Enhancing Canada's Climate Change Ambitions with Natural Climate Solutions

By Risa B. Smith, Ph.D.

Peatlands Hudson Bay. Photo: Andre Erlich/istock

Vedalia Biological Inc.

ACKNOWLEDGEMENTS

This report was made possible with funding from the:

METCALF FOUNDATION

Assistance was provided by:

NATURE CONSERVANCY CANADA

and

IUCN WCPA WORLD COMMISSION ON PROTECTED AREAS

The author would also like to acknowledge the thoughtful review comments of many government, academic and non-government colleagues, which served to make the document stronger and the analysis better, and particularly the support of members of the Protected Areas Climate Change Specialist Group of IUCN/WCPA.

Suggested Citation: Risa B. Smith (2020) Enhancing Canada's Climate Change Ambitions with Natural Climate Solutions. Vedalia Biological Inc. Galiano, Canada. http://doi.org/10.13140/RG.2.2.18243.02088

ISBN 978-1-7773950-0-1

About the Author

Dr. Risa Smith is currently the Chair of World Commission on Protected Areas Climate Change Specialist Group. Over the past 25 years her professional interests have focussed on the interface between science and policy. She has led the development of Canada's positions at the United Nation's Convention on Biological Diversity (CBD), produced several state of environment style reports, including Canadian Biodiversity: Ecosystem Status and Trends 2010, served as Canadian representative and chair of Conservation of Arctic Flora and Fauna, and participated in many task forces and expert groups related to sustainable development, biodiversity and climate change. Her most recent publications focus on enhancing Canada's climate change ambition and the importance of tackling the biodiversity loss and climate change crises together.

Report available here or here

Enhancing Canada's Climate Change Ambitions with Natural Climate Solutions

Dr. Risa B. Smith
Chair Protected Areas Climate Change Specialist Group (IUCN/WCPA)
& Vedalia Biological Research Inc.
Risa.smith.wcpa.iucn@gmail.com

TABLE OF CONTENTS

Enhancing Canada's Climate Change Ambitions with Natural Climate Solutions

EXECUTIVE SUMMARY

This report investigates the most effective ways for Canada to leverage Natural Climate Solutions (NCS) to increase its climate change ambition. Five recommendations plus associated data and methodologies are presented. By far the most effective approach for obtaining short term results (*i.e.* by 2030) is to protect the most carbon-dense/high-biodiversity ecosystems. This is recommendation 1 – targeted protection - which will result in immediate reductions in greenhouse gas emissions (GHG) and large co-benefits for biodiversity and attaining Canada's goal of protecting 25% of its lands and waters by 2025 and 30% by 2030.

Protecting the remaining old-growth forests on high productivity sites, especially in British Columbia; old-growth boreal forest with long intervals between natural disturbances[1]; remnants of old-growth temperate forests, particularly in Ontario and Quebec[2]; and native prairie grasslands, would result in immediate emissions reductions of about 5 Mt CO_2 per year, by maintaining the ability of those ecosystems that are under imminent threat to sequester carbon. In the short-term emissions reductions of 1.8 to 11 billion tonnes (Gt) CO_2e would be achieved from preventing the release of stored carbon. Over the longer term (*i.e.* post 2050) protection of these ecosystems would result in over 500 Mt CO_2 which would continue to be sequestered from the atmosphere and avoided emissions from the release of stored carbon of up to 35 to 186 Gt CO_2e. This same policy would have a co-benefit of increasing total terrestrial conserved and protected areas by approximately 1.3 million km^2.

Protecting the remaining carbon-dense coastal ecosystems, such as saltmarshes and eelgrass beds, would result in direct emissions reductions of up 5.1 Mt CO_2 per year. Further emissions reductions of 33 to 3,750 Mt of CO_2e would be achieved by keeping the stored carbon that is currently

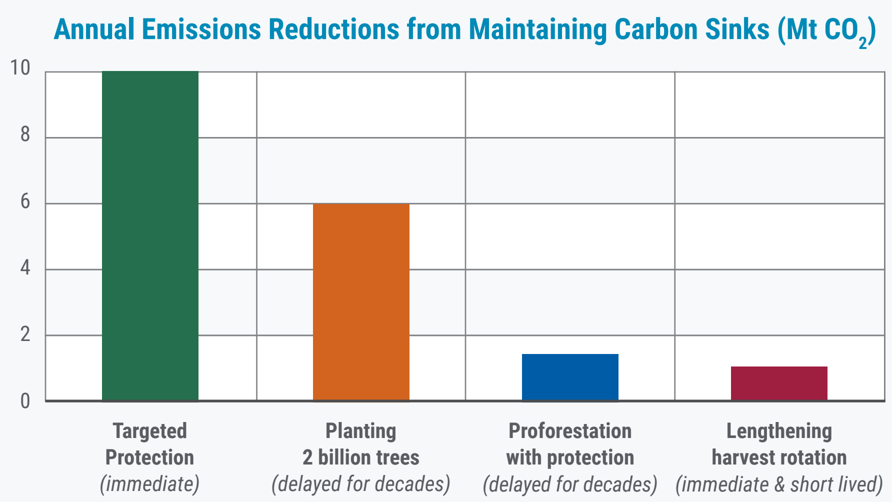


FIGURE 1: Protection of carbon-rich/high biodiversity areas, that are designated for logging or development, results in the greatest immediate reduction in annual greenhouse gas emissions. Note that for boreal forests this includes only forests older than 200 years. For all forests, it includes only the total area that is harvested annually, as that area is immediately threatened. This includes protection of blue carbon (eelgrass and saltmarshes). The impacts of increasing the area of older forests by letting younger forests grow old (*i.e.* proforestation) and planting 2 billion trees are also significant, but they are time-delayed with emissions reductions not being realized for decades or more. Lengthening the harvest period could have immediate benefits for CO_2 sequestration, but eventual harvest of these forests will negate most of the long-term benefits for CO_2 sequestration and carbon storage. Protection has the advantage of large co-benefits for biodiversity and contributing to Canada's goal of protecting 25% of its lands and waters by 2025 and 30% by 2030.

1 For the boreal forest this includes only boreal forest over 200 years

2 These old-growth forests fall within the FAO (2015) definition of primary forest

unprotected, intact. In addition, protecting the remaining saltmarshes and eelgrass beds would add approximately 2,400 km² to marine conserved and protected areas.

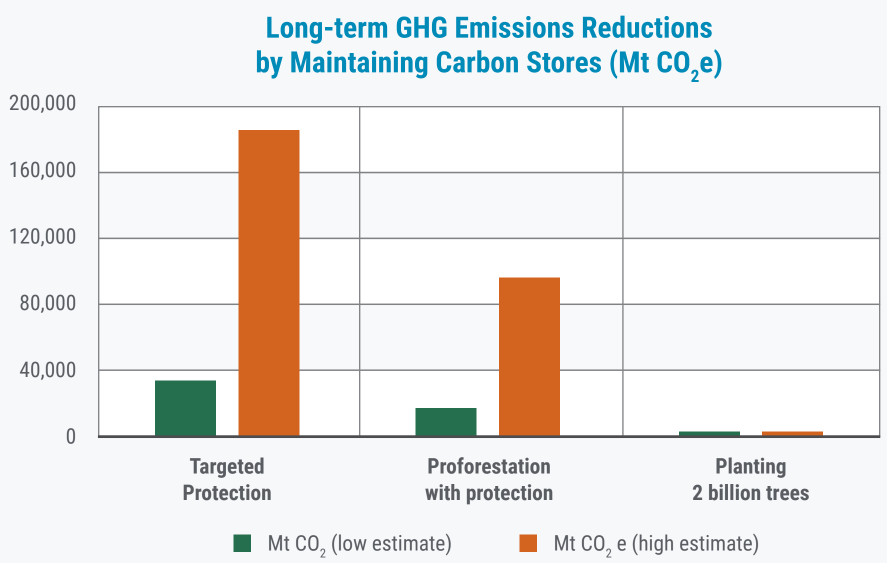


FIGURE 2: Emission reductions are also achieved by avoiding releases of stored carbon. Estimates of stored carbon vary, depending on a variety of factors including assumptions of the researcher, whether soil carbon as well as biomass is included, the ecosystem type, geography and climate. This graph shows the GHG emission savings resulting from full implementation of the recommendations, and including savings from protection of targeted ecosystems that are at risk from human activities, but the risk may or may not be imminent. For targeted protection, boreal forests over 200 years are reflected in the calculations.

