Wetlands in Canada's western boreal forest: Agents of Change

by Lee Foote[1] and Naomi Krogman[2]

ABSTRACT

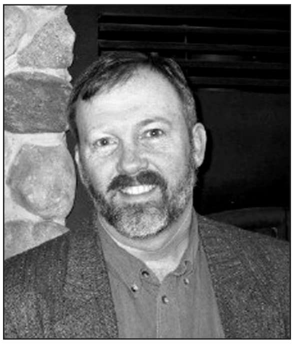
Wetlands of the western boreal forest are poorly studied. In the last decade (1990–2000) there were approximately 1810 northern hemisphere scientific papers published addressing boreal wetlands, tundra, taiga, or bogs. We explore the extent of understanding and impacts of six major agents of change affecting forested wetlands of the boreal zone: (1) commercial forestry, (2) petroleum extraction, (3) mining (bitumen, coal, peat, ore, and diamonds), (4) agriculture, (5) climate change, and (6) hydrologic alteration. Finally, we address the social context, costs, and recommendations for wetland maintenance.

Key words: western boreal forest, wetlands, loss factors, forestry, conversion, wetland retention, wetland values

RÉSUMÉ

Les terres humides de la forêt boréale occidentale ont fait l'objet de peu d'étude. Au cours de la dernière décennie (1990-2000), environ 1 810 articles scientifiques en provenance de l'hémisphère nord ont été publiés en référence aux terres humides boréales, à la toundra, à la taïga ou aux marécages. Nous étudions l'étendu de la compréhension et les conséquences provoquées par les six principaux agents de changement affectant les terres humides de la zone boréale : (1) la foresterie industrielle, (2) l'extraction du pétrole, (3) l'activité minière (les sables bitumineux, le charbon, la tourbe, le fer et les diamants), (4) l'agriculture, (5) les changements climatiques et (6) les fluctuations hydrologiques. Finalement, nous portons notre attention sur le contexte social, les coûts et les recommandations sur la préservation des terres humides.

Mots clés : forêt boréale occidentale, terres humides, facteurs de perte, foresterie, conversion, préservation des terres humides, valeurs associées aux terres



Lee Foote

Naomi Krogman

"Some tall pine snapped by the icy mace of Boreas, earth's forest-fosterling reared by a spring to stately height, amidst long mountain-glens."

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Introduction

The mythological god of the north wind, Boreas, emanated from a vast, northern, and mysterious region and lent his name to the boreal forest. The boreal ecozone is the largest contiguous eco-type in the world, contains more wetlands than any other region and though no longer mythical, its wetlands are still lightly studied and poorly known to science. This is particularly surprising considering that the boreal zone occupies a circumpolar belt through parts of Canada, United States, former USSR, Finland, Sweden, Norway and China. Although well known for its forest, petroleum, and mineral resources, the boreal ecozone (Strong 1992; more specifically, Zoltai *et al.* 1988) also holds and yields water in great abundance; it encompasses the greatest number of wetlands, lakes, and peatlands in the world. Notably, the functions and fates of those wetlands have global significance for climate, resources, and species persistence.

Importance of the Boreal Zone

The boreal forest has become one of the last major economic frontiers on Earth's surface to open up to exploitation. The boreal zone occurs in a circumpolar belt lying between 47° and 70° North Latitude and is bounded by treeless tundra on the north and various prairie parklands and grasslands on the south.

The western boreal forest (WBF) (Fig. 1) occupies 20% of the total circumpolar boreal area (Bonan and Shugart 1989). Though precipitation varies throughout boreal regions, the cold winters are long and evaporation rates are very low; therefore, much of the boreal zone occurs on frozen or saturated organic soils of a peatland or wetland nature (Marshall and Schutt 1999). Rail lines and surfaced roads are rare and there are few population centers north of 55° N for servicing the growing industrial infrastructure. Logistical barriers of distance, transportation, and weather made resource extraction expensive and products such as pulp and sawtimber, furs, peat, and recreational services were initially of insufficient value to overcome production costs. Technology, a cumulative enlargement of road access and the discovery of petroleum and hard rock minerals/precious stones, have changed

[1]Department of Renewable Resources, University of Alberta, Edmonton, Alberta T6G 2H1. E-mail: lee.foote@ualberta.ca
[2]Department of Rural Economy, University of Alberta, Edmonton, Alberta T6G 2H1. E-mail: Naomi.krogman@ualberta.ca

