The Carbon the World Forgot

Conserving the Capacity of Canada's Boreal Forest Region to Mitigate and Adapt to Climate Change

CANADIAN BOREAL INITIATIVE

BOREAL SONGBIRD INITIATIVE
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About the Canadian Boreal Initiative
The Canadian Boreal Initiative (CBI) is a national convener for conservation in Canada's Boreal Forest. We work with conservation organizations, First Nations, industry and other interested parties—including members of the Boreal Leadership Council—to link science, policy and conservation solutions across Canada's Boreal Forest. For more information visit: www.borealcanada.ca

About the Boreal Songbird Initiative
The Boreal Songbird Initiative (BSI) is a non-profit organization dedicated to raising awareness, through science, education, and outreach, of the importance of the Canadian Boreal Forest to North America's birds, other wildlife, and the global environment. For more information visit: www.borealbirds.org

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Foreword

Industrial emissions of greenhouse gases are moving the world into an uncertain future where climate change will dominate environmental, political, and economic issues. Solutions to slow negative impacts of rapid and large changes are still possible, if we act swiftly and strategically on a global scale. First and foremost is, of course, a drastic reduction in industrial emissions of carbon from the burning of fossil fuels. Without real and substantial cuts in the amount of carbon we are putting into the atmosphere, the ecological foundations upon which humans and all life depends will be degraded and changed in more ways than scientists or the public have been able to predict or imagine. The northern parts of the planet, especially including the Boreal and Arctic regions, are already experiencing some of the most dramatic impacts and will continue to be among the hardest hit on the globe as temperature increases and other climatic changes will be greater there than virtually anywhere else on earth.

A second major set of solutions has received limited attention by the global community—that of reducing the loss of carbon from industrial land-use. In particular, the accelerating conversion of natural habitats for agriculture, forestry, mining, oil and gas extraction, hydropower and other industrial purposes must be slowed. Globally, land-use change has accounted for nearly 20% of annual greenhouse gas emissions. Because of these emissions, there has been a recent push to find financial incentives and policy instruments that will encourage developing tropical nations to slow deforestation and retain natural forests through environmental service payment schemes and increased protection efforts. This initiative is critical to helping to slow climate change impacts and to protect the incredible species richness and indigenous cultures of these tropical regions.

But another part of the land-use change solution has been largely overlooked in the climate change policy debate. That missing piece—the massive carbon stores of the Boreal Forest—is precisely what this report, "The Carbon the World Forgot", addresses. The Boreal Forest globally stores more carbon than any other region of the globe, perhaps two or three times as much carbon as is stored in the tropics. The Boreal Forest region is also home to some of the world's last intact terrestrial and aquatic ecosystems, abundant populations of large mammals and birds and to hundreds of indigenous communities. These facts make it imperative that the world's policy makers and public now make a concerted effort to ensure that both the Boreal Forest and its vast stores of carbon remain intact. To achieve this will require both drastic cuts in industrial emissions and importantly, a vast increase in the area designated off limits to the kinds of industrial disturbances that increase the likelihood that more carbon will be released into the atmosphere.

We commend the authors of this report for their scholarship and insight in summarizing the most relevant facts related to the importance of Canada's Boreal Forest region in the climate change policy discussion. We hope that you will read the facts, study the recommendations, and do your part to see that those recommendations are implemented.

International Boreal Conservation Science Panel
Pascal Badiou, John Jacobs, Jeremy Kerr, Micheline Manseau, Gordon Orions, Stuart Pimm, Peter Raven, Terry Root, Nigel Roulet, James Schaefer, David Schindler, Jim Strittholt, Nancy Turner, Andrew Weaver

Executive Summary

Although the Kyoto Protocol represented a giant step forward in climate change policy, it was deficient with respect to how it addressed the continuing release of biotic (non-industrial) carbon—estimated by most experts as contributing nearly 20 percent of global man-made carbon emissions. The protocol fails to fully address carbon release caused by the disturbance of ecosystems by humans. Efforts are underway to address this shortcoming, but the current effort focuses almost exclusively on the fate of tropical forest tracts in developing nations.

Boreal forest in Labrador GARTH LENZ

Boreal Forests: The World's Largest Terrestrial Carbon Bank

Boreal forests circle the globe at subarctic latitudes, cover more than 10 percent of the world's land area, and harbor half of the world's remaining intact wilderness tracts. These vast undeveloped areas provide a stronghold for the world's largest and healthiest populations of northern mammals like caribou, bear, wolves and moose, as well as migratory songbirds and waterfowl. Perhaps even more importantly, boreal forest regions store more carbon than any other terrestrial ecosystem, almost twice as much per acre as tropical forests. Yet, for reasons that are unclear, boreal forests seem to be the carbon the world forgot.

As with tropical and temperate forests, boreal forests sequester and store carbon in surface vegetation, but in addition have accumulated and conserved annual increments of carbon for millennia in associated soils, permafrost deposits, wetlands and peatlands. The carbon stored below ground in the boreal forest dwarfs the surface carbon in the trees, a fact that has not always been fully appreciated. Recent studies reviewed in this report find that previous global carbon accounting vastly underestimated the amount and depth of organic carbon stored below the surface of boreal forests.

When boreal forest vegetation or soils are disturbed, carbon is released, climate change is accelerated, and biotic carbon storage is diminished. Keeping boreal forest carbon reservoirs intact forestalls and limits initiation of feedback loops that could greatly accelerate the pace of climate change.

Boreal conservation contributes not only to reducing the rate of climate change (i.e., mitigation) but also to minimizing its adverse effects (i.e., adaptation). The unprecedented rate of climate change expected in northern regions has profound implications. Anticipated impacts are diverse and include rapid northward shifting of habitat, increased fire and insect outbreaks, altered phenology, and degraded aquatic systems. Fortunately, Canada's Boreal Forest is better suited than most to withstand such changes due to its intactness. Intact ecosystems will help buffer species from a changing climate, while also permitting species migrations needed to track shifting habitat. Canada's Boreal Forest is already a haven for species that have been extirpated from more southern areas, and this role will only increase in the future as species are pushed north by climate change.

The global boreal forest presents the world's best opportunity to apply conservation as a climate change strategy.

Policies that match the scientific understanding of the region's importance for mitigation and adaptation are urgently needed, especially in a new climate change agreement or future international frameworks.

New Policies Needed to Protect Boreal Forests

Two simple changes to the protocol that would have far-reaching beneficial impacts are inclusion of all below-ground carbon sources (including degradation of peatlands) and mandatory accounting of all carbon emissions from forest management. These changes alone would motivate large improvements in the management of biotic carbon. In addition, requiring that biotic carbon projects have a positive or neutral effect on biodiversity and ecosystem services would help maintain the capacity of ecosystems to adapt to climate change.

The global boreal forest presents the world's best opportunity to apply conservation as a climate change strategy, both to avoid release of the region's vast carbon stores and thereby further accelerate climate change, as well as to maintain the ecological integrity necessary to buffer the impacts of climate change on the flora and fauna of the region. Moreover, the wealthy, developed world countries that control large areas of the boreal forest—Canada, the United States and the Scandinavian nations-- have strong rule of law and fewer competing needs, two considerations that bolster the odds of successful environmental protection efforts. As the world works toward a new climate change agreement, and focuses on controlling emissions from deforestation and land-use changes in the tropics, it is essential that the potential contributions of boreal forests be more fully considered.

Figure 1

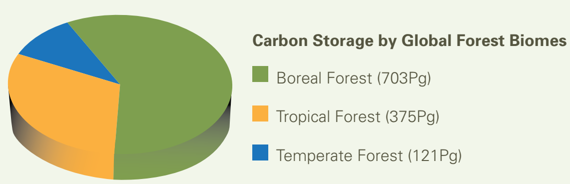
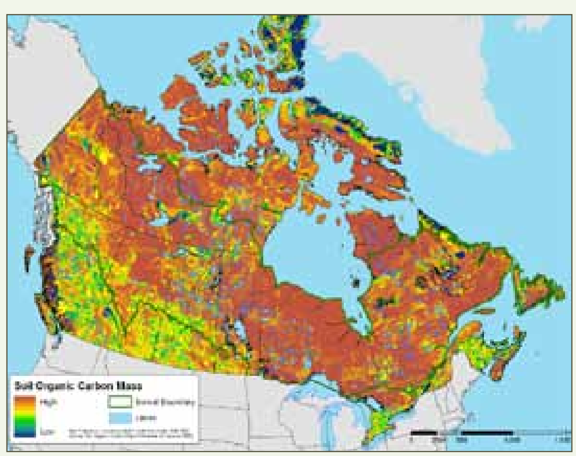


Figure 2



See pages 7 and 9 for full-size graphics

Globally only a small fraction of the boreal forest has been protected in a natural state. Meanwhile, the deleterious impacts of climate change and burgeoning industrial development in the far north threaten rapid loss of the boreal forest's ecological integrity. Common international goals for ecosystem protection, calling for a tenth of the wilderness to be reserved from development, fail to respond to the challenges or capitalize on opportunities in the boreal forest. New approaches and ideas, more extensive in their ambition and reach, will be required.

Canada Leads the World in Boreal Forest Conservation

Canada is leading the way. The Canadian Boreal Forest Conservation Framework (Boreal Framework) presents a vision for protecting over one billion acres (4 million km^2.) of carbon rich, largely intact, contiguous tracts across Canada's North. This proposal, endorsed by over 1500 scientists worldwide, strikes a balance between strict protection and tightly regulated sustainable development. It is also supported by dozens of aboriginal First Nations, resource development companies, financial institutions, and environmental groups.

Following the basic approach of the Boreal Framework, the Canadian federal government and provincial governments have protected over 125 million acres of the Canadian Boreal Forest for new parks and wildlife refuges since 2001, an unprecedented rate of progress in preserving unspoiled landscapes. Over the last two years, the provinces of Ontario and Quebec have gone further, commencing conservation planning on almost 400 million acres (1.6 million km^2.), with the intention of setting aside at least half that area as off-limits to development, while applying strict safeguards regulating development on the remainder.

Protecting large portions of the world's remaining boreal forests, following the leadership of Canada, can make a major contribution to the amelioration of climate change from mankind's activities. This conservation strategy pays multiple benefits, safeguarding existing carbon stocks, providing ample refuge to mitigate climate-induced stress on ecosystems, and securing some of the world's most important remaining natural areas. It is easy to understand how Canada's recent boreal conservation policy decisions have won such broad-based support. What is more difficult to understand is why those polices have not been studied and emulated by other nations of the world. Perhaps the carbon the world forgot will finally be remembered.

Core Messages

1. The global boreal region is the world's largest terrestrial carbon storehouse, containing almost twice as much carbon per unit area as tropical forests. To avoid accelerating climate change, it is important to avoid disturbing the boreal forest's vast carbon reservoirs.