Recommendation 2 identifies additional gains, also with dual benefits for biodiversity and climate change, that can be attained by growing 30% of managed forests currently over 60 years old to ecological maturity and protecting them. This is referred to as 'proforestation with protection'. These forests could replace, over time, up to half of the ancient forests (*i.e.* the high carbon density/ high biodiversity forests) that Canada has lost since pre-European contact. This recommendation would result in reduced annual emissions of 1.5 Mt CO_2, starting now, and emission reductions would increase over time, as the 1.5 Mt CO_2 only includes the portion of forest that is in imminent danger of harvest (*i.e.* annual harvest). In addition, immediate emissions reductions of 126 Mt CO_2e would be realized by retaining the stored carbon in these forests. This too would increase over time as these forests age and increase their carbon stores. Ultimately, over many decades, these forests would sequester more than 470 Mt CO_2 per year. This recommendation would also increase protected areas by approximately 1.4 million km².

Recommendation 3 - increasing the length of time between harvests - as suggested by Canadian Council of Forest Ministers (2018) - would have short term benefits to help Canada enhance its climate change ambitions to 2030. However, as these forests would eventually be logged the benefits would be ephemeral. For example, increasing the period between harvests on 25% of the area currently harvested annually would result in emission reductions of about 1.2 Mt CO_2 per year until these forests are harvested. Depending on the how long the rotation period is extended, this could potentially allow secondary forests to develop some of the old-growth characteristics important for many species at risk.

To put this in context, Canada released 729 Mt CO_2e in 2018 and is currently not on track to reduce its emissions to 511 Mt CO_2e per year by 2030, as promised in its current Nationally Determined Contribution (NDC) to the Paris Climate Agreement. Natural Climate Solutions (NCS) can increase climate change ambitions, while addressing the loss of biodiversity, with the same investment. The resilient, diverse ecosystems resulting from implementation of these recommendations are Canada's best hedge against the impacts of climate change, biodiversity loss and maintenance of the many ecosystem services that natural ecosystems provide.

Canada's most recent GHG inventory claims that in 2018, the latest year for which data are available, the Land Use, Land Use Change and Forestry (LULUCF) sector was responsible for a net removal of 13 Mt CO_2 from the atmosphere, and projects that the contribution of LULUCF will decrease to 10 Mt CO_2e in 2030 (Table 5.6 ECCC 2020). Recommendations 1, 2 and 3 provide options that could more than double the importance of LULUCF by 2030. However, it would require Canada to expand what it reports on to include ecosystems other than forests, such as grasslands, peatlands and coastal ecosystems, in its inventory.

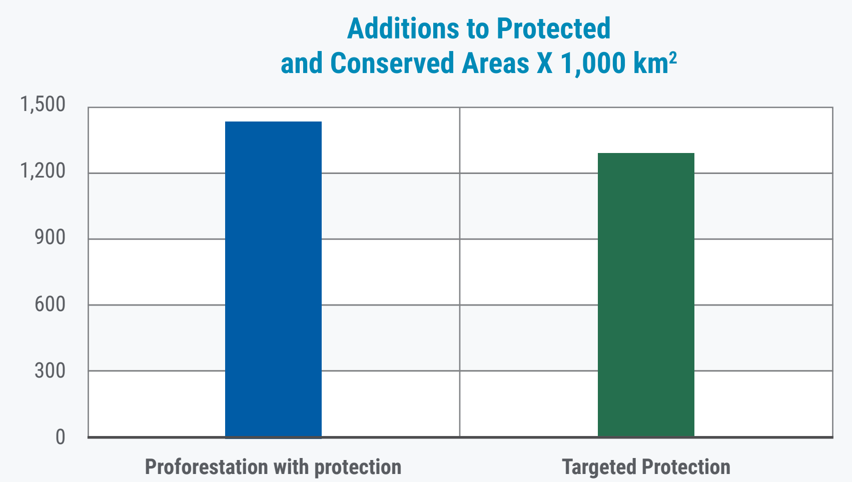


FIGURE 3: Additions to Protected and Conserved Areas. These recommendations would result in significant increases to Canada's protected and conserved areas of 1.3 million km^2 terrestrial and 2,400 km^2 marine areas for recommendation 1, targeted protection, and 1.4 million km^2 for recommendation 2, protection of 30% of forests over 60 years. These are not additive because of partial overlap between areas that would be protected in these two recommendations.

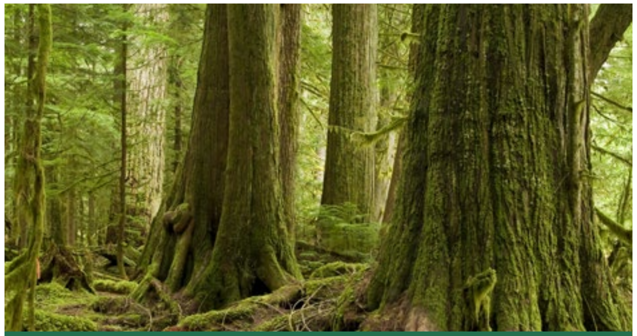
Recommendation 4 discusses two options for restoration. Restoration is not discussed in detail because the focus of this investigation was on short-term results. Most restoration activities, while important, do not realize emission reductions for decades, including planting the 2 billion trees that the government has already committed to.

Planting 2 billion trees would sequester between 4 and 8 Mt CO_2 per year, when they are mature. Depending on what is planted, where it is planted, and if the trees are stewarded to mitigate climate change and reduce biodiversity loss over the long-term, this initiative could have multiple benefits for urban air quality, biodiversity and community well-being decades down the road. The United Nations has declared 2021 to 2030 the "UN Decade on Ecosystem Restoration". This provides an opportunity for all countries, including Canada, to increase their restoration ambitions with the aim of long term gains for biodiversity, climate change and human well-being.

Recommendation 4 also notes the investments in coastal restoration already underway and the benefits for carbon dynamics, which currently go unrecognized.

Recommendation 5 highlights the need to invest in Natural Climate Solutions if the benefits for biodiversity and climate change are to be realized.

RECOMMENDATIONS AT A GLANCE

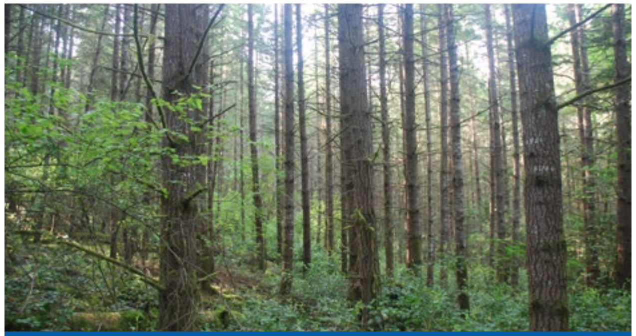


RECOMMENDATION 1

TARGETED PROTECTION

Protect threatened, intact, carbon-dense/high-biodiversity ecosystems: the most effective Natural Climate Solution to 2030.

- Reduces CO_2 emissions by about 10 Mt CO_2 per year, by maintaining carbon sinks, for ecosystems under imminent threat. By 2030 this would increase to over 175 Mt CO_2 per year.
- Avoids emissions of 586 Mt CO_2e per year by maintaining carbon stores, for ecosystems under imminent threat. By 2030 this could avoid emissions of 1.8 to 11 billion tonnes (Gt) of CO_2e that would not be released from Canada's vast carbon stores; beyond 2050 it avoids emissions of 35 to 186 Gt CO_2e.
- Increases protected and conserved areas by 1.3 million km^2 (terrestrial) and 2,400 km^2 (coastal).



RECOMMENDATION 2

PROFORESTATION WITH PROTECTION

Grow 30% of Canada's forests over 60 years old to their ecological potential, recreating a more resilient forest and replacing some of the old forests that have been lost. To make these gains permanent these forests would have to be protected.