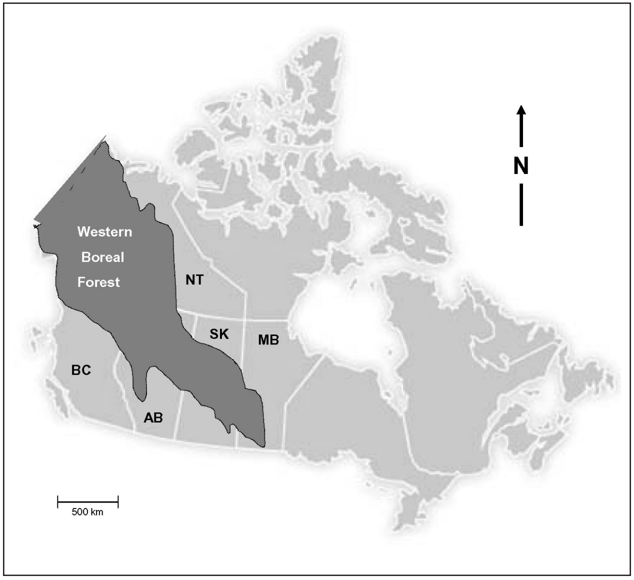

Fig. 1. Darker shading shows the distribution of the western boreal forest (WBF) encompassing Boreal Plain, Boreal Cordillera ecosystems.

the cost: income ratios to favour development. Along with this development have come impacts on wetlands and other non-commercial landscape features.

Boreal wetlands are a crucial landscape feature influencing biotic function and forest structure over most of the boreal because wetlands (including peatlands) in western Canada occupy up to 40% of the landscape by area (Vitt *et al.*1994). Boreal wetlands are of great concern because the carbon content of their peat deposits may represent a volume sufficient to significantly alter the earth's atmosphere if released into gaseous form. Should hydrologic patterns, thermal regimes or fire-frequency conditions change in ways that cause boreal peatlands to release significant portions of their 48 billion tons of peat-based carbon to the atmosphere, global greenhouse effects could be greatly increased (Environment Canada 2001). Policymakers will make decisions but when information is scant and uncertainties rampant, their decisions are less likely to be accurate, correct, or defensible. Given the rapid rates of landscape change in response to resource development, extractive industry development, and climate change and low levels of applied research in the boreal zone, it is apparent why great uncertainty remains.

Our first objective with this paper was to chronicle the extent and temporal distribution of scientific information on boreal wetlands as reported in the primary and secondary literature. Our second objective was to draw on the existing literature we located to characterize key wetland habitat values of the one million km^2 of Canada's WBF. Finally, we use the literature to provide an overview of human-caused changes facing WBF wetlands.

Western Boreal Forest Wetlands: State of Our Knowledge

The second sentence of this paper makes the seemingly presumptuous statement that the boreal zone's wetlands are "lightly studied and poorly known to science." We quantify this assertion, however, through an analysis of refereed and technical article citations. We subset citations by decade and show that boreal wetlands indeed are poorly represented in the scientific literature relative to other regions. Boreal wetlands have remained unfamiliar due to their distance from population centers and markets, and their expense and inconvenience to access.

Because we address the *state-of-knowledge* it is also important to explain that our indicator of public knowledge is a demonstration of *scientific understanding* of boreal wetlands through published works. A great deal of local knowledge has been accumulated and held by early settlers and the indigenous people in the boreal region as evidenced by their cultural adaptations and continued traditional use of the boreal forests and wetlands. Scientists, policy makers and planners have historically had little access or interest in this knowledge and until recently, little traditional ecological knowledge was available to anyone living outside First Nation rural areas.

We undertook a topical literature review by searching the digital records of over 8 million published books, journal articles, theses, and technical reports (excluding newspaper articles) available through 16 major indexing or abstracting services. A total of 16 550 articles met the initial search criteria. We inspected each listing and deleted all that were irrelevant or not in English. We tabulated the 4413 remaining articles by date published (Fig. 2).

Three increases in citation numbers appear in the record of decadal changes. A three-fold increase in citations between the 1940 and 1950s probably represents aircraft access; the 1960–1970s showed another three-fold increase associated with industrial exploration. Many studies in this period were associated with the 1974 start of construction on the $8 billion (1980 US dollars) Trans-Alaska Pipeline project to convey crude oil from Prudhoe Bay to Valdez, Alaska (Alesyska Pipeline Service Company 2001). Citation numbers doubled again between 1970 and 1980 likely represents computer access. For the entire global boreal zone during 1990–2000, there were only an average of 181 articles and reports per year published for all boreal wetland topics. We therefore conclude that the WBF is a lightly studied region.

Habitat Values of Boreal Wetlands

The boreal zone also constitutes one of the world's last great wilderness wildlife areas, providing nesting grounds for up to 40% of North America's waterfowl in some years (E. Butterworth, Ducks Unlimited, personal communication, 2004.), sustaining wintering habitat for hundreds of thousands of migratory and non-migratory caribou (*Rangifer tarandas*), and several key wetland-dependent threatened or endangered species such as Whooping cranes (*Grus americana*), Trumpeter Swans (*Olor buccinator*), one subspecies of the Peregrine Falcon (*Falco perigrinus anatum*) and wood bison (*Bison bison* var *athabascae*). Responses of endangered wetland species to changing boreal conditions may serve as sentinels of unanticipated ecological responses as the WBF appears to be undergoing widespread alterations to its form and function (e.g., fire regime, drought frequency, continuity of forest cover, hydrologic buffering of floods, insect invasions) (Schindler 1998a, Timoney and Lee 2001).