2. Climate change has severe implications for boreal biodiversity and ecosystem services. However, Canada's Boreal Forest region is better suited than most to withstand climate impacts due to its high level of intactness.

3. Protection of intact forest ecosystems and sustainable forest management will not only maintain globally significant carbon stores, but also maintain the capacity of the boreal region to resist and adapt to climate change. This approach is embodied in the Boreal Forest Conservation Framework, which calls for the establishment of a network of large interconnected protected areas covering at least half of the Canadian Boreal Forest and the use of leading-edge sustainable development practices in the remaining areas.

4. It is essential that international policies to address climate change are consistent with scientific understanding of the boreal region's global significance. Accounting for all anthropogenic impacts to forest and peatland carbon should be mandatory, and biotic carbon projects should be required to have a positive or neutral effect on biodiversity and ecosystem services.

Introduction

Introduction

For at least two decades, scientists and conservationists have recognized the importance of tropical forests for carbon sequestration and biodiversity protection. This focus has thankfully led to the adoption of policy mechanisms that have directed monies from carbon trading revenues and other sources towards protection of tropical forests. Outcomes from international policy actions have also included recent increases in the amount of protected area within the largest, intact tropical forest block, the Amazon forest, as compared with any other region globally (Jenkins and Joppa 2009).

In contrast, boreal forest regions have been largely overlooked as a global conservation priority. This oversight continues despite their massive carbon stores that are important for climate change mitigation and their high ecological intactness which sustains a host of globally significant biodiversity and cultural values (Bradshaw et al. 2009). Outdated and incorrect information that downplays the volume of carbon stocks in boreal forest regions is still widely cited and used by policy makers, media, and some scientists. This has contributed to a serious underrepresentation of the critical global importance of boreal carbon stocks in ongoing carbon management policy initiatives.

Box 1. Definition of Key Terms

Mitigation: activities intended to delay or lessen human-induced climate change

Adaptation: activities intended to minimize the adverse effects of climate change on humans and the natural environment.

Boreal forests and peatlands worldwide store more terrestrial carbon than any other single biome on earth. The high carbon density of the boreal forest region has resulted from the slow accumulation of carbon over millennia. Whereas carbon flux in tropical forests is balanced between plant growth and decay, the cool temperatures of boreal ecosystems lead to carbon accumulation by preventing the breakdown of dead biomass. Keeping boreal carbon reservoirs in place is important if we wish to avoid accelerating the pace of climate change. The boreal forest region's intactness also provides essential buffering against rapid climate-induced changes that are already affecting northern ecosystems, impacts made worse by industrial land uses that are increasing in rate and intensity across the boreal region. Conservation of boreal ecosystems helps mitigate climate change by protecting large carbon stores. Conservation is also key to adaptation, as conservation helps maintain the resilience of the region to effects of rapid climate change. Maintaining intact habitat will allow the necessary range shifts of plants and animals without the additional stress of habitat loss and fragmentation.

Action is needed to conserve a region that contains 'the carbon the world forgot.' As the world develops climate change agreements, it is essential that policies are adopted that are consistent with the globally significant contribution of the boreal region to climate change mitigation and adaptation. To help inform such policy development, this report describes the significance of Canada's Boreal Forest region and identifies strategies suited to conserve both its carbon and its resilience to climate change.

Background photo: GARTH LENZ

Protecting the Carbon Bank

Canada's Boreal Forest Region and Mitigation: Protecting the Carbon Bank

Globally, the boreal biome is the world's largest and most important forest carbon storehouse (Figure 1), holding almost twice as much carbon per unit area as tropical forests (IPCC 2000). Canada's Boreal Forest stores about 71.4 billion tonnes of carbon in forest ecosystems[1] and 136.7 billion tonnes in peatland ecosystems.[2] In addition to these terrestrial carbon stores, the numerous lakes located in Canada's Boreal Forest region account for a portion of the approximately 0.6 billion tonnes of carbon that are buried globally each year in inland water sediments, a carbon store that has been accumulating for thousands of years (Battin et al. 2009). The 208.1 billion tonnes of carbon estimated to be stored by forest and peatland ecosystems within Canada's Boreal Forest region is equivalent to 26 years worth of the world's carbon emissions from fossil fuel burning, as measured in 2006.[3]

Ecosystems store carbon as plants sequester carbon dioxide during photosynthesis, contributing to a cooling of the climate. Although forests also contribute to warming by absorbing solar radiation (i.e., due to the low reflectance of forest cover), the overall effect is cooling due to the magnitude of carbon sequestration and, to a lesser extent, evaporative cooling. Recent empirical research using high resolution satellite data demonstrates that the net climate effect of afforestation (converting non-forested land into forest) in the boreal forest region would be cooling as a result of carbon sequestration, contrary to previous, coarse resolution modeling studies that had suggested a warming effect (Montenegro et al., in press). Canada's vast forests, the majority of which are located within the boreal region, sequestered an average of 205 million tonnes of carbon per year between 1920 and 1989 (Kurz and Apps 1999), which approximates the 204 million tonnes of total annual Canadian greenhouse gas emissions (Environment Canada n.d.). Forests continue to sequester carbon as they age, so older forests store more carbon (Luyssaert et al. 2008). The implication is that natural

Oscar Lake in the Northwest Territories

D. LANGHORST, DUCKS UNLIMITED CANADA

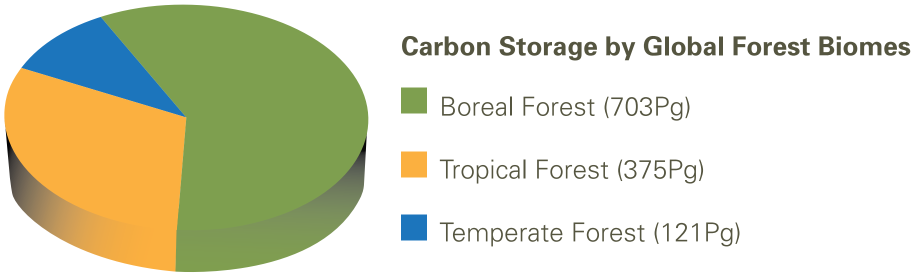


Figure 1: A comparison of carbon storage by global boreal, tropical and temperate forests. One Pg (petagram) is equivalent to one billion tonnes.

Source: Kasischke 2000

1 Kurz and Apps (1999) estimate that Canada's forests store 85.8 billion tonnes of carbon. Of this, 71.4 billion tonnes are located in the following ecoclimatic zones that approximate Canada's boreal region: boreal west, boreal east, subarctic, cordilleran and subarctic cordilleran.
2 Tarnocai (2006) estimates that Canada's peatland ecosystems store 147 billion tonnes of carbon of which approximately 93% is located in the boreal region.
3 In 2006, global CO_2 emissions from consumption of fossil fuels were 29 billion tonnes (Energy Information Administration 2009), which is equivalent to 7.9 billion tonnes of carbon. Therefore, approximate Canadian boreal carbon storage (208.1 billion tonnes of carbon) is equal to 26 years of the world's CO_2 emissions from the consumption of fossil fuels.

Canadian wetlands store large amounts of carbon GARTH LENZ

forests store more carbon than forests managed for timber production due to their older average age (Kurz et al. 1998). Although sequestration has been offset in recent years by emissions from increased fire and insect disturbance (Kurz and Apps 1999), carbon storage by boreal vegetation in Canada remains immense (about 10 billion tonnes[4]).

Even more important to carbon storage are boreal soils and peats (Figure 2). The region's cool temperatures suppress decomposition rates, resulting in deep organic soils and vast accumulations of peat that contain large quantities of carbon. Approximately 85% of boreal forest carbon (Kurz and Apps 1999) and 98.5% of peatland carbon (Gorham 1991) is stored in soils as opposed to vegetation. Globally, peatlands store more carbon per area than any other terrestrial ecosystem, storing the equivalent of half of the carbon in the atmosphere (Dise 2009). The tendency of boreal ecosystems to accumulate carbon is most apparent in peatlands where organic matter (mainly from *Sphagnum* mosses) has built up as peat over thousands of years. Canada's peatlands store an estimated 147 billion tonnes of carbon (Tarnocai 2006), and the cooling effect of this carbon accumulation exceeds the warming effect of methane release from peatlands (Frolking and Roulet 2007). Also important are perennially frozen soils referred to as permafrost. Like peat, permafrost soils have been accumulating carbon for thousands of years and can be very deep. The typical permafrost thickness in the discontinuous permafrost zone of the Northern Hemisphere is 1 to 50 m (Schuur et al. 2008). Globally, the northern circumpolar permafrost zone is estimated to store 1,672 billion tonnes of carbon (Schuur et al. 2008, Tarnocai et al. 2009).

4 Kurz and Apps (1999) estimate that Canada's forest vegetation stores 14.5 billion tonnes of carbon. Of this, 10.4 billion tonnes are located in the following ecoclimatic zones that approximate Canada's Boreal Forest region: boreal west, boreal east, subarctic, cordilleran, and subarctic cordilleran.

Recent studies of carbon storage in northern ecosystems suggest previous global accounting of carbon stocks has vastly underestimated carbon storage in northern regions, especially under permafrost (Tarnocai et al. 2009). These studies indicate there is twice as much carbon in the top one metre of these soils as originally thought and that there are also large stores in deeper deposits. Total carbon stored in northern circumpolar permafrost regions (such areas broadly overlap with the boreal region) is now estimated to account for about 50% of the global below-ground carbon pool (Tarnocai et al. 2009). Carbon storage by boreal peatlands is also frequently underestimated because the average peat depth of 2.3 m (Gorham 1991) is more than twice as deep as the one metre of soil typically included in global assessments of carbon storage (e.g., IPCC 2000).

Through the disturbance or removal of vegetation and soil, land-use can increase carbon emissions and diminish biotic carbon storage. Impacts from land-use such as deforestation accounted for nearly 20% of global anthropogenic CO_2 emissions during the 1990s (IPCC 2007). The proportion of Canadian

Globally, peatlands store more carbon per area than any other terrestrial ecosystem.