- Reduces emissions by 1.5 Mt CO_2 per year by maintaining carbon sinks for forests under imminent threat. Beyond 2050 this would increase the forest carbon sink to over 470 Mt CO_2 per year.
- Avoids emissions of 126 Mt CO_2e per year by maintaining carbon stores, under imminent threat. Beyond 2050 this would avoid emissions of 17.7 to 99 Gt CO_2e.
- Increases protected areas by approximately 1.4 million km^2.

RECOMMENDATION 3

LENGTHENED HARVEST ROTATION

Lengthen the harvest rotation in managed forests by letting forests grow until they reach their full carbon sequestration potential.

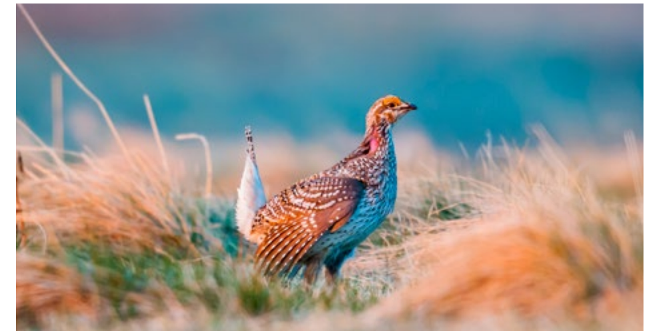
- If implemented on 25% of the harvested land base, reduces emissions by at least 1.2 Mt CO_2 per year for every year of delayed harvest. Annual increases would depend on multiple factors.
- No long-term benefits for either protected areas or maintaining carbon stores would be achieved, as these forests would eventually be harvested.

RECOMMENDATION 4

RESTORATION EXAMPLES

Plant 2 billion trees and quantify the GHG emission benefits of ongoing saltmarsh and eelgrass restoration. These are two of many long-term commitments needed to restore lost and degraded ecosystems that sequester CO_2 from the atmosphere, are important carbon stores and provide co-benefits for biodiversity and other ecosystem services.

- Results not measurable for decades or more.
- 2 billion trees would reduce emissions by 4 to 8 Mt CO_2 per year by creating carbon sinks, with benefits being realized post 2050.
- Long term benefits for carbon storage and biodiversity would be substantial, but depend on many factors and are difficult to quantify.
- Restoration of saltmarshes and eelgrass beds will have a large impact on carbon sinks. For example, restoration of 20% of the saltmarshes in the Bay of Fundy, by one estimate, would sequester an additional 3.55 Mt CO_2 per year.



RECOMMENDATION 5

FINANCIAL RESOURCES

Commit the necessary financial investments to ensure that NCS have significant impacts on reducing GHG emissions and reversing the loss of biodiversity.

- Addressing the linked crises of biodiversity loss and climate change together leverages multiple benefits from the same investments and avoids unintended negative consequences.

CONTEXT

All pathways to limiting global warming to increases of either 2°C or 1.5°C of pre-industrial levels require the use of NCS (IPCC 2018) to both reduce greenhouse gas (GHG) emissions and to remove CO_2 from the atmosphere. There is also general agreement that biodiversity loss and climate change are twin crises, and that enhancing the contributions of natural systems to climate change mitigation and adaptation has to include addressing biodiversity loss at the same time (Rogelj et al. 2018) (UNFCCC 2020a, Dec. 1/CP.25/para 15; Executive Secretary of Convention on Biological Diversity 2019). This report recommends NCS include only solutions that both reduce GHG emissions and address biodiversity loss. Solutions that may reduce GHG emissions but have unintended negative consequences for biodiversity are excluded.

There are two equally important aspects to NCS: i) protecting the vast carbon stores in Canada's ecosystems from release into the atmosphere through human activities; and ii) avoiding human activities that reduce the ability of Canada's natural ecosystems to remove carbon dioxide (CO_2) from the atmosphere. As Canada is responsible for nearly one-third of global land-based carbon storage (estimated by Shea et al. 2018), Canada has a global responsibility to protect these carbon stores as well as to improve the ability of its ecosystems to sequester CO_2 from the atmosphere.

It is important to acknowledge that Canada has, over the last 30 years, invested in the difficult exercise of tracking greenhouse gas (GHG) emissions, that are a result of human activities, from some ecosystems. For example, Canada tracks the extent to which its managed forests sequester CO_2 from the atmosphere, and GHG emissions released into the atmosphere from logging. Therefore, Canada is able to credibly report, using rules established under the United Nations Framework Convention on Climate Change (UNFCCC), on the extent to which its managed forests and some other ecosystems sequester or emit GHGs. However, increasing ambition in Canada's Nationally Determined Contribution (NDC) to the Paris Agreement requires being able to account for emissions from human activities in natural ecosystems outside forests, such as coastal ecosystems, peatlands and native grasslands. It also requires being able to differentiate the harvest of intact, primary forests from secondary forests, particularly because the replacement of a primary forest with a secondary forest results in a large reduction in carbon stores (~40%) (Kurz et al. 1998; Lewis et al. 2019).

TEMPORAL CONSIDERATIONS

IPCC (2019) emphasized that some NCS have immediate impact, while other solutions take decades or more to deliver measurable results. Immediate impacts can be obtained from conservation of high-carbon ecosystems (*i.e.* primary forests, peatlands, wetlands, rangelands, and blue carbon that are slated for industrial activities). Other options are important and require implementation within the next few years to deliver real results for GHG emissions by 2050 or beyond. These options include afforestation, reforestation and reclamation of degraded soils. As well, some approaches are temporary and do not sequester carbon indefinitely (*i.e.* afforestation, reforestation of lands that will be harvested, increasing the period between harvests). Conservation of some ecosystems, such as peatlands, can continue to sequester carbon for centuries and store it for equally long periods (IPCC 2019).

LIMITATIONS OF THESE RECOMMENDATIONS

These recommendations are limited to how natural ecosystems such as forests, coastal blue carbon ecosystems, peatlands and grasslands can be leveraged to enhance Canada's ambitions in its NDC by 2030. Other practices, such as improvements in agriculture, are also important aspects of increasing Canada's ambitions. For example, on a global scale, it is recognized that improvements in agriculture could reduce emissions by 22% (Tubiello et al. 2014; Griscom et al. 2017). Canada's fourth report to the UNFCCC (ECCC 2020) indicates that cropland in 2017 sequestered 6.6 Mt CO_2 and predicts that this will decrease to 1.5 Mt CO_2 in 2030. An entire report could be written on scenarios for improving the ability of agricultural soils in Canada to sequester and store carbon. However, this report is focussed on natural ecosystems and gains to be made by 2030.

Grasslands near Kamloops, BC. Photo: Miroslav_1/istock

METHODOLOGY

In this analysis, the baseline for emissions reductions is measured against emissions that would occur if planned activities take place. For example, in the recommendations it is suggested that the remaining old-growth forest on high productivity sites in BC be protected. As these forests are currently designated for harvesting, there will be emissions reductions if they are protected rather than harvested. All of the emissions reductions by not logging old-growth forests also take into consideration that the forests proposed for protection are not subject to frequent natural disturbance by fire.

However, the extent to which climate change might cause feedbacks which change the patterns of natural disturbances on Canada's ecosystems was not estimated. Any of Canada's ecosystems could reach tipping points that turn sinks into sources. This in turn could alter the significance of particular NCS pathways. These types of predictions are very difficult to make with reasonable certainty. Still, it is well understood that the best hedge against complex feedbacks to natural systems from climate change is to manage for the resilience provided by natural, biologically diverse ecosystems.

There is no comprehensive data source for carbon sequestration and carbon storage in natural ecosystems in Canada. Most of the information was mined from peer reviewed research, where the estimates of carbon dioxide sequestration and carbon storage vary widely. The issue of data variability was resolved by providing the ranges and sources for each number. As well, separating immediate threats from longer term threats is possible for forests, where the area harvested annually is readily available. Therefore, for forests, emissions reductions from the imminent threat of logging are separated from longer term threats. For other ecosystems, credible numbers on imminent threats as compared to longer term threats are not available. Finally, although the carbon stored in peatlands is provided in Annex I, it is not included in the total calculations as the greatest threat to carbon dynamics in peatlands is methane releases as a result of warming permafrost. The extent to which this is happening, and the time frame on which it will happen, is a matter of conjecture. The detailed ranges, methodologies and sources for all calculations are in Annex I and its endnotes.