High species richness is often cited as a desirable state and as a rationale for imposing protection on threatened "hotspot" habitats, particularly in tropical forested areas. In contrast, the WBF is a "coldspot of biodiversity" (*sensu*

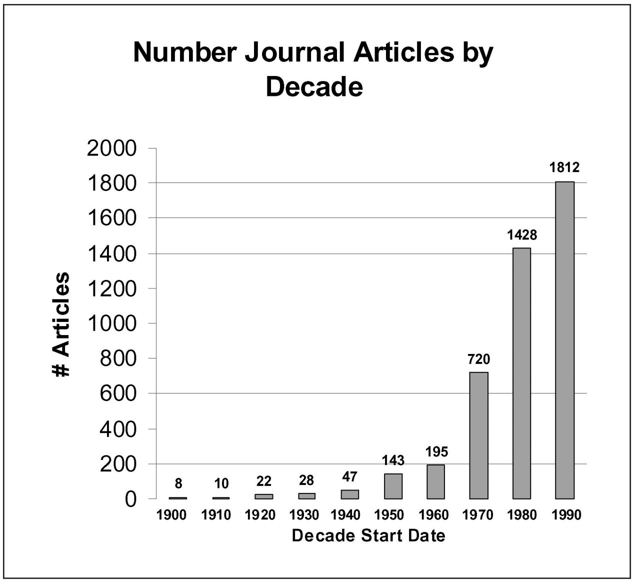

Fig. 2. Numbers of boreal articles found, sorted by decade (e.g., 1900 = 1900–1910).

Karieva and Marvier 2003). For example, tree species richness is low; the WBF contains only eight commercial species compared to over 50 in the southern United States, versus over 200 in Panama, Central America. However, the magnitude of the influence of boreal carbon and water supplies may overshadow biodiversity contributions in terms of global repercussions. In very pragmatic and economic terms, functions, values and ecosystem services provided to humans from the vast boreal ecosystem exert a large influence over millions of more southerly humans by altering climatic conditions, affecting atmospheric gas balances, capturing and delivering water for hydro-power, producing habitat for billions of migratory birds, partially regulating precipitation and storm patterns, producing forest products, and maintaining recreational opportunities for people. These goods and services are important, in part, because of the multi-million km^2 scale from which they emerge. Wetlands however, provide a disproportionate amount of production of these ecological goods and services. Because wetlands are dependent on a single major driver, hydrology, they may experience greater rates of change than terrestrial systems under climate change scenarios (Schindler 1998a).

Boreal wetlands have been considered stable, productive, and protected by virtue of their remoteness. Little management, other than some trapping and burning, has been undertaken on boreal wetlands because previously it has been neither necessary nor economically practical. Good cases for aboriginal influence on boreal wetlands are made by Schindler (1998b) with regard to trapping of beavers, and by Clark and Royall (1995) regarding the deliberate use of fire to affect patterns of post-fire vegetation.

The rate of industrial development may yet increase in the WBF. For example, in 2005 the Alberta government requested comment on plans to move from a project-by-project approval for the oil sands region in NE Alberta, to a Mineable Oil Sands Strategy that would allow the entire region to be considered a development zone, where "production has the potential to double within the next five to seven years, and triple by 2020" (Government of Alberta 2005). If this or similar rule changes occur, industrial development may proceed more efficiently but environmental and protectionist groups (Sierra Club 2006) feel the pace is reckless and results in too much environmental damage to ecosystems and other landscape users, particularly forestry interests (Schneider 2002). Even the mayor and council in Fort McMurray voted unanimously to try slow all future oil sands development (Canadian Press 2006).

Wetland Change – Major Factors in the Boreal

The formerly intact and inaccessible WBF now contains well-gravelled road access to most townships in the southern third of its land area comprising approximately 70 million ha of WBF in Alberta and Saskatchewan (Subcommittee on boreal forests 1999); hence, it is open for industrial development. The forest has changed from intact, continuous cover punctuated by fire scars of various successional stages and bog-fen complexes, to a well-roaded, resource-rich, commercially exploited region. Land clearing followed by wetland degradation or loss have been particularly rapid in the forest's southernmost region as a result of greater human activity (Wiken *et al.* 2003).

Management goals vary with the type of disturbance or alteration considered. The "big six" of anthropogenic ecosystem alteration in the WBF are (1) commercial forestry, (2) petroleum extraction (oil, gas, coal-bed methane), (3) mining (bitumen, coal, peat, ore, and diamonds), (4) agriculture, (5) climate change, though unclear what proportion is human-induced, and (6) major hydrologic construction projects. These are set in a shifting social context of differential access and rights to wetland areas. At stake are the overlapping, and sometimes conflicting interests of First Nations, agricultural producers, landowners, fishermen, hunters, forestry operators, oil and gas developers, environmentalists and multinational investors. Provincial laws are weak in addressing cumulative effects of development near wetlands and there is no comprehensive federal protection provided (Boyd 2003).