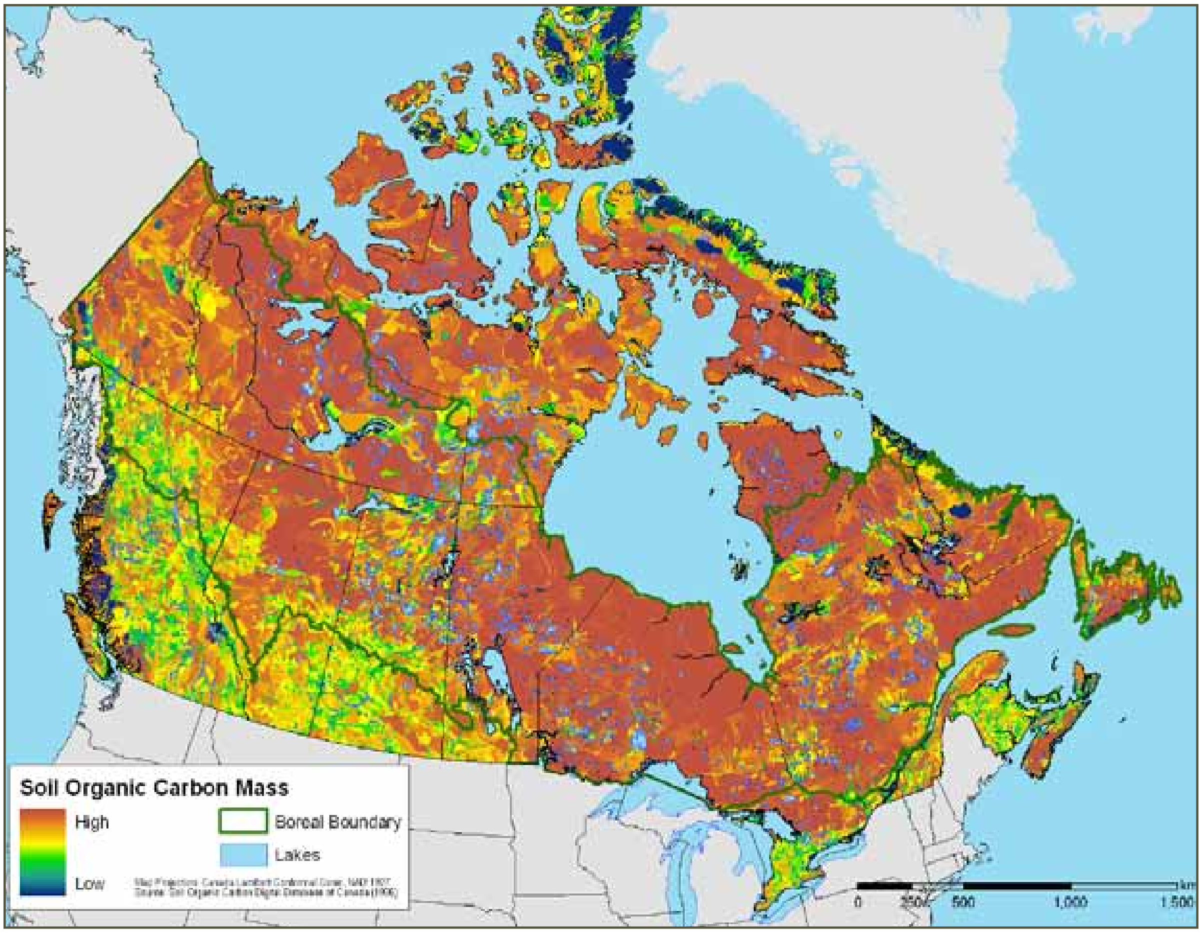


Figure 2. Soil carbon stores of Canada. More carbon is stored in the global boreal forest region than any other of earth's forest biomes. Canada's Boreal Forest region stores approximately 208 billion tonnes of carbon in soil and vegetation, an amount equivalent to 26 years of industrial carbon emissions at 2006 levels.

Logging also affects carbon storage by removing forest biomass (i.e., timber) from ecosystems.

Clear-cutting in Ontario's Boreal Forest JEFF WELLS

carbon emissions associated with land-use is substantially lower than this global average due to Canada's low rate of deforestation, although regional impacts can be substantial. For example, 73% of the boreal transition ecoregion in Saskatchewan has been converted to agriculture; deforestation in the province continues at a rate three times the global average (Hobson et al. 2002).

The tar sands region of northeastern Alberta provides another example of substantial biotic carbon loss that is attributable to land-use (Lee and Cheng 2009). As of 2009, surface mines and associated footprints had disturbed 686 km^2 of land, with half of the area existing as carbon-rich peatlands and wetlands prior to disturbance (Figure 3). Tar sand deposits near the surface are extracted by draining overlying wetlands and removing all surface vegetation and soils, which accounts for losses of large above- and below-ground carbon stores.

The total above- and below-ground biotic carbon content of the already developed area is approximately 21 million tonnes. Approved and proposed mining projects account for another 29.6 million tonnes of biotic carbon. Under a full development scenario of surface and insitu bitumen in the region, it has been estimated that 238 million tonnes of biotic carbon would be released from tar sands industrial development (Lee and Cheng 2009).

Logging also affects carbon storage by removing forest biomass (i.e., timber) from ecosystems. Although some of the harvested timber is subsequently stored as forest products and in landfills, the scale of the activity is such that emissions can be substantial. Almost 10,000 km^2 of harvest activity (Canadian Council of Forest Ministers 2008) extracted close to 45 million tonnes of carbon from Canada's forests in 2006 (Environment Canada 2008a).

Maintaining the climate regulation services provided by Canada's forest landscapes
In 2007, the Canadian Boreal Initiative and Richard Ivey Foundation organized a workshop attended by some of Canada's leading experts on the role of forest and peatland ecosystems in climate regulation. The scientists were asked to recommend management strategies for maintaining the climate regulation services provided by Canada's forest landscapes. These strategies are summarized below, with details provided by Carlson et al. (submitted). The strategies are readily achievable and,

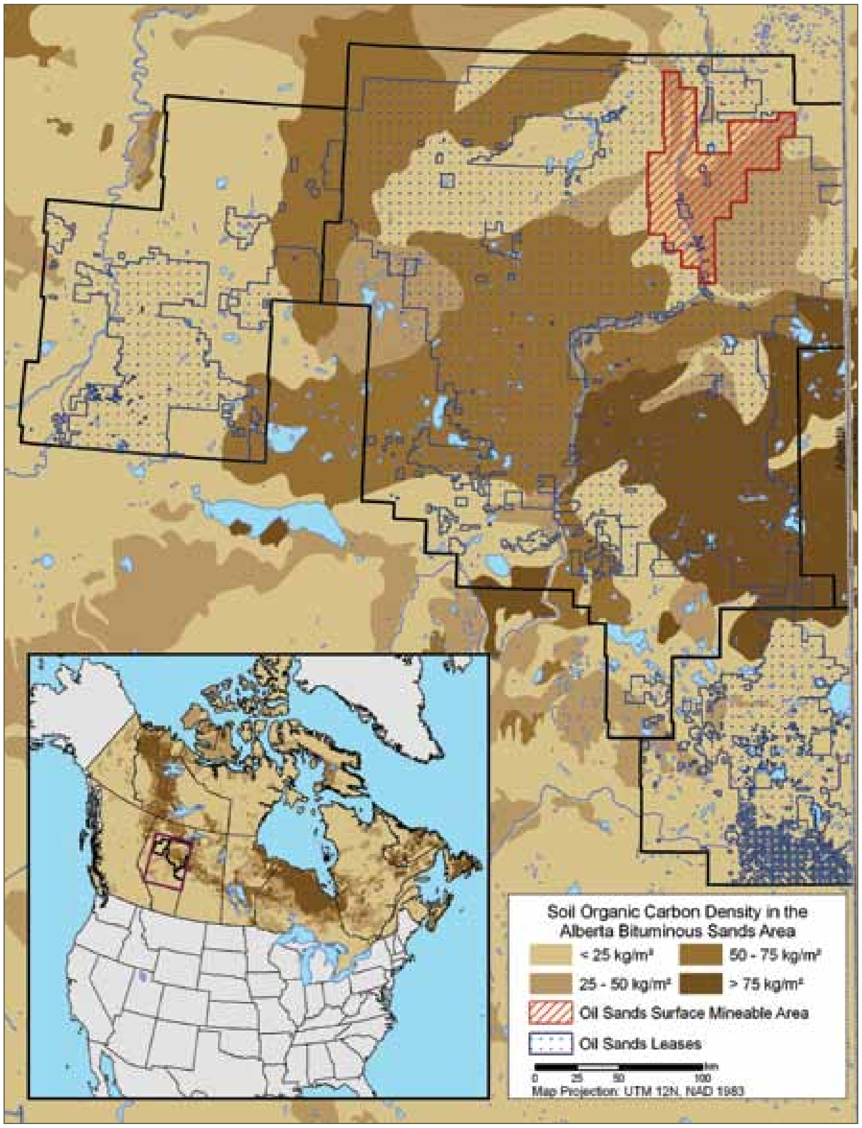


Figure 3. Soil carbon stores in the tar sands region of Alberta. Peatlands rich in carbon storage occur in the tar sands region. Under a full development scenario of surface and insitu bitumen in the region, it has been estimated that 238 million tonnes of biotic carbon would be released from tar sands industrial development (Lee and Cheng 2009).

Source: Global Forest Watch Canada and the Soil Organic Carbon Digital Database of Canada (1996).

Carbon storage can be maximized by conserving carbon-rich natural forests while at the same time producing timber from existing managed forests to substitute for greenhouse gas-intensive products such as steel.

given the quantity of carbon at stake, should be part of Canada's response to climate change.

1. **Avoid deforestation and peat extraction.** The loss of peatlands is of particular concern due to their high carbon density and because peatland loss is effectively permanent.

2. **Avoid logging of natural forests.** Carbon storage can be maximized by conserving carbon-rich natural forests while at the same time producing timber from existing managed forests to substitute for greenhouse gas-intensive products such as steel.

3. **Adopt forest harvest practices that conserve biotic carbon.** Use longer rotations to increase biotic carbon density, and promote postharvest sequestration by accelerating regeneration.

4. **Avoid soil disturbance.** Minimize soil disturbance during harvest, especially in low-lying areas or where soils are saturated or frozen.

5. **Minimize emissions associated with forest product processing, transport, and disposal.** Strategies such as burning wood waste to power forestry mills have substantial mitigation potential due to the high proportion of forestry emissions related to forest product processing, transport, and disposal.

6. **Reduce the adverse climate impacts of fire and insect disturbances.** Suppression and salvage logging can reduce emissions, but should be limited to the managed forest and carefully applied to limit negative ecological impacts such as loss of wildlife habitat and reduced forest regeneration.

Clearwater River in Alberta GARTH LENZ

Maintaining Resilient Ecosystems

Maintaining the boreal forest's intactness will be vital for species adaptation ASHLEY HOCKENBERRY

Canada's Boreal Forest Region and Adaptation: Maintaining Resilient Ecosystems

Rapid and drastic cuts in worldwide industrial carbon emissions are essential to avoid the most severe projected climate change impacts. Even with major reductions in carbon emissions, substantial changes in the earth's climate will continue due to today's high atmospheric greenhouse gas concentrations and the time lag between emissions reductions and climate alteration. Today's emissions will drive weather effects decades from now (Hansen et al. 2002, Wigley 2005, Weaver 2008), forcing ecosystems and society to adapt rapidly to climatic changes. As described below, the boreal forest region will be confronted with some of the largest modifications to its climate on the planet. Fortunately, Canada's Boreal Forest region is better suited than most to withstand such changes due to its high level of intactness (Ruckstuhl et al. 2008). Conservation of intact Canadian Boreal Forest ecosystems is needed to maintain the region's resilience to climate change and minimize losses to biological diversity and ecosystem services. The diverse biota supported by Canada's Boreal Forest region includes billions of migratory songbirds (Blancher 2003, Blancher and Wells 2005) and among the world's largest and healthiest populations of northern mammals like caribou, bear, wolves and moose. Its ecosystem services are estimated to be worth 14 times the value of natural resources extracted each year (Anielski and Wilson 2009).