3 STEPS TO ATTAINING THE PARIS CLIMATE AGREEMENT

1. Reduce fossil fuel emissions

Emissions from transportation. Photo: FatCamera/istock

2. Prevent conversion of carbon sinks and stores

Boreal forest deforestation for oil sands development. Photo: Jiri Rezac

3. Remove CO_2 from the atmosphere by protecting carbon sinks

Boreal Forest in Quebec. Photo: Onfokus/istock

PRINCIPLES FOR THE CANADIAN CONTEXT

1. While NCS can make a significant contribution to reducing GHG emissions both globally and in Canada, the benefits of NCS do not decrease the imperative for direct reduction in GHG emissions from the energy sector (Anderson et al. 2019; Seddon et al. 2020). In other words NCS are an important piece of the puzzle in reducing GHG emissions, but in Canada, where GHG emissions from the combustion of fossil fuels overwhelm the national GHG inventory (ECCC 2020), NCS do not replace the importance of reducing emissions from fossil fuels quickly (Baldocchi and Penuelas 2019).

2. Achieving co-benefits for climate change and biodiversity is essential when considering NCS. Solutions that might have a short-term impact on GHG emissions but unintended negative consequences on biodiversity are not viable NCS. Solutions that, for example, result in increased use of wood for construction, thereby storing the carbon in structures rather than releasing it into the atmosphere, might have a short-term benefit for GHG emissions, but could have a negative consequence for biodiversity if they result in increased harvesting of carbon-dense primary forests (which contain the best trees for lumber). The negative consequences would be on the already at-risk biodiversity that is dependent on the now rare primary forests (*e.g.* Mountain caribou, boreal birds).

3. Accounting for the risks to permanence of NCS is paramount. Several disturbances can affect the ability of ecosystems to continue to sequester carbon or to maintain their carbon stores including fires, droughts and insect outbreaks. In addition, these risks are exacerbated by climate change, but difficult to quantify. Consideration of risk to permanence has been included in Recommendation 1, where only forests with long intervals between fires are recommended for protection.

4. Addressing rights and title of Indigenous Peoples is increasingly recognized as going hand-in-hand with effective NCS. Much of the remaining intact landscapes and seascapes of interest for both conservation and climate change mitigation are within Indigenous territories – both within Canada and internationally (Artelle et al. 2019) (Figure 4).

5. There are two equally important aspects to NCS: protecting the carbon stored over long periods (*i.e.* often hundreds but sometimes thousands of years) so that it doesn't end up back in the atmosphere; and protecting and increasing the amount of carbon dioxide that an ecosystem can take out of the atmosphere annually, to counter emissions from other sources. Climate smart policy, including implementation of NCS, requires both 'catch and store' (Talberth 2017).

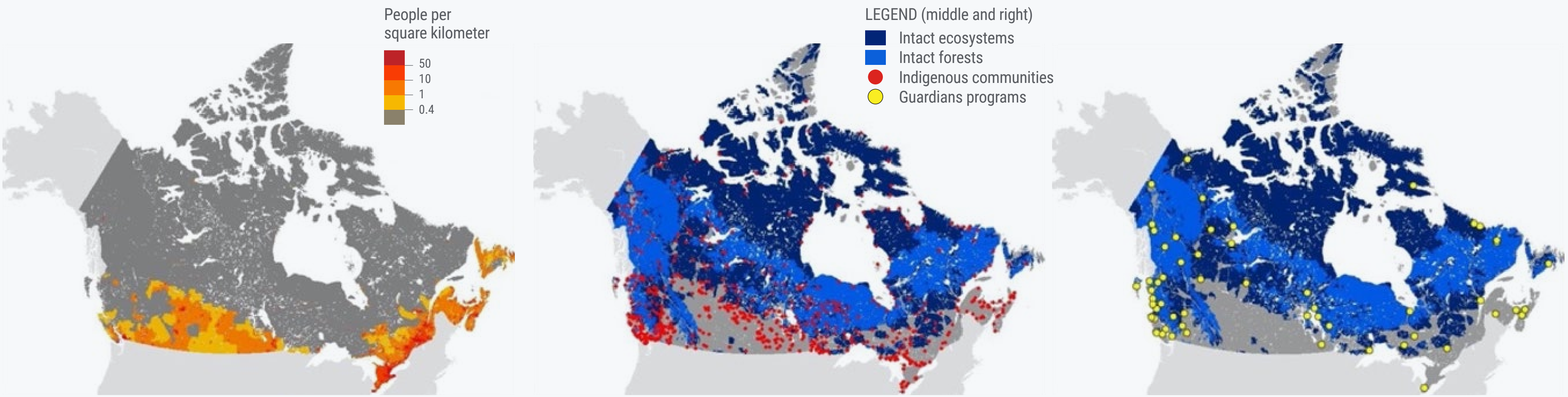


FIGURE 4: Source (Artelle et al. 2019) (Left) Total human population density across Canada, based on 2016 census. (Middle) Indigenous communities locations represented as red dots, as described by Crown-Indigenous Relations and Northern Affairs Canada's "First Nations Location" and "Inuit Community Location" datasets. (Right) Present and emerging Guardian programs represented as yellow dots, as depicted in the "Indigenous Guardians Toolkit" (indigenousguardianstoolkit.ca/map), the "Indigenous Guardians Pilot Program Map" canada.ca/en/environment-climate-change/services/environmental-funding/indigenous-guardians-pilot-program/map.html , and a map of Coastal Guardian Watchmen locations at Coastal First Nations coastalfirstnations.ca/our-environment/programs/coastal-guardian-watchmen-support/. Underlying polygons in the middle and right panels denote intact ecosystems as described in the "last of the wild" dataset (Watson et al., 2018b; dark blue), and Intact Forest Layer (Potapov et al., 2017; light blue)

RECOMMENDATION 1

TARGETED PROTECTION

Protecting threatened, intact, carbon-dense/high-biodiversity ecosystems: the most effective Natural Climate Solution to 2030.

Western Red Cedar, Coastal BC. Photo: Timothy Epp/Shutterstock.com

ANALYSIS

RECOMMENDATION 1: TARGETED PROTECTION

Protection of carbon-dense ecosystems slated for some form of industrial activity, be it logging old-growth forests, removing saltmarshes through dyking, building roads, hydro dams or fossil fuel infrastructure on peatlands, or converting grasslands to agriculture, results in emissions reductions from retaining in situ carbon. Protection also reduces emissions by maintaining the ongoing ability of these ecosystems to remove carbon dioxide from the atmosphere (Anderson et al. 2019; Smyth et al. 2014; Böttcher and Lindner 2010; IPCC 2019).

Protection of the most carbon-dense/high-biodiversity ecosystems, under imminent threat, would result in removal of up to 10 Mt CO_2 per year from the atmosphere on implementation, to over 175 Mt CO_2 per year by 2030. As well, emissions of 586 Mt CO_2e would be avoided by maintaining carbon stores under imminent threat. By 2030 this would increase to 1.8 to 11 billion tonnes (Gt) of CO_2e and beyond 2050 it would increase to between 35 and 186 Gt of CO_2e.

In the Canadian context, this means reduced human activity, particularly in the areas with the highest stored carbon and the greatest potential for carbon sequestration, the greatest potential to reverse the loss of biodiversity and the greatest potential to ensure resilient ecosystems. Specific actions are : i) a moratorium on harvesting in the now rare carbon-dense old-growth forests, on high productivity sites, in British Columbia, old-growth boreal forests, which are mostly in Quebec, Ontario and Newfoundland and Labrador, and remnants of old-growth Carolinian forests of Ontario, Quebec and the Maritimes; ii) no further conversion of natural grasslands to other uses, such as agriculture, mostly in Alberta, Manitoba, Saskatchewan; iii) increased protection of intact boreal forests with high soil carbon densities, particularly in Ontario, Quebec and Newfoundland and Labrador; iv) moratorium on further destruction of remaining eelgrass meadows and saltmarshes on all three coasts; v) moratorium on drainage of peatlands for industrial activities.

The importance of conservation is increasingly recognized as a key policy tool to achieve the dual targets of reducing greenhouse gas emissions and reversing biodiversity loss (Böttcher and Lindner

2010; Stinson et al. 2011). For example, the European Union (EU) has recently decided to strictly protect the EU's remaining primary forests, as well as other carbon-rich ecosystems such as peatlands, grassland, wetlands and coastal marine zones (European Commission 2020).