Forestry

Commercial forest harvesting and subsequent regeneration has increased dramatically in the WBF since 1990 with sales of wood products increasing from $20 to almost $50 billion (2002 CDN$) (Natural Resources Canada 2003). Governments have promoted industrial forestry development and have assisted with infrastructure such as roads, municipal services, hospitals, and law enforcement designed to further "open up" the North.

For thousands of years humans lived a subsistence lifestyle throughout the boreal zone. Road access was nonexistent and there were minimal land-use impacts. Interestingly, the rivers and fens of the region were the primary transport routes by boat in summer and dog sled in winter. During the 1900s commercial interests entered and facilitated white settlement, forest product harvesting and mineral extraction. Due to climate and poor access to markets, forestry was relegated to light removals of a few high-value species in a few areas, mostly large white spruce (*Picea glauca*) of good form and with easy access. As governments acted to develop the north in the 1960s, forest management agreements (large scale area leases; FMAs) were auctioned to large forest companies to facilitate proprietary harvesting of commercial timber. Such large multi-national investors could better provide the financial backing to fund the construction of mills, road and bridge networks, although some low-interest provincial loans were also extended and sometimes later written off or written down.

Provincial governments of British Columbia, Alberta, Saskatchewan, and Manitoba have granted exclusive harvesting rights through FMAs on most provincially owned woodlands in return for employment generation. Relatively low stumpage fees have been charged for timber harvesting partly due to low timber values and long distances to markets. FMAs were granted tenures of 10 to 20 years in Canada and up to 50 years in Alaska, usually with renewal options to allow industry to recoup their investments or trade their holdings. Shortly after the first wave of FMA assignments, technological improvements allowed extensive use of the heretofore low-value aspen for pulp production. Boreal harvesting, wood processing technology and improved forestry production methods were borrowed from Fennoscandia. Provincial assistance in low-interest loans and the installation of a more comprehensive road network facilitated access. As a result, the intensity of utilization has increased dramatically in the last 30 years.

The vast majority of the commercially valuable timberland in the central WBF has been allocated or scheduled for harvest over the next 40 years. Simultaneous access needs of agriculture and petroleum activities during the 1990–2005 period also increased road access. A dynamic and diffuse competition for resources and land-use exists between various stakeholder groups. In the boreal plain ecosystem, agriculture and forestry interests vie for land; preservationists and forest companies compete for use of forests in older age classes (those over 90 years old), and the petroleum and forestry industries collectively remove wood in the forms of rights of way, road beds, pipelines, seismic lines, well sites, oil sand mining and logging operations. Efficiency of harvest, land deletions and clearing for agriculture have increased to the point that many pulp and saw mills are planning for wood shortages and reductions in their provincially mandated annual allowable cut quotas in the next 30 years. To offset fibre shortfalls, the largest FMA holder in Alberta is currently leasing private land in previously cleared areas for intensive forestry (Neumann *et al.* 2006). Replacement of natural forests with plantations may affect wetlands because the establishment phase of plantations usually involves irrigation and groundwater withdrawals or runoff from excessive irrigation can impact wetlands. Many forestry plantations are established on previously cleared agricultural land, thereby mitigating previous disturbances.

Wetland trees (larch and black spruce) have rarely been harvested commercially in Alberta because of their lower value and the difficulties associated with reforesting these stands — regeneration to previous stand characteristics is a requirement in most provinces — but if these restrictions are relaxed in the future, dramatic changes may be expected for WBF wetland forests. Black spruce is commercially harvested in eastern Canada's boreal and for the WBF it may be seen as "the boreal wood of the future." There is an anticipated shortfall of white spruce and aspen resulting from current harvesting rates and fire removals of merchantable timber (Cumming and Armstrong 2004). The character, functions and habitat values of forested fens and bogs could change dramatically if their black spruce and larch trees are harvested and not replaced.

Petroleum extraction

The scale and timing of petroleum extraction are best shown by a few statistics. Alberta's northeastern bitumen-rich area has $66 billion in projects underway or scheduled for 2005–2007 (Alberta Economic Development reported in Edmonton Journal 6 April 2005 pg G1), which is approximately an order-of-magnitude investment increase over the preceding decade. Alberta is in the center of the WBF and supports the bulk of the region's oil and gas fields with over 80 named oilfields and 306 natural gas fields resulting in over 88 000 well sites in Alberta's portion of the boreal forest alone (ERCB 1994). Between 1986 and 1995 approximately one half million km of seismic lines were approved to be cleared (Alberta Environmental Protection 1998). Farr *et al.* (2004) calculated that by 2050 under moderate oil development scenarios there would be approximately 40 000 ha of seismic lines in the Alberta Pacific FMA alone. In 1998, more hectares of land were being cleared each year for oil and gas pipelines, seismic lines, roads and well sites than were cleared by forest harvesting in Alberta. Petroleum extraction disturbance is generally in the form of linear cut lines, road networks, pipeline rights-of-way and well pads that impact stream flows, groundwater, permafrost, predator access, human access, forest aesthetics, noise pollution and chemical residues from flaring or emitting petroleum by-products that may affect wildlife (Strosher 1996).