Today's emissions will drive weather effects decades from now, forcing ecosystems and society to adapt rapidly to climatic changes.

Climate Change Impacts

Increased fire frequency associated with climate change will make the threatened Woodland Caribou more sensitive to human-related disturbance

NORTHERN IMAGES BY WAYNE SAWCHUK

Climate change over the last century has already resulted in species, including plants, insects, fish, birds, and mammals, shifting ranges northward in latitude or upslope to higher altitudes.

Climate Change Impacts to Boreal Forest Ecosystems

Climate change at high latitude regions, including the Canadian Boreal Forest region, is expected to be greater and occur more rapidly compared to temperate and tropical forest biomes. The projected average increase in annual mean temperature over the next 100 years in northern Canada is 4 to 5 degrees C (Christensen et al. 2007), substantially higher than the global projected average increase of 3 degrees C (Meehl et al. 2007). Winter temperatures are projected to increase in northern Canada by as much as 10 degrees C (Christensen et al. 2007). The pronounced climate change expected in the northern regions has large implications for ecological processes and biodiversity and provides further justification for both drastic cuts in greenhouse gas emissions and increased protection of carbon-rich regions like Canada's Boreal Forest.

Aspects of climate, especially temperature and precipitation, are important determinants of habitat. Rapid climate change affects the distribution of plants and wildlife (Crozier 2004, Root and Hughes 2005, Root and Schneider 2002). Climate change over the last century has already resulted in species, including plants, insects, fish, birds, and mammals, shifting ranges northward in latitude or upslope to higher altitudes (Figure 4) (Hickling et al. 2006). An analysis of 130 tree species in North America, including many boreal species, predicted an average northward shift in climatic niche (i.e., suitable climate conditions) of 700 km over the next 100 years (McKenney et al. 2007). Yet, natural migration of trees and other plant species is unlikely to keep pace with such a dramatic shift, suggesting that the persistence of some species may be jeopardized. Typical tree migration rates are in the order of 20-40 km per century, far below the expected shift in climatic niche due to climate change (Davis and Shaw 2001). Migration rates necessary to keep up with climate change are predicted to be greatest in the northern hemisphere regions such as taiga/tundra and boreal coniferous forest (Malcolm and Markham 2000). In the absence of disturbance, existing communities may resist change for decades. Once these communities are disturbed, however, colonization will favour weedy species with high dispersal abilities, jeopardizing the existing forest communities and having an impact on the people who rely on them.

Wildlife will also be negatively affected if the plant communities on which they depend are not able to keep up with climate change. Northward range shifts consistent with those expected from climate change have already been documented in hundreds of Northern Hemisphere bird species (Hitch and Leberg 2007, Thomas and Lennon 1999), with some species shifting winter ranges toward colder latitudes by several hundred miles (National Audubon Report 2009). Current models of potential changes in the distribution of wildlife species as a result of climate change suggest that large numbers of species are at risk of large decreases in population size and that many are extinction prone (Huntley et al. 2007, Ferreira de Siqueira et al. 2004, Mathews et al. 2004).

Phenology, or the timing of plant development, animal breeding, migration, and other life history events, is often triggered by climate variables such as maximum or minimum

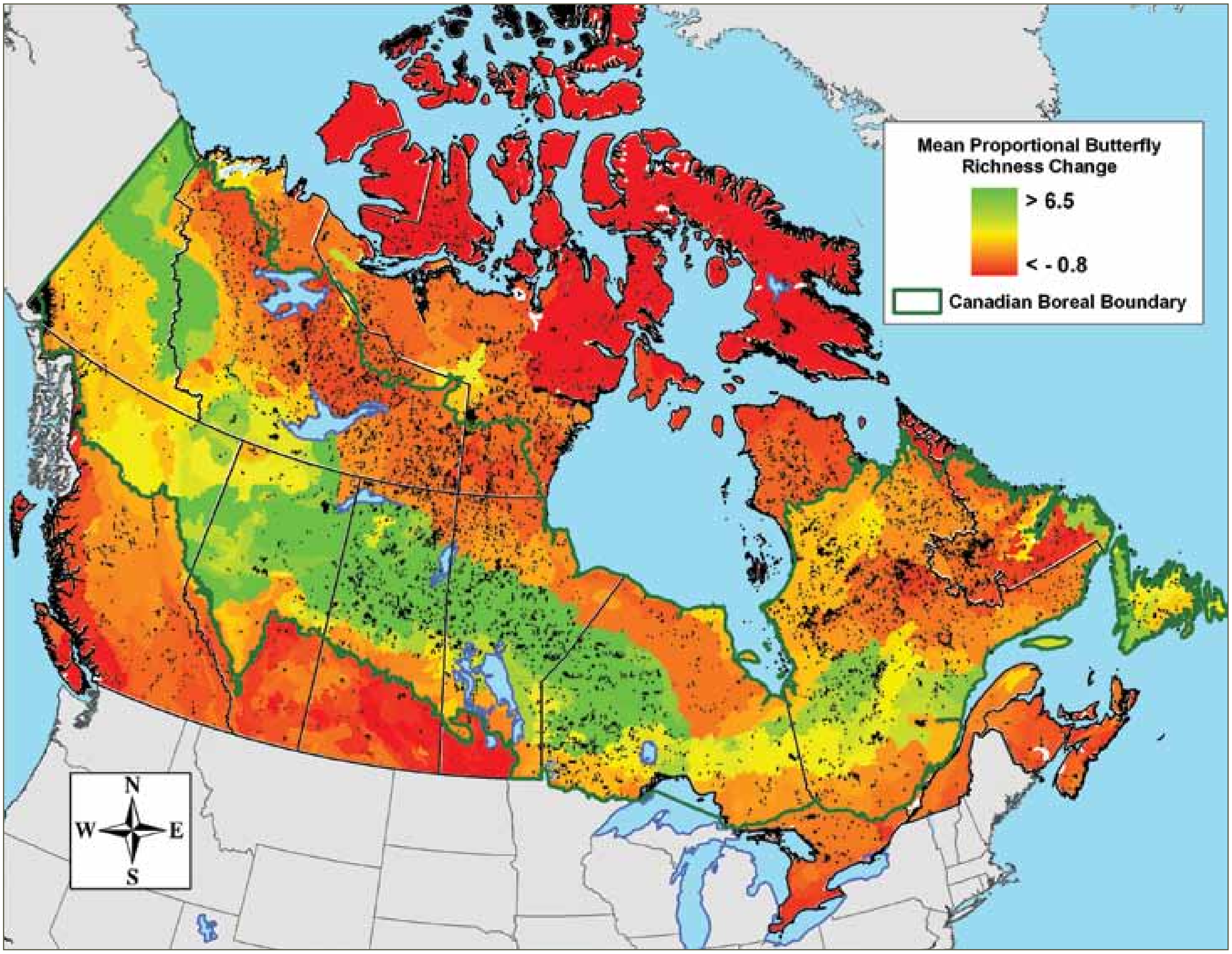


Figure 4. Canada's Boreal Forest region is likely to become a refuge for species pushed northward by climate change. The map conveys the extent to which butterfly species richness changed over the past century. Green indicates an increase in species richness whereas red indicates a decline. The prevalence of green within the Canadian Boreal Forest region suggests that climate change may have already caused a northward shift in the ranges for some species. Maintaining the region's intactness will aid future species range shifts into the region. The map was reproduced from Kharouba et al. (2009) with permission from the authors.

JEFF NADLER

Events such as insect emergence are already occurring earlier than 50 years ago, which may impact bird species whose migration has evolved to coincide with the peak abundance of prey insects

temperatures, and is therefore sensitive to climate change. Many wildlife species have evolved phenologies to match other species upon which they depend. Given the major shifts in resource availability between winter and summer that occur in boreal ecosystems, mismatches in phenology between species are already apparent and are expected to increase due to climate change (Parmesan 2006, 2007). A study of West Greenland caribou documented such a mismatch in which caribou calving has not kept pace with earlier leaf emergence (the young leaves are critical food for milk formation in female caribou), leading to significant increases in calf mortality (Post and Forchhammer 2008).

One review (Root et al. 2003) found that in over 694 species of Northern Hemisphere plants and animals examined over the last 50 years, there had been an average advance of 5.1 days per decade in spring life history events. These events ranged from leaf-out in trees to flowering and fruiting times, to egg-laying dates in amphibians, to insect emergence. The earlier nesting dates of birds result from their adaptation to these advances in various other biological events. For example, when insects emerge earlier than in the past, birds must lay eggs sooner if they are to raise their young when the caterpillars and other prey insects are at maximum abundance. For residents and short-distance migrants this is possible because they can effectively track the climatic changes that are occurring with global warming in the more northerly climes where they winter. Long-distance migrant birds that winter in the tropics, however, may be at a disadvantage because they do not use climatic cues to begin spring migration but rather rely on seasonal changes in daylight. As a result, these birds may not arrive on the breeding grounds soon enough to ensure that hatching of their young coincides with the abundant insect food supply required to raise them. In the Pied Flycatcher of Europe, the one species in which this phenomenon has been effectively studied, the birds arrive from their African wintering grounds too late, so that the unfortunate young hatch after peak insect abundance, resulting in lowered reproductive output and natural selection favouring those individuals that start nesting earlier (Both et al. 2006, Visser at al. 2006, Visser et al. 1998).

It is not only migratory birds that are threatened by climate change. Some resident birds hoard food to get through the winter and early spring and to feed young that can hatch early in the spring, before new food supplies are available. With global warming causing warmer autumns in the boreal region, later freezes could affect food-hoarding birds. One Canadian Boreal Forest species, the Gray Jay, may be particularly impacted. Gray Jays in the southern boreal region may be most affected by recent warmer autumns, because cached food can spoil before it has a chance to freeze. Hoarded food allows Gray Jays to survive through the winter and early spring. Gray Jays also rely on stores of frozen food to feed their young, which typically hatch in April. Scientists found these birds had more young in years after cold autumns than after warm autumns (Waite and Strickland 2006).