FORESTS

The intact temperate and boreal primary forests of the US Pacific Northwest, Canada and Russia are responsible for 8 to 20 % of the global terrestrial carbon sink of roughly 0.4 billion tonnes (Gt) of carbon dioxide sequestered per year (Biello 2008). Equally important as carbon sequestration is carbon storage. Temperate forests store about 119 Gt of carbon, most of it above ground. Only 9.6% of primary temperate forests remain globally. By contrast, boreal forests store about 1042 Gt of carbon, the vast majority of it below ground. About 42.6% of primary boreal forest remain intact (Pan et al. 2011).

Several international organizations have mapped the remaining intact ecosystems of Canada and the world (*e.g.* Figure 5). Russia, Canada, Australia, U.S. and Brazil together contain about 70% of the world's remaining intact ecosystems (Watson et al. 2018b). The exceptional value of these intact ecosystems for climate mitigation and adaptation, water regulation, biodiversity conservation, and maintenance of large-scale ecosystem processes has been demonstrated by many (Watson et al. 2018a; Woods Hole Research Center et al. 2020; Strassburg et al. 2010).

Soto-Navarro et al. (2020) demonstrated that Canada is among the top countries with both high carbon density and high ecosystem intactness (Figure 5). The carbon density of both forest biomass and soil has been mapped by World Wildlife Fund Canada (Arabian et al. 2019), showing that carbon density is not equally distributed across the country (Figure 6).

Forest harvesting targets carbon-dense old-growth stands – referred to as ancient or primary forests internationally - because they provide the best quality and highest yield timber. As a result, old-growth stands are becoming increasingly rare (Didion et al. 2007; Statistics Canada 2018; Gorley and Merkel 2020).

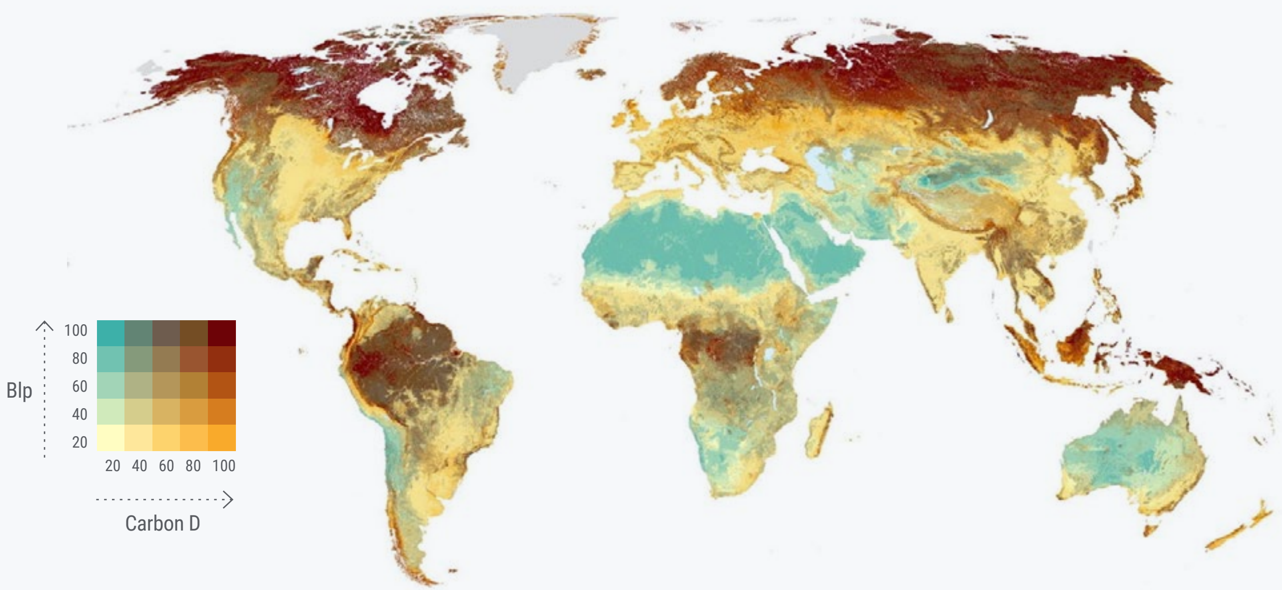


FIGURE 5: Map showing the overlap of carbon dense areas and areas of high irreplaceability for biodiversity. For Canada this is in Western Canada, including coastal and interior BC forests, Alberta, North, Hudson Bay Lowlands, Boreal Forests of Quebec, Ontario and NL, and parts of Nova Scotia. The BIp (Proactive biodiversity index) represents areas of high local biodiversity (high richness and range size rarity of remaining species, high local intactness and high average habitat condition across the broader area). These areas urgently require targeted protection to ensure the long-term persistence of biodiversity and to maximize the climate mitigation potential of ecosystems. Source: (Soto-Navarro et al. 2020). Reprinted with permission.

Carbon storage in primary or old-growth forests

There is general agreement that old-growth forests in Canada store a lot of carbon and that anywhere from 40% (DellaSala 2018) to 66% (Woods Hole Research Center et al. 2020) is lost to the atmosphere in the first 5 years after logging. Carbon accounting for all of the remnant old-growth forests, and particularly those forests with big trees on productive lands, remains elusive. Examples of estimated stored carbon in some of these forests range from:

- 197 to 468 Mt carbon for the old-growth forests on high productivity sites in British Columbia (calculated using Price et al. 2020; Stinson et al. 2011; Mosseler et al. 2003a; Fredeen et al. 2005). Note however that the lower estimate does not include soil carbon;
- 4.8 Mt for the 240 km² of unprotected old-growth forests of Algonquin Park, Ontario (calculated using Henry 2020);
- 24,850 to 137,850 Mt C for the boreal forests over 100 years old; 13,694 to 75,960 Mt C for the boreal forests over 200 years; 8,114 to 45,010 Mt C for the boreal forests over 300 years. Old-growth boreal forest carbon is calculated from Bradshaw and Warkentin (2015) and Wiken et al. (1996).

The age of boreal forests varies across the country, with some stands well over 200 years in eastern Quebec and sub-boreal British Columbia and over 100 years in Manitoba (Kneeshaw and Gauthier 2003). 71%, 80% and 89% of the carbon in old-growth boreal forests 100 years, 200 and 300 years old, respectively, is in the Boreal Cordillera, Hudson Plains, Eastern Boreal Shield, and Eastern Taiga Shield ecozones of Yukon, Manitoba, Ontario, Quebec and Newfoundland and Labrador. Boreal forests are generally younger in Western Canada because of more frequent and extensive natural disturbance by forest fires. It might seem counter-intuitive that older boreal forests store less carbon than younger boreal forests. On a per hectare basis, the older forests store more carbon. However, the larger area of the 100 year boreal forests, compared to the 300 year boreal forests, results in more total carbon being stored in the 100-year old forest.