With regard to economics, politics, and landscape impacts, conventional oil and gas activities are dominant and dominating players. Though most of this activity is in the south-central portion of the WBF, it is moving northward rapidly and the cumulative impacts with forestry demonstrate the level of fragmentation that can occur in more remote regions where they contain extractable petroleum. Rough calculations from geographic information systems show most townships in the Alberta portion of the WBF contain between 0.5 and 3.5 km of linear features per km^2 (Unpublished 2000 data courtesy of S. Cumming and J. O'Neill). The disproportionately large body of literature on pipeline impacts that emerged from the Alaska Pipeline provides an excellent background for pipelines currently under construction in boreal zones of NWT and Alberta though few wetland researchers or industry consultants seem to access this rich and varied literature.

Coal bed methane is a new petroleum source found in parts of the WBF that may extend and expand the footprint of roads, seismic surveys, pipelines, and well pads. Early exploration by the petroleum industry is underway in a pilot phase, primarily in Alberta and Saskatchewan. Coal bed methane extraction requires the de-watering of coal seams to release methane gas for capture. These gasses are trapped, compressed, and piped to users. The dewatering of coal seams has raised many concerns for wetlands and groundwater quality (Nikiforuk 2005). The above-ground disposal of waters rich in selenium, chlorides and petroleum generates pollution (Kuipers *et al.* 2004); therefore, the preferred option is to re-inject produced waters into deep geologic formations for safer storage.

Mining

Mining is distinguished from conventional petroleum extraction mainly by the depth of the extracted material but also by the visible presence of tailings or soil disturbance. Extraction of conventional liquid or gaseous petroleum produces relatively few visible residues other than contaminated water and some gas emissions; however, poorly researched health effects have been hinted at (Kilburn and Warshaw 1995, Kilburn 1997, Milby 1999). In contrast, surface mines produce large volumes of tailings; subsurface oil sands mining may deplete local hydrology with groundwater withdrawals to produce vast volumes of injected steam or develop hundreds of square kilometres of contaminated tailings ponds. Diamond mines usually focus on kimberlite "pipes" often surrounded by water that must be displaced. In most industries there are problems with noise, light, water demands and thermal pollution as well.

The mining of oil sands is unique to Alberta. Northeastern Alberta contains an estimated 1.7 trillion barrels of crude bitumen (extracted fossil fuel), 315 billion recoverable, in vast oil sand deposits (AEUB 2005). Surface mining for bitumen has been under way since the 1960s, with expansion in the Fort McMurray, Alberta area projected to encompass a total of 149 000 km^2, roughly 23% of the province of Alberta (AEUB 2005, Woynillowicz *et al.* 2005). Although the impacts on the mining area are dramatic, the total area affected, though growing, is still less than forestry or agriculture. Site impacts are localized and some (yet undemonstrated beyond research plots) wetland remediation or mitigation appears possible. Return to original peat-forming wetland types is not anticipated in the near term because of the centuries required for such peat-accumulations to reform. Reclamation of land to a productive status, called "Equivalent land capability" (Government of Alberta 2004) is provincially required for most landscape impacts. Concerns remain about effects to groundwater, downstream effects in river systems and duration of impacts (Alberta Chamber of Resources 2004).

Peat extraction directly affects wetlands. Approximately 150 000 T of peat worth approximately $28 million is shipped annually from the WBF, primarily from five operations in Alberta and one in Saskatchewan (Environment Canada 2001). Only a small proportion of the peat-producing regions are slated for peat removal because of the quality needs of peat for commercial use. Though peat extraction is called "peat harvesting," until improved peatland reclamation techniques are found, this removal cannot be considered renewable in sub-century time frames. Annual peatland replacement rates on extraction sites are currently less than 0.1% of the removal rate at present. The absolute area of peat harvesting remains relatively small however.

Agriculture

Currently, agriculture is limited to the southern fringe of the Canadian boreal zone, called the aspen parkland, the Peace River Valley in northwestern Alberta/northeastern British Columbia and scattered isolated communities. The conversion rates of forest to agriculture have been significant, however, and may increase with increasing population and a climatic warming trend. Approximately 200 km^2 per year of aspen parklands were converted from forest cover to agriculture between 1949 and 1993, mostly for small grain cropping and pasture (McCartney 1993). This conversion often changes the wetland conditions dramatically and farmers usually drain, fill and convert wetlands to croplands where feasible. Provincially-owned forest lands located on agricultural soils continue to be sold to farmers to convert from woodlands to agricultural fields. Currently 32% of Alberta is classified as farmland (Statistics Canada 1997). Agriculture has been considered the highest and best use of arable rural land by provincial planners.