Natural disturbances that shape the boreal forest are also being altered by climate change. Warmer temperatures will affect fuel moisture, and therefore increase fire ignition and spread. Increased fire risk associated with climate change is projected to double forest fire rates in Canada over the next century (Flannigan et al. 2005), and more than triple fire rates in western Canada (Balshi et al. 2009). Insect disturbance is also affected by climatic changes, as demonstrated by the mountain pine beetle epidemic in western Canada that has affected more than 130,000 km^2 of forest (Kurz 2008a). Warmer temperatures, especially during winter, contributed to the epidemic by allowing the pine beetle to escape its primary population control—overwintering mortality—and thereby expand its range to the north and east and into higher elevations.

Boreal biodiversity is adapted to the region's historical fire regime; increased disturbance rates arising from climatic changes can be expected to impact wildlife. Higher fire rates will reduce the abundance of older forest, with negative implications for species associated with such habitat. This consequence of climate change is especially problematic considering that the proportion of older forest is already reduced below historical levels in regions where forestry occurs (Cyr et al. 2009). Increased rates of natural disturbance may therefore reduce the capacity of Canada's Boreal Forest ecosystems to absorb direct anthropogenic disturbance without losses in species diversity. Woodland caribou, for example, are sensitive to disturbance, both natural and anthropogenic. A Canadian Boreal Forest-wide analysis of caribou ranges concluded that caribou recruitment (the addition of young to the adult population, an indicator of population trend) declines with increasing total disturbance (Environment Canada 2008). The implication is that increased fire frequency will make caribou more sensitive to human-related disturbance. Ecosystem services provided by Canadian Boreal Forest ecosystems are also likely to be disrupted by the rise in climate-related "natural" disturbances. Carbon storage, for example, will be detrimentally affected by increased combustion and decay of biomass caused by more prevalent burning and insect outbreaks (Kurz et al. 2008b). However, the overall effects of climate change on carbon storage are complicated by the positive effects on carbon sequestration of climate warming, CO_2 deposition, and nitrogen deposition (Chen et al. 2003).

The Gray Jay stores food over the winter, but rising temperatures could cause food to spoil
JEFF NADLER

Fires in the boreal forest are expected to increase due to climate change GARTH LENZ

Lake temperatures are expected to rise, affecting species such as lake trout GARTH LENZ

Canadian Boreal Forest aquatic ecosystems will also be severely affected. Northern aquatic systems are sensitive to a variety of climate-induced physical, chemical, and biological changes (Schindler and Smol 2006). Thermal optima for coldwater species is often less than 20 degrees C and will likely be surpassed in some regions with a warming climate (IPCC 2002). Species such as lake trout will be detrimentally affected by water temperatures that exceed their tolerances and by competition, predation, or disease from southern taxa expanding northward (Reist et al. 2006). Northern rivers are already exhibiting changes in their flow regimes (Schindler and Smol 2006). Changes in flow regime that are likely attributable to climate change include earlier but reduced peak flows, increased winter flows, and reduced summer flows (Woo et al. 2008). Timing of egg laying, hatching, and emergence of many aquatic organisms is synchronized with changes in water flow and temperature; shifts in these variables may have unexpected results, especially for aquatic predators that rely on pulses of food abundance. Just as in terrestrial ecosystems, additional human-caused impacts on aquatic systems from pollution, hydropower and other activities may lessen the ability of aquatic species and ecosystems to adapt to climate change.

Much of Canada's Boreal Forest region receives low amounts of precipitation, but contains abundant aquatic habitat due to cool temperatures that suppress evapotranspiration. Warmer temperatures expected in the southern and western Canadian Boreal Forest region will increase wetland evapotranspiration (Tarnocai 2006), resulting in drying and potentially reducing habitat for wetland dependent species such as the 12 to 15 million ducks that depend on Canadian Boreal Forest wetlands (Morissette et al., in press). In the northern Canadian Boreal Forest, melting of permafrost will also contribute to the disappearance of aquatic habitat by causing wetlands and lakes to drain. Permafrost melting has already caused a decrease in wetland habitat in boreal regions of Alaska since the 1950s (Riordan and Verbyla 2006), as well as the disappearance of lakes in Siberia (Schindler and Smol 2006).

Of great concern is the potential for feedback loops whereby climate change causes the release of carbon from boreal soils thereby contributing to further climate change. Water has a controlling effect on peatland carbon balance, and the drying of peatlands could cause the release of large quantities of carbon dioxide into the atmosphere (Tarnocai 2006). The thawing of permafrost could also result in carbon flux from boreal soils, although the loss may be at least partially offset by increased sequestration due to higher productivity (Turetsky et al. 2007). Drying may also affect the chemistry of Canadian Boreal Forest aquatic ecosystems. Acidification can result from higher fire rates and drought, both of which cause the release of acid anions such as sulfate and chloride that may have accumulated in catchments from past acid precipitation (Bayley et al. 1992).

Conservation: an effective strategy for climate change adaptation


Forest fragmentation from forestry in Alberta DAVID DODGE, THE PEMBINA INSTITUTE

Many examples exist from the fossil record of species persisting and migrating in the face of a changing climate. Why, then, are future climate changes expected to devastate diversity, threatening as many as 20-30% of plant and animal species (IPCC 2007)? One reason is the rapidity of climate change. There are no known analogues in the climate record for this scale of "global" as opposed to "regional" climate change; moreover, changes that typically took millennia are now forecasted to occur in decades. Presently, climate change is affecting ecosystems that are already stressed by a multitude of human-caused disturbances. The majority of earth's ecosystems have been substantially modified by humans, reducing their capacity to moderate the effects of a modified climate and impeding range shifts needed for species to react to changing conditions. In addition, human activity has already reduced the abundance of many species and populations, making them more vulnerable to extinction or extirpation from climate change (Noss 2001). The exception to this pattern is the world's remaining intact ecosystems, areas that remain largely unaltered by human activities. These ecosystems, including much of Canada's Boreal Forest region, present an enormous opportunity for climate change adaptation due to the higher capacity of these ecosystems to withstand expected impacts.

One of the most worrisome expected impacts of climate change is that rapid, large-scale shifts in the distributions of plants and animals may be required to enable species to persist. Intact forest ecosystems are well-suited to resist this impact because of characteristics that temper changes to climate conditions. Due to the long lifespan of trees, forests can persist for centuries after the climate has changed (Noss 2001). As a result, intact forest ecosystems are likely to slow ecosystem shifts caused by climate change, buffering species against changing conditions. Once degraded, however, these ecosystems are susceptible to rapid invasion by weedy species (Sakai et al. 2001, Thompson et al. 2009). Another moderating effect of intact ecosystems is that the microclimates of interior forests tend to exhibit muted temperature variations and increased humidity relative to outside the forest (Innes et al. 2009). Conditions amenable to native species

One of the most worrisome expected impacts of climate change is that rapid, large-scale shifts in the distributions of plants and animals may be required to enable species to persist.

can therefore be maintained despite changing atmospheric conditions. Once fragmented, however, exposure to wind and sunlight can diminish this climate inertia and expose forests to conditions not favourable to existing species (Noss 2001).

DUCKS UNLIMITED CANADA

The boreal forest is a haven for animals already extirpated from southern ranges, like the Gray Wolf

While intact ecosystems may slow the pace of distributional changes demanded by climate change, species range shifts will still be required that rival even the largest apparent from the fossil record. Landscapes altered by human activities present numerous potential barriers to range shifts, such as farmland, roads, areas of high human density, and industrial footprints (e.g., cutblocks). Rates of distributional change are expected to slow substantially when habitat availability in the direction of the required range shift becomes patchy due to human impacts (Collingham and Huntley 2000). Given the high range shift rates that will likely be required, the constraining effect of human-altered landscapes could be fatal to species. Establishing corridors of habitat parallel to climatic gradients can alleviate this impact, and this strategy should be adopted to facilitate range shifts through regions already altered by human activities (Chapin et al. 2007). Ensuring corridors are effective is challenging, however, especially given the wide range of species that will likely need to shift their range. Wide corridors with diverse compositions are more likely to accommodate species with large area requirements or specific habitat needs. The creation of corridors is not an exact science and evidence regarding their effectiveness is relatively inconclusive (Beier and Noss 1998). The preferred approach is to maintain the functional connectivity of whole landscapes.

Intact ecosystems across climatic gradients such as those in parts of Canada's Boreal Forest region are likely to be most effective at permitting species movement, such as occurred during periods of climate change prior to large-scale alteration of ecosystems by humans. Where land-use exists, functional connectivity can still persist if the region's integrity is sufficient to permit movement (Lindenmayer and Franklin 2002). Maintaining the intactness and integrity of ecosystems affords higher resistance to invasions by exotic and weedy species. Weedy species are expected to prosper in the face of climate change due to their high dispersal ability (Malcolm and Markham 2000). Anthropogenic disturbances exacerbate this problem through the creation of habitat amenable to invasive species and the inadvertent transport of invasives over long-distances along roadways and other transportation corridors (Sumners and Archibold 2007). As such, minimizing anthropogenic alteration of habitat can slow the detrimental advance of invasive species while also aiding the migration of native species.

Perhaps the most important attribute of intact ecosystems for climate change adaptation is their high levels of species abundance and diversity. The complexity of climate change and biodiversity makes it difficult to predict precisely how species will be affected, but the impacts are likely to be severe (Pimm 2009). Abundant populations found in intact ecosystems will be better able to absorb uncertain impacts while still maintaining their viability. Canada's Boreal Forest region is already a haven for species that have been extirpated from more southern areas (e.g., many large mammals including bears, wolves, caribou, and wolverine; Laliberte and Ripple 2004). One can expect that the region's role as a refuge for species pushed out of the southern portion of their range will only increase with ongoing climate change. Species diversity is another important factor contributing to the resilience of intact ecosystems (Thompson et al. 2009). The existence of multiple species with similar ecological roles allows ecological processes to continue if some species disappear or decline because of climate change impacts. Another benefit of species diversity in the context of resilience is reduced susceptibility to natural disturbances such as insect outbreaks. Genetic diversity within species is also important because it enhances the capacity of species to adapt to climate change through natural selection (Thompson et al. 2009). Intact ecosystems are likely to support more abundant and therefore more genetically diverse populations.

Abundance and diversity are important not only in the context of species, but also habitats. Natural disturbances including fire and insect outbreaks are expected to become more prevalent and severe. Boreal ecosystems are adapted to recover from natural disturbance, but this resilience can only be maintained if some areas are left unaffected to act as source areas for species reliant on older forest. Research in the Northwest Territories concluded that a protected area should be at least three times the size of the maximum expected fire in order to maintain a long-term existence of all habitat types (Leroux et al. 2007). Fires in Canada's Boreal Forest region often span thousands of km^2, so that large-scale intact forest ecosystems will be needed to maintain resilience to natural disturbance.