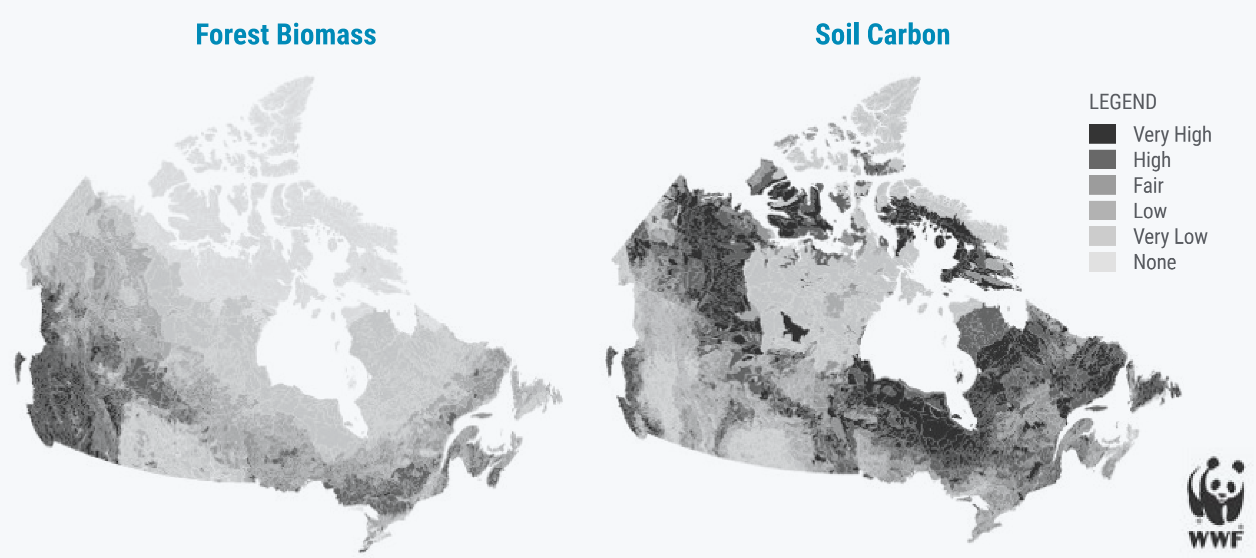


FIGURE 6: Areas of high carbon density in Canada. Reducing GHG emissions by protecting carbon-dense ecosystems from both the loss of their carbon stores and their ability to continue to sequester CO_2 is the most effective way to reduce greenhouse gas emissions in the short term (*i.e.* before 2030) using Natural Climate Solutions. In Canada, the areas storing the most above ground carbon are found in British Columbia and throughout the boreal forest and the Maritimes. The areas with the highest density of soil carbon are found in Newfoundland and Labrador, Quebec, Northern Ontario and the Yukon/Northwest Territories boundary. These maps and accompanying analysis were created by WWF-Canada 2019 and are used with permission from WWF Canada. Source: (Arabian et al. 2019).

Emissions Reductions by Maintaining Stored Carbon in Forests Under Imminent Threat from Logging (Mt CO_2e)

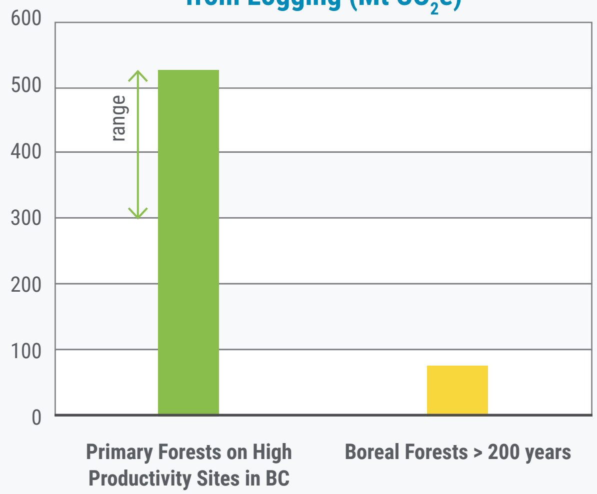


FIGURE 7: The small remaining area of primary forest on high productivity sites in BC (~ 415,000 ha) is believed to be one of the most carbon dense ecosystems in the world. This small area will release up to 526 Mt CO_2e when logged. Its vulnerability to logging makes it particularly important for immediate protection, both from carbon dynamics and biodiversity viewpoints. Older boreal forests are also important, particularly for below ground carbon storage. However, a smaller area is under imminent threat of logging. Although release of stored carbon from older boreal forests is estimated at about 60 Mt CO_2e over the next few years, over the long-term, release of carbon stores from currently unprotected boreal forests over 200 years old could reach up to 174 billion tonnes (Gt) CO_2e.

Carbon dioxide sequestration by forests

Some controversy exists around the role of old-growth forests in carbon sequestration. For many years it was believed that once a forest reaches a certain age, depending on a number of biological and environmental parameters, it no longer sequesters CO_2 from the atmosphere. This was used as a rationale for targeting old-growth forests for logging. More recent research has shown that old-growth forests continue to sequester CO_2 from the atmosphere, thereby continually increasing their carbon stores, for up to 400 years (Morales-Hidalgo et al. 2015; Gray and Whittier 2017; DellaSala 2018).

Estimates of CO_2 sequestration in old-growth forests range from:

- 0.14 to 2.7 Mt CO_2 per year for the 4,150 km^2 old-growth forests on the most productive sites in British Columbia (Gray et al. 2016; Canadian Council of Forest Ministers 2018);
- 925 Mt, 510 Mt, 302 Mt CO_2 per year for boreal forests older than 100 years, 200 years and 300 years, respectively. Most of these old-growth boreal forests are in Ontario, Quebec, Manitoba and Newfoundland and Labrador. Boreal forests are generally younger in Western Canada because of the more frequent and extensive disturbance by fire (calculated using data from: Bergeron and Fenton 2012; Canadian Council of Forest Ministers 2018; Wiken et al. 1996).

Converting old-growth forests with high carbon stocks and low CO_2 sequestration rates into young, fast-growing plantations with low carbon stocks but higher CO_2 sequestration rates, has a negative impact on the net carbon balance. This is because the large initial loss of carbon from harvesting cannot be compensated for within a conceivable period by the additional CO_2 sequestration in the growing plantation and storage in harvested wood products (Böttcher and Lindner 2010; Schulze et al. 2000; Kurz et al. 1998).

Carbon debt

One way to think about the impacts of logging on climate change mitigation is to consider how long it takes to recover the stored carbon and the carbon sequestering properties after logging, *i.e.* examining the so-called ‘carbon debt’. Some examples of carbon debt are:

- It takes 100 (Crowther et al. 2015) to more than 250 years (Harmon et al. 1990) after clearcut logging for a forest to reach its original level of carbon storage;
- Where stand-replacing natural disturbances are infrequent, such as the old-growth in BC’s highly productive sites and boreal old-growth in parts of Quebec, Ontario, Alberta and BC with fire intervals over 200 years (Kneeshaw and Gauthier 2003), transition from a natural forest to a managed forest results in a 42% reduction in carbon content of the managed forest (Kurz et al. 1998; Lewis et al. 2019);
- It takes 15 (Rooney et al. 2012) to 20 years (Lewis et al. 2019) for a freshly planted forest to exceed carbon emissions from decomposition of organic matter and become a net carbon sink;
- Increasing the use of wood from the boreal forest to replace coal in power plants or to generate liquid biofuels from wood creates a carbon debt of 190 to 340 years (Holtsmark 2012).

GRASSLANDS

Global grasslands, accounting for 40% of the terrestrial land mass, sequester approximately 0.5 Gt of carbon per year and store up to 343 Gt in the top metre of their soils. Carbon stocks in temperate and boreal grasslands, like those in Canada, have some of the highest carbon stocks in the world (Lorenz and Lal 2018). Most of Canada's original 615,000 km^2 of native grasslands were lost to other uses prior to 1990 (Wang et al. 2014), including 15-19% of British Columbia's Bunchgrass sagebrush, 70% of Prairie grasslands, 99% of Tallgrass prairie grasslands in Saskatchewan and 97% of Tallgrass savannah in Ontario (Federal Provincial and Territorial Governments of Canada 2010c).

Scientists agree a moratorium on further conversion of Prairie grasslands to crop agriculture is critical to protect carbon storage but also to provide habitat for declining grassland species.

Wild bison herd on prairie grassland. Photo: Nafinney/istock

Since 1970, populations of grassland birds have declined by 57% and species dependent on native grasslands by 87% (North American Bird Conservation Initiative Canada 2019).

Carbon storage in grasslands

Canada's remaining 12,700 km^2 of native Prairie grasslands store an estimated 2 to 3 billion tonnes (Gt) or 2,000 to 3,000 Mt of carbon. Ensuring no further conversion of Prairie grasslands could avoid emissions of 381 to 1905 Mt of stored carbon. This represents a loss of 30 to 50% of the stored carbon.

Carbon sequestration in grasslands

The remaining native prairie grasslands sequester about 2.41 Mt CO_2 per year. Most of the sequestration of atmospheric CO_2 from prairie grasslands would be lost by conversion to cropland or other uses.

PEATLANDS

Globally peatlands, tropical, temperate and boreal, remove CO_2 from the atmosphere and store it in deep layers of organic soil, which builds up over hundreds to thousands of years. Global peatlands store 600 Gt of carbon – equivalent to 30% of the worlds carbon stocks (Moomaw et al. 2018).