Proposals by Riewe *et al.* (1983) suggested that intensive gardens, greenhouses, and commercial production of wild meats could expand significantly throughout the northern boreal zone if markets were developed. Because of the extensive wetlands in the region, a great deal of drainage would be required, which in turn would affect wildlife productivity and increase emissions of the undesirable CO_2 greenhouse gas, thereby increasing climatic change rates. The incidence of a cow diagnosed with bovine spongiform encephalopathy (BSE or mad cow disease) in Alberta during 2003 and tracing of a second BSE cow originating in Alberta and a two-year closure of the US border to some types of beef sales has slowed progress toward livestock intensification in western Canada in the short term. Speculative holding of cattle in hopes of re-establishing an export market with the United States, the primary trading partner, has caused localized habitat degradation as cattle numbers and age both increase.

Climate change

The character of the boreal ecozone is partly determined by the long cold winters where November through March median temperatures are below freezing (Strong 1992) and moist short summers (397 mm total annual precipitation; June and July are peak months). Enrichment of atmospheric carbon dioxide is predicted and expected to result in southern Canada experiencing higher temperatures (Mooney and Arthur 1990, Johnson and Poiani 1991). Mean annual temperatures in southern Canada may increase by as much as 4.20°C (Boer *et al.* 1992). This is expected to lead to drier conditions, more frequent and more severe droughts (Lenihan and Neilson 1995), reduced river and stream flows and higher rates of wildfire (Suffling 1995).

The tree cover composition of the boreal zone transitions from mostly hardwood in the south to almost predominantly conifers in the north thereafter, grading into treeless tundra as one continues northward. Some models of climatic change forecast these zones to slowly shift northward due to warming (Hogg and Hurdle 1995). Under one warming scenario, Mills (1994) predicted that up to 16 million ha of Canadian land would become suitable for crop production, thereby linking climate change effects to those from agriculture.

Plant growth involves CO_2 removal from the atmosphere for cellulose production and peat-based soils of the boreal ecosystems accumulate and hold atmospheric carbon in the leaves, stems, and roots of plants. Whereas upland plants die, decompose and return their carbon to the atmosphere as CO_2, plants that grow and die in saturated wetland soils do not decompose as rapidly because flooded soils are relatively free of the oxygen necessary for aerobic decomposition and nutrient cycling. Thus, on saturated soils supporting dense wetland plant growth, plants usually capture more carbon in their yearly cycle than is released to the atmosphere from the decaying organic matter from the previous generations of plants. Consequently, peatlands and wetlands are often considered a *de facto* sink for atmospheric carbon so long as they remain wet (Intergovernmental Panel on Climate Change 2001). Drainage and cultivation of peatlands for cropping allows soils to warm more rapidly and permits oxygen to enter the soil thereby initiating rapid oxidation (decomposition) of the stored organic material. Under aerobic decomposition, CO_2 and N_2O emissions increase while CH_4 (methane, another greenhouse gas) emissions decrease (Kasimir-Klemedtsson *et al.* 1997). Drainage of boreal wetlands is expected to yield an overall increase in the earth's atmospheric warming.

Hydrologic developments

Alteration of energy and material flows of existing hydrologic systems has caused dramatic and far-reaching wetland change. Unlike Canada's eastern boreal forests, there are few large hydro-power developments in the WBF, yet still, over 900 000 ha have been flooded for hydroelectric reservoirs in the boreal and an additional one million more ha have been proposed (Schindler 1998a). One development, the W.C. Bennet Dam on the Peace River in eastern British Columbia, has been criticized for causing drying effects on the largest inland wetland delta in North America, the Peace Athabasca Delta (Peters and Prowse 2001, Roy *et al.* 2001; but also see Timoney and Lee's (2001) pointed contrary view). Most interruptions of riparian zones in the WBF are at a much smaller scale, primarily by roads and beaver dams. These two may differ in their permanence and their impacts on wetlands (Martell 2004). Relatively small dams or diversions on rivers sometimes produce a cascade of wetland influences downstream that is seemingly disproportionate to the relatively small changes at the dam site. Some dam effects on species distributions are obvious where salmon runs are blocked, but more common are the disconnection between habitat and species due to improperly placed culverts on streams that can restrict fish from accessing their spawning areas in headwaters. Hundreds of km of former fisheries habitat may be lost due to the emplacement of a single faulty culvert. Though the actual number is not known, central Alberta alone has tens of thousands of such faulty culverts.

Social issues involving boreal wetlands

The sociological implications of broad ecosystem changes have been underplayed despite substantial study of the problems (Bennett 1982, George and Preston 1987, Berkes and Fast 1996). There are more than 100 000 aboriginal and Metis people living in Canada's boreal zone (McLaren 1990), usually in small villages (< 1000 people). Many of these people depend at least seasonally on environmental goods and services from wetlands for subsistence (Beckley and Hirsch 1997) and as transportation corridors. Rural First Nations and Métis people use wetlands for medicinal, spiritual, and recreational activities (Treseder *et al.* 1998, Davis 2005).