Given the higher capacity of intact ecosystems to resist and adapt to climate change, it is not surprising that conservation and sustainable management are common elements of recommended strategies for climate change adaptation. Government and nongovernmental climate-change adaptation plans frequently include conservation strategies such as increasing protection, maintaining or restoring connectivity, and reducing non-climate impacts (Mawdsley et al. 2009). The International Union for Conservation of Nature (IUCN) recommendations (IUCN Position Paper June 2009) for conserving biodiversity and maintaining ecosystem services under a changing climate include: maintaining intact and interconnected ecosystems; investing in the development and management of protected area systems that can provide adaptation and resilience to climate change; facilitating sustainable use of renewable resources; and, restoring fragmented or degraded ecosystems. Similarly, strategies identified by other authors (Innes et al. 2009, Secretariat of the Convention on Biological Diversity 2009) include (but are not limited to): protecting primary forests; maintaining representative forest types across environmental gradients in reserves; strategically increasing the size and number of protected areas; and, reducing non-climatic stresses.

It is not only other species that will benefit from conservation in the context of climate change adaptation, but also humans. Humans depend on a wide range of services provided by ecosystems, including clean water, food and medicine, flood control, pollination, recreation, and, as discussed previously, climate regulation. Ecosystem services provided each year by Canada's Boreal Forest region are valued at approximately $700 billion (Anielski and Wilson 2009). Slowing the pace of changing conditions by maintaining the integrity of ecosystems will help humans to cope with the challenges presented by climate change. This is perhaps

Cree children picking wild blueberries GARTH LENZ

Humans depend on a wide range of services provided by ecosystems, including clean water, food and medicine, flood control, pollination, recreation, and climate regulation.

Canada's Boreal Forest contains one quarter of the remaining intact forest ecosystems on the planet and the largest contiguous forest ecosystem left on the globe.

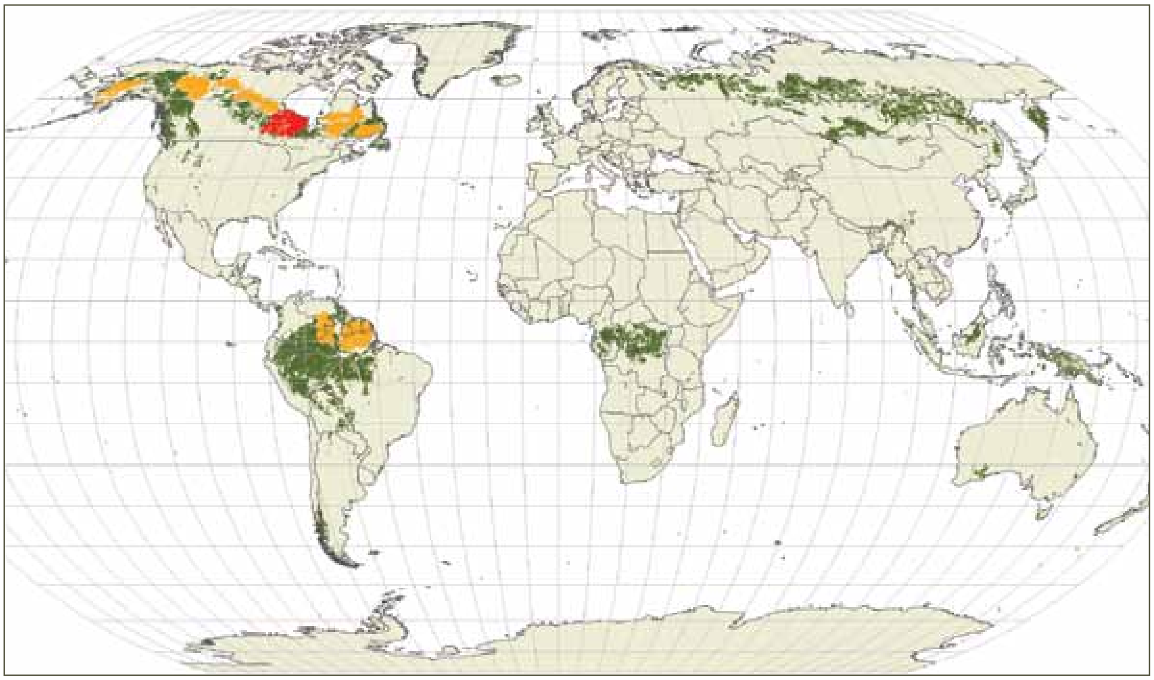


Figure 5. Locations of the 10 largest, intact forest blocks on earth (the largest in red and the other nine in yellow).

Source: Global Forest Watch Canada.

most true for Indigenous people whose identity and livelihood are often closely tied to their homeland environments. Indigenous communities across the world have evolved over generations in conjunction with local environments. Many communities within Canada's Boreal Forest region are witnessing rapid changes to their environments. These changes will only accelerate in northern regions as climate change progresses. Maintaining the ability of communities to adapt goes hand-in-hand with maintaining diverse biological communities (Salick and Ross 2009). In recognition of the susceptibility of Indigenous peoples to climate change and their inherent expertise in dealing with environmental variability, the IUCN (2009) calls for the support of Indigenous and local communities dependent on vulnerable ecosystems in their effort to adapt to change using traditional knowledge systems. A highly relevant strategy in support of Indigenous communities' fight against climate change is the conservation of natural ecosystems, as proposed by numerous land-use plans developed by Indigenous communities in Canada's boreal and tundra regions.

Canada's Boreal Forest presents perhaps the best opportunity globally to apply conservation as a climate change adaptation strategy. Canada's Boreal Forest contains one quarter of the remaining intact forest ecosystems on the planet and the largest contiguous forest ecosystem left on the globe (Figure 5). At present, much of Canada's Boreal Forest is inherently resilient. Conservation is fundamental to maintaining the capacity of this globally significant biome to adapt to climate change.

The United Nations Convention on Biodiversity (CBD) was formally established in 1992 and has now been signed by the majority (192) of the world's countries including Canada.[5] The CBD commits the signatories to three major goals: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from the use of genetic resources. Recently the CBD signatory nations have recognized that climate change is the overriding long-term driver of loss of biodiversity and have commissioned several technical reports (Secretariat of the Convention on Biological Diversity 2009, Thompson et al. 2009) to describe the issues and provide recommendations for merging biodiversity conservation with climate change mitigation. A few of the many findings and recommendations contained in these reports that are relevant to Canada's Boreal Forest region are listed below.

FROM: *Connecting Biodiversity and Climate Change Mitigation and Adaptation* (Secretariat of the Convention on Biological Diversity 2009) and *Forest Resilience, Biodiversity and Climate Change. A Synthesis of the Biodiversity/resilience/stability Relationship in Forest Ecosystems* (Thompson et al. 2009)

- Ensure that there are national and regional networks of scientifically designed, comprehensive, adequate, and representative protected areas. Build these networks into national and regional planning for large-scale landscape connectivity.

- Policies that integrate and promote the conservation and enhanced sequestration of soil carbon, including in peatlands and wetlands, can contribute to climate change mitigation and be beneficial for biodiversity and ecosystem services;

- Observations from indigenous and local communities form an important component of impact assessments and should be conducted with prior informed consent and with the full participation of indigenous and local communities;

- Explore uses of and opportunities for community-based monitoring linked to decision-making, recognizing that indigenous people and local communities are able to provide data and monitoring on a whole system rather than single sectors based on the full and active participation of indigenous and local communities.

The CBD commits the signatories to three major goals: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from the use of genetic resources.

5 President Clinton signed the CBD in 1993 but the Senate has never ratified the agreement and therefore the U.S. government, while an official observer and participant, has no official vote in CBD deliberations.

Co-benefits

Realizing the Co-benefits of Boreal Forest Conservation

The high carbon content and intactness of boreal ecosystems (Bradshaw et al. 2009) point toward conservation as being an effective approach for achieving the co-benefits of climate change mitigation and adaptation. Protecting intact landscapes across Canada's Boreal Forest region will reduce the release of terrestrial carbon into the atmosphere, especially for ecosystems that store high amounts of carbon, including peatlands, permafrost regions, and older forests. Protection is also essential for maintaining the capacity of Canada's Boreal Forest region to resist and adapt to climate change. A comprehensive protected areas network will aid the migration of species in response to shifts in climate conditions and will help species to withstand increases in the occurrence of and area impacted by natural disturbances (Secretariat of the Convention on Biological Diversity 2009).

The mitigation and adaptation co-benefits of conservation in Canada's Boreal Forest are demonstrated by the spatial overlap of carbon storage with other ecological attributes. Areas such as northern Ontario and the Mackenzie Valley in the Northwest Territories, for example, not only store large quantities

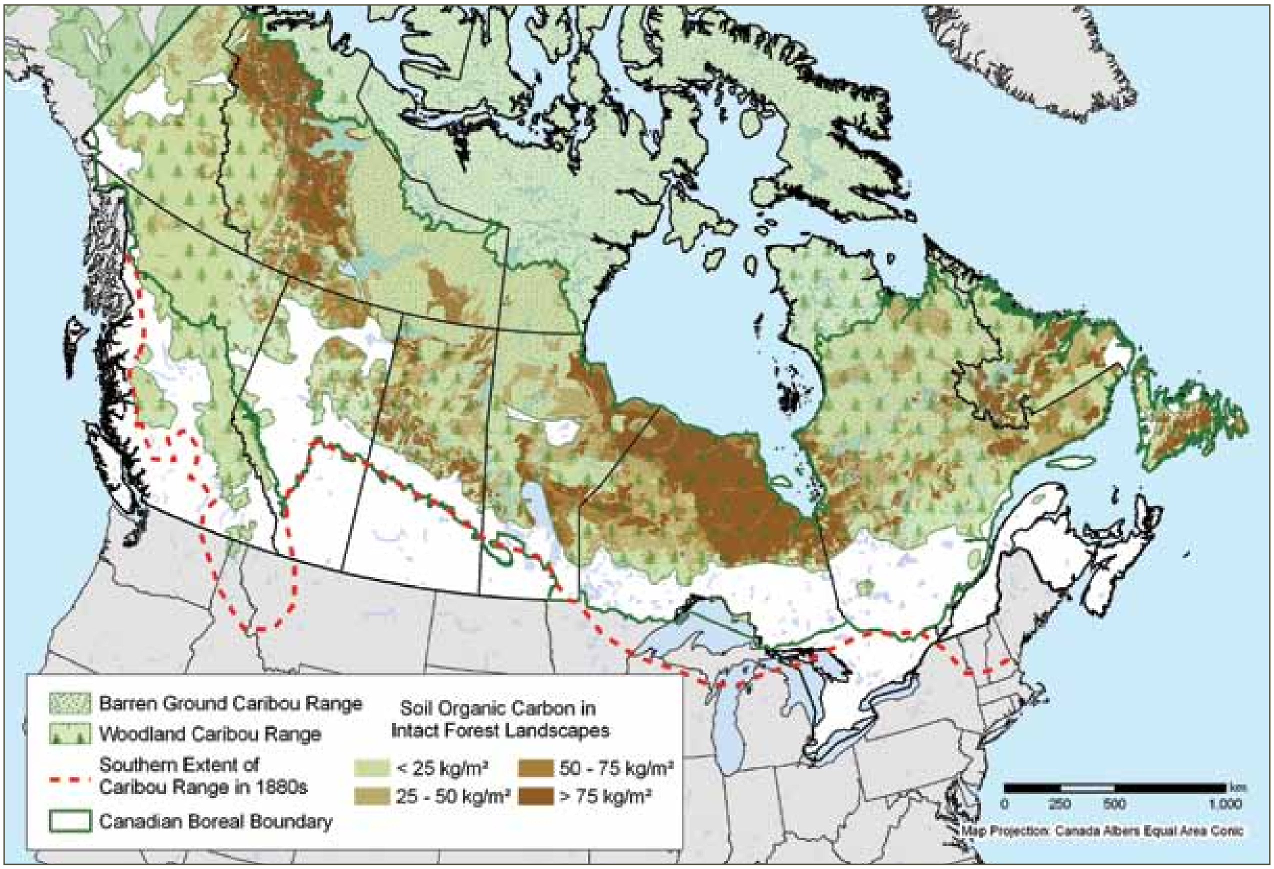


Figure 6. The Canadian Boreal Forest region's largest carbon stores occur within the still intact range of the threatened Woodland Caribou.