Carbon storage in peatlands

Canadian peatland systems store 136,700 to 154,000 Mt of carbon. Note that there is some double counting as these numbers are also included in boreal forest on peatlands (Carlson et al. 2009). Hudson Plains in Northern Canada is a significant and largely intact peatland complex covering 353,000 km^2. It provides habitat for many species of national and international concern and is only 12.8% protected (Abraham et al. 2011). Eighty-eight percent, 78% and 69% of the boreal forests in the Hudson Plains are over 100 years, 200 years and 300 years old, respectively. The peatland forests of the Hudson Plains sequester 74.6 Mt of CO_2 per year (Bergeron and Fenton 2012; Wiken et al. 1996).

Peatlands in Yukon. Photo: Pi-Lens/shutterstock.com

Because peatland soils store so much carbon, disturbing peatlands for development projects can result in turning a carbon sink into a carbon source fairly quickly. For example, the carbon impacts from changes to land approved for oil sands development in Alberta will release between 41.8 and 173.6 Mt CO_2 and reduce carbon sequestration potential by 57.34 to 72.41 Mt CO_2 per year (Rooney et al. 2012).

Because it is difficult to assess the imminent threat to peatlands, other than from the oil sands and peat extraction, peatlands were not considered in the totals for CO_2 sequestration and avoided emissions. However, avoiding threats from human activities, as they are identified, would result in significant reductions in GHG emissions from peatland loss. Forests on peatlands are included in the calculations for boreal forest.

PERMAFROST

Permafrost regions store 60% of the world's soil carbon in 15% of the global soil area amounting to 18 million km^2 of permafrost soils. The projected thawing of terrestrial and subsea Arctic permafrost – and the subsequent release of methane, which is estimated to have 87 times more global warming potential than CO_2 over 20 years (IPCC 2019) – is expected to increase the loss of soil carbon and affect the global terrestrial carbon sink (Turetsky et al. 2020).

BLUE CARBON

Blue carbon refers to the vegetated coastal zones on the near-shore. The most important blue carbon ecosystems for climate change mitigation and adaptation are mangroves, eelgrass beds and saltmarshes. Having the longest coastline in the world, over three coasts, Canada has both eelgrass and saltmarshes. Although coastal blue carbon systems sequester more carbon than forests, on an area basis, the sheer extent of forests makes forests a larger carbon sink (Smith et al. 2020).

Conservation of blue carbon ecosystems have significant co-benefits for biodiversity, livelihoods and protection of coastal communities. Blue carbon ecosystems provide protection from storm surges, flooding and sea-level rise (Thomas et al. 2020) and serve as nurseries and habitat for commercial fisheries species as well as 'at-risk' marine species. The role of blue carbon for climate change mitigation is particularly relevant for climate change adaptation, which is also an important component of NDCs to the Paris Agreement.

Saltmarshes

Tidal saltmarshes are found from the Arctic to Patagonia. They provide a variety of ecosystem services such as food and habitat for fish and birds, sinks for pollutants, protection from storms, and climate change mitigation. Like other blue carbon ecosystems, they are carbon dense on a per hectare basis. Estimates of global saltmarsh area varies from 22,000 to 400,000 km^2 (Duarte et al. 2013) to 55,000 km^2 (McOwen et al. 2017). Carbon storage in global saltmarshes has been estimated from 0.4 to 6.5 Gt C (Duarte et al. 2013) to 9.8 to 19.9 Gt (Fourqurean et al. 2012) to 0.09 to 3 Gt (Ouyang and Lee 2020). Global estimates of carbon sequestration by saltmarshes vary widely (4.8 - 87.3 Mt/year (Duarte et al. 2013); 27.4 – 40 Mt/year (Fourqurean et al. 2012); 0.9 - 31.4 Mt of CO_2/year (Ouyang and Lee 2020).

Saltmarsh at high tide in Prince Edward Island.
Photo: Crwpitman/istock

Seventy-seven percent (330 km^2) of pre-existing saltmarshes in the Bay of Fundy have been drained. Today Bay of Fundy saltmarshes cover 101 km^2 and store 14.2 Mt of carbon (Wollenberg et al. 2018). By the first half of the 20th century, 70% of the Fraser River estuary and 32% of estuaries on the east coast of Vancouver Island had been lost. Much of these lost estuaries contained saltmarshes. Although saltmarshes in Northern Canada are more sheltered from development than those in the south, one third of the saltmarsh area in the Hudson Plains has been destroyed by foraging pressure from increasing populations of Lesser Snow Geese (Federal Provincial and Territorial Governments of Canada 2010a). In addition, it is anticipated that sea-level rise will submerge over one third of remaining saltmarshes of the Fraser River (The Review Panel for the Roberts Bank Terminal 2 Project 2020).

This recommendation proposes protection of the remaining saltmarshes. However, it appears that environmental assessments of coastal developments do not consider the climate change impacts of development on saltmarshes. For example, the proponents of the Robert Bank Terminal 2, outside of Vancouver, have proposed to remove 12.26 hectares of saltmarsh. The offset proposed in this case (15 ha) is significantly smaller than the 4:1 offset (49 ha) proposed by Environment and Climate Change Canada (The Review Panel for the Roberts Bank Terminal 2 Project 2020).

Carbon storage and sequestration in saltmarshes in Canada

Although estimates of the area coverage of saltmarshes in Canada vary, the most recent estimate is 1,113 km^2 (McOwen et al. 2017). Canadian saltmarshes are estimated to store anywhere from 1.1 to 971 Mt of carbon and sequester 0.2 to 4.42 Mt CO_2/year (see Annex I notes 21-25). These numbers are comparable to those found for saltmarshes in Clayoquot Sound British Columba (Chastain 2017).

Eelgrass bed, Vancouver Island, BC. Photo: David Denning

Eelgrass

Eelgrass beds are important as both carbon sinks and stores. Carbon storage in global eelgrass beds is estimated at 4.2 to 8.4 Gt carbon (Duarte et al. 2013). Global eelgrass beds sequester between 48 and 112 Mt CO_2 per year. Eelgrass beds provide critical habitat for a multitude of fish, invertebrate and other species using eelgrass as nurseries and shelter from predators. For instance, 20% of the world's most-landed fish species use eelgrass as nursery areas (Baez 2020). Eelgrass beds also provide blue infrastructure, protecting coastal communities from storm surges and coastal erosion, as do saltmarshes.

Carbon sequestration and storage in eelgrass beds

Canada has mapped at least 643 km^2 (64,300 ha) of eelgrass, but mapping is incomplete. For northern British Columbia, there are almost 10,000 km of eelgrass measured with line data, but no area data. A fair amount of eelgrass area data exists for Canada's east coast and in Hudson Bay, but it is not included in total eelgrass area mapped by the Commission for Environmental Cooperation (CEC). As well, observations of eelgrass occurrences in the Gulf of St. Lawrence and the Maritimes are based on point observations without area data (CEC 2016). For this analysis it was assumed, based on the gaps in area data, and the amount of linear and point occurrence data that is known, that Canada has at least twice the area of eelgrass as has currently been mapped.

Canada's eelgrass beds are estimated to store 7.8 to 52.8 Mt of carbon and to sequester 0.1 to 0.71 Mt CO_2 per year.

RECOMMENDATION 2

PROFORESTATION WITH PROTECTION

Grow 30% of Canada's forests over 60 years old to their ecological potential, recreating a more resilient forest and replacing some of the old forests that have been lost. To make these gains permanent these forests must be protected.

Second growth forest, coastal BC. Photo: Risa Smith

ANALYSIS

RECOMMENDATION 2: PROFORESTATION WITH PROTECTION

The practice of letting young forests grow old to recreate some of the characteristics of lost primary forests is referred to as proforestation. Approximately 75% of Canada's managed forests (2,468,876 km^2) (Table 5, NFIS 2020) and almost all harvested areas (756,000 ha in 2017) fall within the over 60-year age class (Statistics Canada 2018).

Thirty percent of the managed forest over 60 years (~ 74,066,290 ha) sequesters about 474 Mt CO_2 from the atmosphere each year. Implementation of recommendation 2 would reduce GHG emissions by 1.5 Mt CO_2 per year, by maintaining the carbon sink on the relatively small portion of this forest under imminent threat of logging. These savings in GHG emissions would increase over time. Annual GHG emissions would be further reduced by 126 Mt CO_2e, by maintaining stored carbon. Beyond 2050, this recommendation would result in the prevention of between 17.7 and 98.5 Gt CO_2e of stored carbon being released.