Traditional and modern use of the WBF by Native peoples is widespread. In the Mackenzie Valley, the Gwich'in's continued use of forest, river and wetland resources in a time-honoured way is affected by the development of major petroleum pipelines proposed for the area. Access roads have facilitated efficient trapping and hunting but their required culverts may cause many disruptions to water flow and the movement of aquatic species. In the two small WBF communities of Fort Liard and Nahanni Butte, NWT that Beckley and Hirsch (1997) studied, important meat and fur income were derived from wetland species moose (*Alces alces*), woodland caribou (*Rangifer tarandus*), beaver (*Castor canadensis*), mink (*Mustela vison*) and muskrat (*Ondatra zibethicus*) with 44% and 61% of their respective populations engaging in trapping and the majority of the community was partially reliant on wild meats. Berkes *et al.* (1994) found from a survey (N = 235) in Moose Factory, Ontario, that the community's replacement value of Canada Geese (*Branta canadensis*) and Lesser Snow Geese (*Chen caerulescens*) was $296 222, while the value of furbearers, e.g., beaver and marten (*Martes americana*), was $44 256. Scott (1987) and Davis (2005) found that the rituals of hunting beaver and waterfowl, sharing the meat, and learning ecological knowledge in the process of such rituals, continue to be central to the identity of Cree First Nations.

Many WBF native communities are being affected by commercial investment because they are located along the route of planned major petroleum pipeline rights of way, and near diamond mining, and petroleum exploration regions. Observance and respect for Treaty and Aboriginal rights, and social justice issues such as benefits sharing and authentic two-way sharing of information and decision-making between development proponents and local leaders remains controversial in many boreal located Aboriginal areas (Natcher 2001, Treseder and Krogman 2002). Aboriginal and Métis communities vary in their support for increased industrial activities. Communities often have disputes within them over proposed developments. While there may be variation in conflict within communities, and between communities and proponents of development, consistent across socio-environmental studies on indigenous communities is the reported desire to maintain hunting, fishing and trapping lifestyles that are central to identity and resilience in Native communities (Berkes 1999, Natcher and Hickey 2002, Davis 2005, Schramm 2005). Their interests and uses of the northern forests and wildlife will be difficult to reconcile with production of non-renewable resources. Hessing and Howlett (1997) argue that Aboriginal and Métis people will continue to have strengthened roles in resource and environmental decision-making for several reasons: 1) their claim to prior ownership and use of resources; 2) their expertise in aspects of resource use, especially related to hunting, trapping and fishing; and 3) the impacts of resource policy on their lives.

Wetlands are important for non-Native rural people as well, for hunters, bird-watchers, and those who have a sense of place from their intimate knowledge of the birds and wildlife that frequent wetlands (Aleksiuk and Nelson 2003, Whitson 2003). Many rural residents choose to live "in the country" in part because they have access to wetlands for wild game, and other animals, their aesthetic appeal, and water quality benefits among others (Oleweiler 2004). The loss of wetlands near rural people thus not only affects ecological functions of the area, but potentially cultural resources and sources of rural identity (Beatley 1997).

Finally, a central challenge for WBF protection lies in implementing existing policies designed to protect wetlands. A myriad of statutes, regulations, policy directives and common law rules effect what activities may occur in and around wetlands (Kwasniak 2001). The federal government has responsibility for 29% of Canada's wetlands, specifically those located in federal lands and waters, particularly in the northern territories (Cox 1993). The jurisdiction over the remaining wetlands is divided between provincial governments and private landowners (Wiken *et al.* 2003). Wiken *et al.* (2003) argue that, "The governance and care of wetlands has suffered from a lack of political will, basic resources and implementation, and forums for cross-border/agency management discussions and actions, scientific and technical knowledge, and perhaps a sense of urgency." More directly, Boyd (2003) and Kennet (1999) contend that the central difficulty is the protection of (boreal) wetlands without an overall policy framework for land-use planning, i.e., an overall vision, while cumulative effects of land continue to diminish remaining wetlands.

Information gaps

All of the important land cover alterations and climatic change have profound hydrologic impacts that directly affect water surfaces and consequently, wildlife habitat and human valuation. Understanding hydrologic alteration and conducting wetland change analyses are costly, labour-intensive and are rarely conducted for basic scientific understanding. However, the ability to forecast wetland changes is one of the largest gaps in our attempts to predict availability of habitat, alteration of ecological goods and services, and estimation of natural capital (*sensu* Oleweiler 2004). Climatic warming is forecasted to cause some drying (Manabe *et al.* 1992), logging may affect sedimentation, and wetland infilling (Joensuu 1997 in Trettin 1997), yet these responses are all diffuse (in scope and responsibility) and difficult to quantify.