Source: Global Forest Watch Canada and the Soil Organic Carbon Digital Database of Canada (1996).

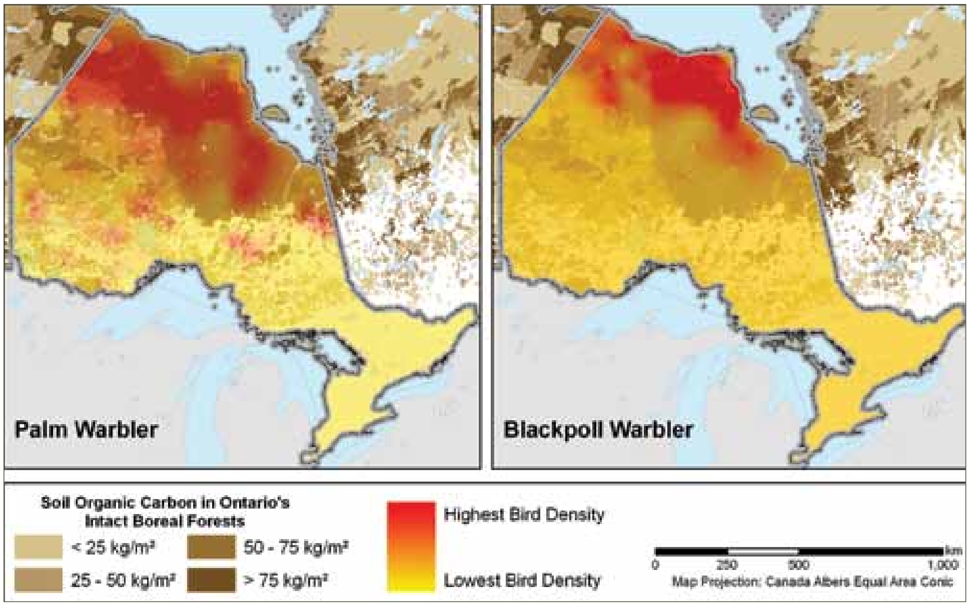


Figure 7. High density of soil carbon overlaps with the highest breeding densities of Palm Warblers and Blackpoll Warblers in Ontario, where both warbler species prefer peatland habitat. Northern Ontario houses one of the largest peatland complexes in the world.

Bird density data from Ontario Breeding Bird Atlas, courtesy of Andrew Couturier, Bird Studies Canada.

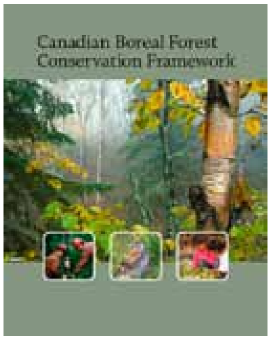
of carbon due to the prevalence of peatlands, but also provide habitat for caribou populations that are sensitive to climate change and land-use (Figure 6) and provide quality breeding habitat for long-distance migratory songbirds (Figure 7).

Increasing protection of these areas will not only help safeguard globally significant carbon stores, but will also help to maintain the resilience of threatened caribou populations to climate change. More generally, areas of high carbon density are focused in ecosystems with a high level of intactness. This overlap of mitigation and adaptation potential is a fortuitous outcome of the lack of industrial development historically. As development expands northward, proactive planning is needed to protect areas of high carbon density and high conservation value. Development decisions should be informed by thorough full cost accounting that considers the long-term implications of land-use activities that release large quantities of carbon into the atmosphere where it will affect the climate for decades.

There are also opportunities for mitigation and adaptation through the adoption of sustainable management principles on lands already committed to industrial activities. Forest products could help to mitigate climate change if they substituted for more greenhouse gas (GHG) intensive products such as cement and steel. Producing timber from existing managed forest rather than expanding forestry into intact natural forests can realize the carbon benefits of product substitution while minimizing impacts to terrestrial carbon stores. Timber production from the existing managed forests could be augmented

ASHLEY HOCKENBERRY

Species like the Blackpoll Warbler would benefit from conservation



The Canadian Boreal Forest Conservation Framework has been signed by environmental groups, First Nations, and industry leaders

WEBSITE: BOREALCANADA.CA

by reforesting marginal agricultural land to forest plantations. Over 70 thousand km^2 of Canada's Boreal Forest region has been converted to agriculture (Smith et al. 2000), a land-use change that reduces ecosystem carbon storage by approximately 50% (Grunzweig et al. 2004). Creating timber plantations on a portion of the converted land would sequester carbon, create timber that can substitute for GHG-intensive products, and, if located close to mills, reduce emissions associated with hauling timber to the mill. Plantations may also have higher biodiversity values than certain agricultural lands and, more importantly, provide timber supply without requiring the expansion of logging into intact forests that have high carbon and conservation values. On the managed forest landbase, adopting sustainable management principles will reduce impacts to terrestrial carbon stores and help to maintain the capacity of Canada's Boreal Forest ecosystems to adapt to climate change by reducing non-climate impacts.

The described approach of large-scale Canadian Boreal Forest protection combined with sustainable management is embodied in the Boreal Forest

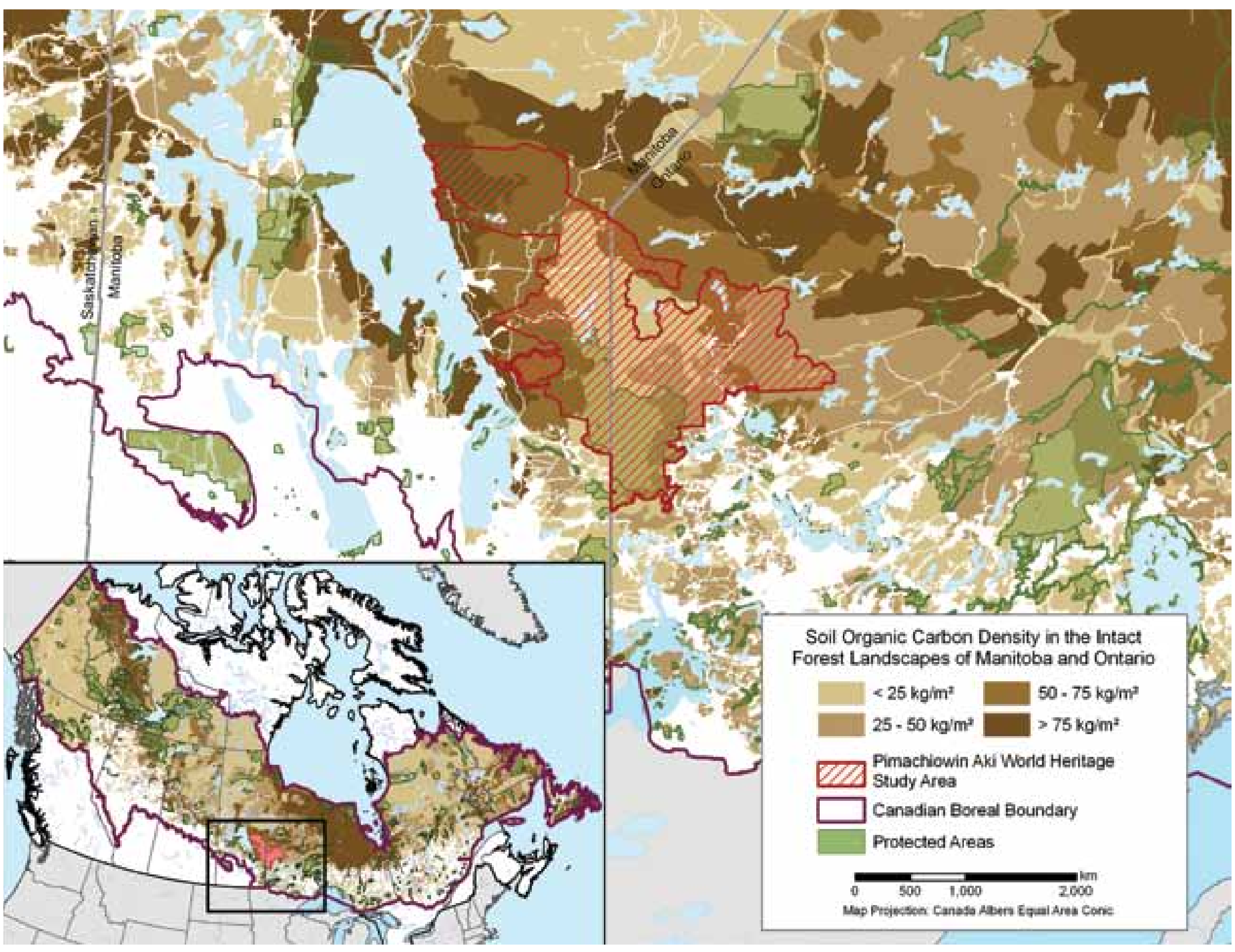


Figure 8. UNESCO Pimachiowin Aki Corporation proposed World Heritage Site.

Source: Global Forest Watch Canada and the Soil Organic Carbon Digital Database of Canada (1996).

An elder of the Poplar River community, part of the potential future UNESCO site GARTH LENZ

Conservation Framework, a national vision for conserving the ecological and cultural integrity of Canada's Boreal Forest region. The Framework calls for the establishment of a network of large interconnected protected areas covering at least half of Canada's Boreal Forest region and the use of leading-edge sustainable development practices in remaining areas. This balanced approach of protection and sustainable management is not only rooted in the best available principles of conservation biology and land-use planning, but, as described previously, is also capable of maintaining the climate change mitigation and adaptation capacity of one of the world's most expansive ecosystems.

