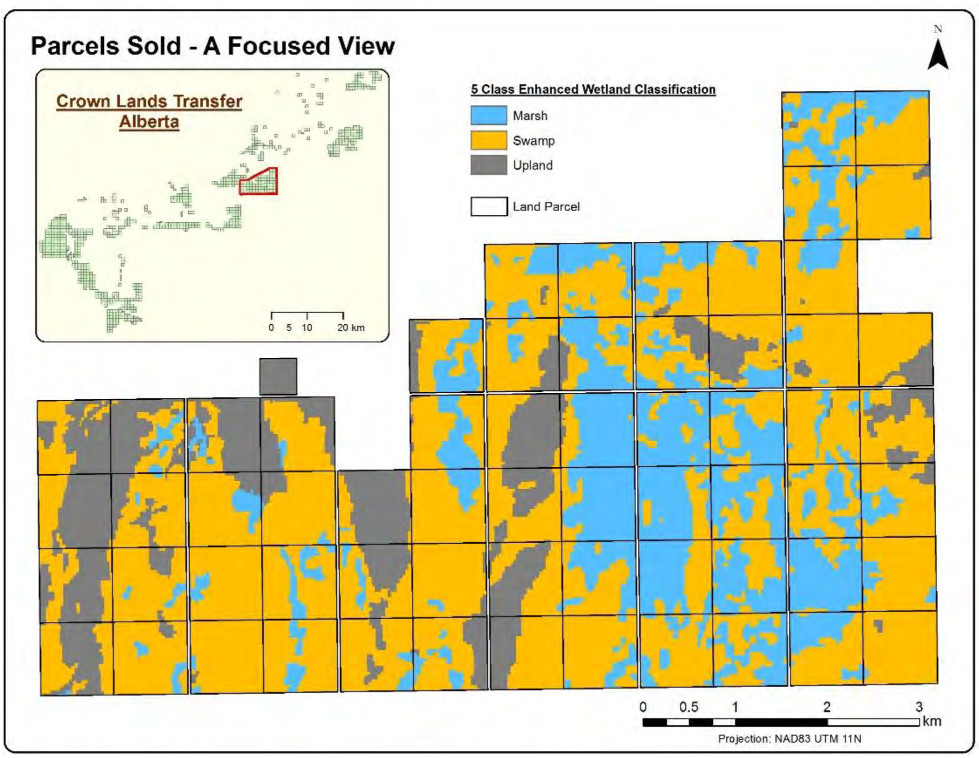

Parcels Sold - A Focused View
N
Crown Lands Transfer
Alberta
0 5 10 20 km
5 Class Enhanced Wetland Classification
Marsh
Swamp
Upland
Land Parcel
0 0.5 1 2 3
km
Projection: NAD83 UTM 11N

Figure 1b.