The relative value of wetlands, by type, is not well understood. It is generally believed that bogs and poor fens are crucial repositories of carbon, very marginal habitat for most waterfowl species yet are critical for certain passerines. Rich fens, marshes, beaver ponds and lakes are not easily ranked in terms of habitat quality for wildlife either. Habitat quality indicators for waterbirds include: water permanence, nutrient levels, shoreline vegetation, size, drainage basin characteristics and landscape proximity to other habitats. Careful study of multi-area, multi-year projects is needed to determine the relative attractiveness and contribution of various wetland types.

Even less social science research is available on a) institutional predictors in wetland policy effectiveness; and b) the social and economic values of wetlands to rural native and non-native residents. Social science research can contribute to policy makers understanding of the ways in which institutions and local decision-makers can contribute to greater wetlands protection and management (Farr *et al.* 2004).

Creative paths to wetland retention

Interpreting "wetland change" in terms of landscape, economic repercussions, ecological functioning, and social equitability is a staggering task of questionable interpretability. However, these general and prudent principles may help inform policies:

(a) *retention* of existing wetlands is generally the easiest approach. Retention is part of the goal of the forestry operating ground rules that provide no-harvest zones adjacent to water bodies;

(b) *restoration* of degraded wetlands. Simple restoration may involve reconnecting hydrologic flows or proper culvert installation, or demobilization of roads constructed adjacent to wetlands (Martell *et al.* 2006);

(c) *intervention* and policy formulation may lead to effective wetland conservation that is complimentary with development in the WBF, particularly if concepts of natural capital are used to promote conservation easements, development buffers, and best management practices for extractive industries. We should continue to question how governments choose net-down or assignment of unharvested areas to maximize the conservation value obtained for stakeholders. For example, forestry operators interested in harvesting within streamside buffer areas may be able to provide an ecologically sound rationale for relocating equal areas of retention to headwaters that currently encompass unprotected small headwater streams. This results in no change in harvested area yet better representation of preserved habitat types. Currently, the headwaters of virtually all boreal plain regions that contain merchantable timber are slated for harvest. Publicly funded incentives for greenhouse gas reductions or sequestration may be used to attract would-be consumers of habitat to do business in a different way. The creation of "passive carbon farms" may be used to offset emissions under some interpretations of the Kyoto Protocols and could provide lucrative and ecologically beneficial business opportunities.

(d) *involvement* with local people; include Aboriginal, Metis and non-Aboriginal communities in land use planning to protect those wetlands most central to rural use, identity and potential for other values. Under their Constitutional rights, Aboriginal and Métis people should be more genuinely engaged in land use decision making where their traditional uses of surrounding land may be affected (Ross and Smith 2002, Farr *et al.* 2004). Where downstream or downwind people or landscapes are to be affected, fairness dictates that the beneficiaries provide compensation or mitigation for absentee producer's profit-based activities.

(e) *education* through rural schools, higher and continuing educational institutions on wetland functions and benefits. For example, this may include education that demonstrates to agricultural producers the economic benefits of wetlands within the landscape, including groundwater recharge, cattle watering and forage sites, hay production zones, natural fire breaks, and sediment catchments.

We recognize that it is difficult to quantify economic values associated with fish and wildlife in the WBF; therefore, they receive little consideration in policy formulation. If we are to make the retention of high quality habitat economically viable to land stewards (including FMA holders and agricultural producers) the voluntary production of these habitats will likely occur. Agricultural producers in western Canada are well accustomed to federal and provincial payments with stipulations attached. Such programs could also be used to empower farmers to "ranch" public goods and services in the form of clean water, wildlife, aesthetics, and recreation potential. *Alternative land use services* is an agricultural concept that ties payments to farmers to their ability to use their land to provide ecological goods and services to the public. These programs may be effectively brokered through existing agricultural advisory institutions or non-governmental organizations with wetland expertise such as Ducks Unlimited or the Delta Waterfowl Foundation.

As future development unfolds and progresses northward, it is important to understand and manage for the impacts of human-caused change to wetland extent, connectivity, range of variation, and extreme events. In lieu of direct wetland management, as is common in the prairie pothole regions further south, the tools most useful in the boreal zone mirror those proposed by Aldo Leopold (1933) when he said "Axe, cow, match and plow"; grazing, logging, fire suppression should be planned adaptively and responsively to eliminate unprecedented combinations of impacts in boreal wetland systems. While natural and social scientists have increasingly placed attention on boreal wetlands, the interaction between natural processes, human activities, policies designed to reduce wetland impacts, and identification of local and national social and ecological wetland values is in its infancy. Perhaps it is in these interdisciplinary studies that the most policy-relevant research will be provided.

We maintain that there is indeed a lack of understanding about wetlands in Canada's boreal zone and that strong systematic forces of development are altering wetlands faster than either science-based management or culture-based human wishes can formulate responses. We simultaneously encourage greater study of boreal wetlands and greater action using what is already known to maintain the social and ecological benefits of these valuable habitats.

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