The twenty signatory organizations committed to the Framework include First Nations, conservation groups, resource companies, and financial institutions. The vision is also supported by more than 1500 scientists from around the world and endorsed by more than 75 companies with combined annual revenue of more than $30 billion.

The Framework was developed in response to concerns that land-use policies under which less than 10% of the region was protected were inadequate to address threats, including accelerating resource development and climate change. Currently, land-use practices in Canada's Boreal Forest region remain insufficient to conserve biodiversity or mitigate climate change (Bradshaw et al. 2009), and only eleven percent of Canada's soil carbon is now within protected areas (Figure 9). However, the Framework's principles are beginning to be reflected in improvements to protected areas networks and sustainable management practices in the region. Many of these advances have explicitly referenced climate change as a rationale for increased conservation efforts. The governments of Ontario and Quebec, for example, have both identified terrestrial carbon conservation as part of the basis for commitments to protect half of their northern boreal forest, an area accounting for over 725,000 km^2.

Box 2. Protecting Cultural Landscapes Benefits Global Conservation Efforts

In 2002, four neighbouring First Nations in Manitoba and Ontario came together with a shared desire to protect their cultural values and traditional lands. Their vision was to establish a UNESCO World Heritage Site on the east side of Lake Winnipeg within a 40,000 km^2 boreal forest landscape (Fig. 8). Manitoba and Ontario have both joined in to support the proposal, which is now tracking towards a draft nomination. The partners have formed the Pimachiowin Aki Corporation and Manitoba recently announced a $10M contribution to a trust fund, which (along with UNESCO World Heritage Site status) will be used to advance the communities' work to care for the land over the long term.

This case study in collaboration demonstrates the multiple benefits of conservation. In addition to its ecological importance, including as critical habitat for threatened woodland caribou, its soils, peat, and wetlands make it particularly dense in carbon. Efforts to reduce deforestation and protect carbon-dense forests can often coincide with the cultural and ecological values of protection, making protection more politically feasible.

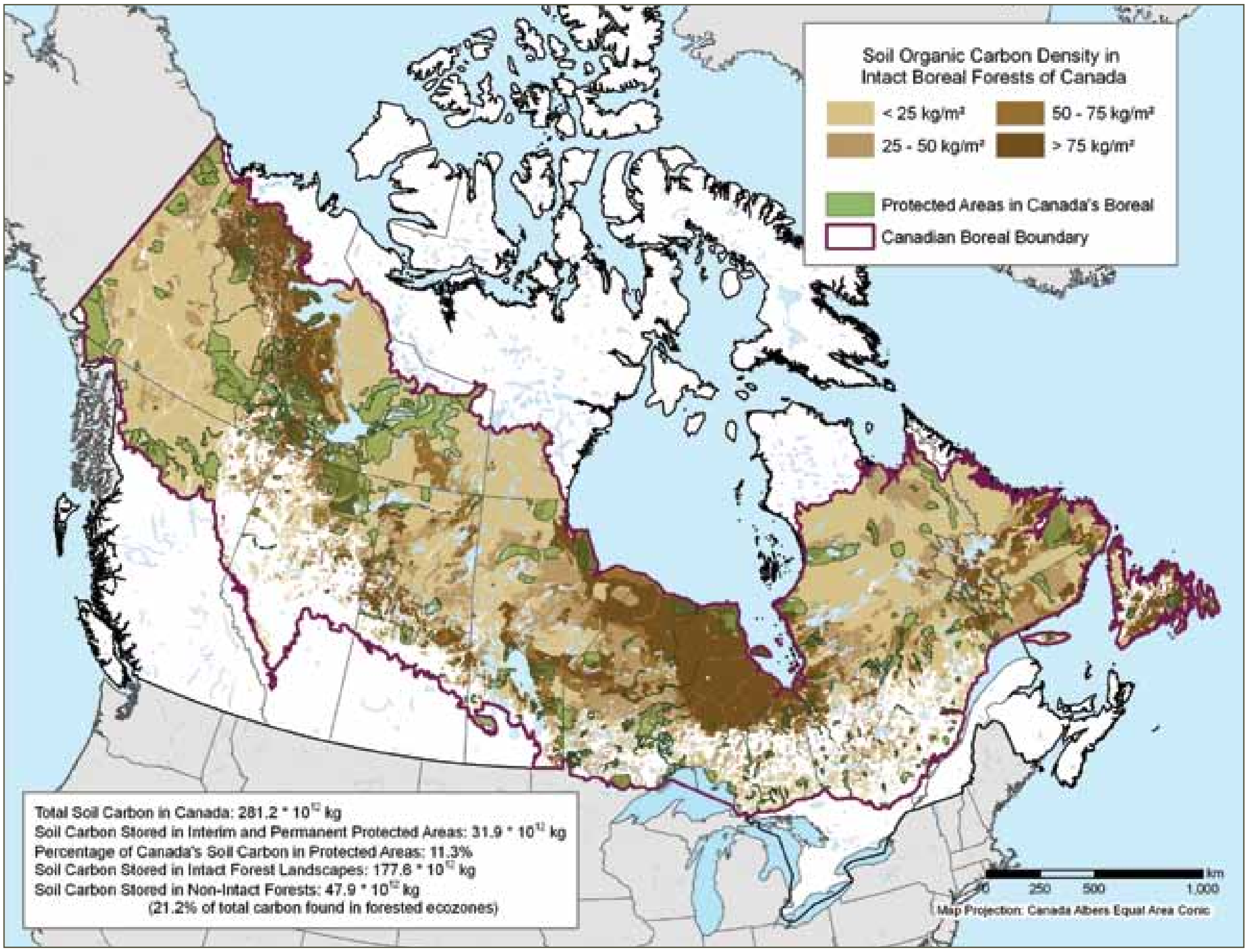


Figure 9. Protected areas and carbon storage in Canada's Boreal Forest. Almost 90% of Canada's soil carbon remains outside protected areas.

Source: Global Forest Watch Canada and the Soil Organic Carbon Digital Database of Canada (1996).

The governments of Ontario and Quebec have both identified terrestrial carbon conservation as part of the basis for commitments to protect half of their northern boreal forest, an area accounting for over 725,000 km².

Peatlands are among the most carbon-rich ecosystems on the planet, storing the equivalent of half of the carbon that exists in the atmosphere as CO_2

JEFF WELLS

Implications for Policy

Although the Kyoto Protocol was a step forward in climate change policy, the protocol has several deficiencies with respect to how it accounts for biotic carbon. The protocol's framework for Land Use, Land-Use Change and Forestry (LULUCF) rightfully requires signatories to account for changes in forest area caused by deforestation, afforestation, and reforestation. Inclusion of forest management activities such as forestry, however, is optional and many countries (including Canada) have chosen to exclude it. Kyoto's rules for forest management require countries to report changes in forest carbon caused not only by human activities but also natural disturbances. Understandably, many countries have been unwilling to shoulder the risk to carbon associated with fires and insect outbreaks, a risk that is likely to increase in the future. As a result, for Canada and many other countries, Kyoto does not create an incentive for forest conservation and sustainable management practices beneficial to biotic carbon. Another glaring deficiency of the Kyoto protocol is that peatlands are not included. Kyoto therefore also does not create an incentive for conserving peatlands, among the most carbon-rich ecosystems on the planet.

Future climate change protocols must be better suited to motivate stewardship of the massive quantity of carbon stored in forest and peatland ecosystems. First and foremost, countries must commit to ambitious reductions in greenhouse gas emissions. Northern ecosystems such as those of Canada's Boreal Forest region are already experiencing the effects of rapid climate change, and emission reductions are urgently needed in an attempt to avoid catastrophe. Given the size of the biotic carbon store, however, we cannot afford to have land-use impacts only partially addressed by the protocol. Two simple changes to the protocol that would have far-reaching beneficial impacts are 1) inclusion of peatland carbon; and 2) mandatory accounting of all carbon emissions

Northern ecosystems such as those of Canada's Boreal Forest region are already experiencing the effects of rapid climate change, and emission reductions are urgently needed in an attempt to avoid catastrophe.

Canada's Boreal Forest has a particularly high density of wetlands GARTH LENZ

Boreal forest on the north shore of Lake Superior GARTH LENZ

Future climate change protocols must be better suited to motivate stewardship of the massive quantity of carbon stored in forest and peatland ecosystems.

from forest management, without an obligation to account for emissions caused by natural disturbances. These changes alone would motivate large improvements in the management of biotic carbon. Many of the improvements would be related to conservation and sustainable management, and would therefore also help maintain the capacity of ecosystems to adapt to climate change. It is likely, however, that some mitigation activities motivated by policy as complex as the climate change agreement will negatively affect the integrity of ecosystems and reduce the capacity of ecosystems to adapt. The post-2012 agreement should ensure against such counter-productive activities by requiring biotic carbon projects to have a positive or neutral effect on biodiversity and ecosystem services in order to maintain capacity to adapt.[6]

While changes to United Nations Framework Convention on Climate Change protocols are vital in advancing solutions to climate change, many other actions are underway to help in achieving reductions in greenhouse gas emissions and ensuring the protection of carbon stored in terrestrial ecosystems. These include both regulated and voluntary regional carbon trading schemes like the European Union Emission Trading Scheme, the Australian New South Wales market, and in North America, the Western Climate Initiative and the Regional Greenhouse Gas Initiative. Many or most of the emerging schemes include or are considering ways to include afforestation, reforestation, avoided deforestation, and/or other land-use management options that protect existing carbon or increase carbon sequestration. These and other policy mechanisms should formally recognize the importance of maintaining intact carbon stores in the Canadian Boreal Forest region and other terrestrial ecosystems and provide incentives for protecting and conserving large intact carbon rich ecosystems.

Awareness is building of the Canadian Boreal Forest region's crucial role in the earth's climate change future. As the world's largest terrestrial carbon storehouse and most intact biome, the global boreal region, including Canada's Boreal Forest region, is uniquely positioned to contribute to climate change mitigation and adaptation. At the same time, northern ecosystems are experiencing the fastest rate of climate change on the planet. Although considered a remote region by many, the Canadian Boreal Forest region is very much on the front lines of the battle against climate change. Policies, including a new international climate change agreement, are urgently needed that match scientific understanding of the region's mitigation and adaption potential.

6 A requirement for positive or neutral effects on biodiversity could be achieved through simple but effective sets of rules. For example, the following guidelines for forest biotic carbon projects are based on the relevance of mitigation options to different landscape contexts identified by the Secretariat of the Convention on Biological Diversity (2009): a) forest conservation is the only eligible project activity within an existing intact forest; b) afforestation and reforestation are appropriate in landscapes that have been previously cleared or degraded; and c) forest management, restoration, and conservation aimed at maintaining or increasing forest carbon stocks are appropriate in modified natural forests or plantations.

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