As a co-benefit for biodiversity, and attainment of Canada's commitment to protect 25% of its lands and waters by 2025, and 30% by 2030, terrestrial protected areas would increase by 1.4 million km^2.

Growing existing forests to ecological maturity is a low-cost approach to improving the ability of forests to sequester carbon and create more of the increasingly rare old-growth habitat for species dependent on it (Moomaw et al. 2019). Although defining of old-growth forests is complex, there is some agreement that naturally regenerated forests in Canada have old-growth characteristics when they reach 120 to 140 years for most forests and 250 years for coastal rainforests (Gorley and Merkel 2020). Approximately 14.6% of Canada's managed forests are over 120 years (NFIS 2020). It has been estimated that 60% of British Columbia's forests were in a state of old-growth pre-European contact (Federal Provincial and Territorial Governments of Canada 2010b).

Logging in Boreal Forest. Photo: Onfokus/istock

Similar estimates are not available for the rest of Canada. However, there has been a general shift towards younger forests, largely as a result of harvesting (Statistics Canada 2017).

Growing back forests so that they can develop some of the characteristics of old-growth forests important for biodiversity and carbon dynamics is a practical option. Although intact primary forests are irreplaceable, growing second growth forests to ecological maturity is the only option for regaining some of the important qualities of primary forests. To enhance the biodiversity benefits of this action special attention should be paid to ensuring that the newly protected forests are connected across the landscape, to allow for range changes and movement of species caused by climate change.

The total managed forest available for harvest would be reduced by 30%. Although only 1% of the managed forest is harvested every year, the annual harvest would have to also be reduced to ensure that implementation of this recommendation does not put additional pressure on the remaining managed forests (*i.e.* to prevent what is referred to as leakage).

RECOMMENDATION 3

LENGTHENED HARVEST ROTATION

Lengthen the harvest rotation in managed forests by letting forests grow until they reach their full carbon sequestration potential.

Intact boreal forest. Photo: River Jordan for NRDC

ANALYSIS

RECOMMENDATION 3: LENGTHENED HARVEST ROTATION

This action has been proposed by the Canadian Council of Forest Ministers as one of several long term forest management strategies to increase forest carbon stocks (Canadian Council of Forest Ministers 2018). Growing existing forests to their ecological potential is an effective immediate and low-cost approach that can be mobilized across suitable forests of all types (Moomaw et al. 2019; Böttcher and Lindner 2010; Rijal et al. 2018).

A lengthened harvest rotation allows an increase in carbon sinks and stores, as well as the development of some of the old-growth characteristics important for biodiversity. Also, older forests are generally more resilient, providing a buffer from the unpredictable effects of climate change.

Increasing the period between harvests on 25% of harvested land would result in an estimated additional sequestration of 1.2 Mt CO_2 per year for every year of delayed harvest. Benefits will be ephemeral because these forests will eventually be harvested.

Carbon dioxide is sequestered from the atmosphere by forests at different rates depending on a number of variables such as the tree species, stand age, site productivity and climatic conditions. In general, CO_2 sequestration is more rapid in stands up to 200 years followed by a slow decline in the rate of sequestration. There is some debate about the age at which carbon accumulation is maximized – anywhere from about 170 years to 200 years (Gray and Whittier 2017; Gray et al. 2016). Although managed secondary forests have reduced carbon stocks compared to primary unmanaged forests (Böttcher and Lindner 2010; Kurz et al. 1998), they still have the potential to sequester additional carbon for many decades or longer if allowed to grow to ecological maturity (Moomaw et al. 2019; Lewis et al. 2019; Keith et al. 2009).

Although the age at which forests maximize the sequestration of CO_2 from the atmosphere is under some debate, there is no doubt that the current harvesting rotations are far below that maximum. As well, even past the maximum rate of sequestration old forests continue to sequester significant amounts of CO_2 from the atmosphere.

Second-growth Douglas Fir forest, Coastal BC. Photo: Risa Smith

Simply lengthening the harvest rotation of managed forests by 30 years on 25% of the managed forest land that is harvested each year could result in emissions reductions of over 36 Mt of CO_2 over those 30 years. Of course, additional greenhouse gas emissions reductions from the increased stored carbon during the extended rotation period would not be permanent.

RESTORATION EXAMPLES

Plant 2 billion trees and quantify the GHG emissions benefits of ongoing saltmarsh and eelgrass restoration. These are two of many possible long-term commitments needed to restore lost and degraded ecosystems that sequester CO_2 from the atmosphere, are important carbon stores and provide co-benefits for biodiversity and other ecosystem services.

Juvenile Atlantic herring in eelgrass bed, Nova Scotia. Photo: Nick Hawkins/naturepl.com

RECOMMENDATION 4: RESTORATION EXAMPLES

Restoration is a long-term commitment, as measureable results for both climate change and biodiversity may take several decades or more to be realized. Natural ecosystems particularly important for restoration are forests, peatlands, grasslands and coastal vegetation, particularly saltmarshes and eelgrass beds. Restoration of natural elements on agricultural lands could also be an important focus for climate change mitigation and adaptation.

It is beyond the scope of this report to quantify the carbon benefits from the full spectrum of restoration possibilities. However, all pathways that lead to keeping temperature increases at 2°C or 1.5°C above pre-industrial levels require removing CO_2 from the atmosphere. The most efficient and effective way to remove CO_2 from the atmosphere is through sequestration by natural ecosystems, so the long-term benefits from restoration are guaranteed.

Planting 2 billion trees could result in long term emissions reductions of 4 to 8 Mt CO_2 per year, with benefits not realized until after 2050. Restoration of only 20% of the lost saltmarshes in the Bay of Fundy, for example, could sequester an additional 3.55 Mt of CO_2 per year.

PLANTING 2 BILLION TREES

In their now famous paper in Science, Bastin et al. (2019) suggested that a massive tree planting program, on 0.9 billion hectares of degraded land, could increase forested area by 25% and store more than 200 Gt of additional carbon at maturity. More than half of the planting proposed would take place in six countries: Russia, United States, Australia, Brazil, Canada and China. In response, the World Economic Forum launched a platform to facilitate the planting of 1 trillion trees (World Economic Forum 2020). Canada announced its intention to contribute to the initiative by investing $3 billion in planting 2 billion trees over 10 years.

The amount of carbon that could be sequestered from the atmosphere from 1 trillion trees was estimated at 1 to 10 Gt of CO_2 a year. The original report was heavily criticized and some authors have suggested that the realistic carbon sequestration potential of 1 trillion trees is closer to 3-4 Gt a year (Vaughan 2020). As well, it would take several decades for newly planted forests to begin sequestering CO_2, depending on what was on the land beforehand. In the long term, Canada's 2 billion tree program could have significant benefits for biodiversity, as well as climate change mitigation and adaptation, if the right trees are planted in the right places and for the right reasons.

Saltmarsh at Cape Engrage Nature Reserve, Bay of Fundy, New Brunswick. Photo: SimplyCreativePhotography/istock

To have real benefits for climate change any afforestation initiative must not infringe on important non-treed ecosystem, like grasslands, that are themselves significant carbon sinks, and more resistant to natural disturbance than forests (Dass et al. 2018). As well, like all forest restoration, the co-benefits for biodiversity are only realized if the newly planted forests are diverse, resilient and protected from harvesting so that they can, over time, maximize benefits for forest-dependent species (Seddon et al. 2020).

An additional two billion trees in Canada could sequester 4.1 to 8 Mt of CO_2 per year, when they have reached ecological maturity, somewhere between 100 to 200 years.

COASTAL VEGETATED SYSTEMS (BLUE CARBON)

Since 2017 Fisheries and Oceans Canada has invested over $70 million in projects to restore coastal habitats on all coasts (Fisheries and Oceans Canada 2019). These investments are helping to restore lost and damaged blue carbon ecosystems to enhance habitat for coastal and marine species and the ability of blue carbon ecosystems to mitigate the impacts of climate change. Unfortunately, the impacts of this restoration on carbon sequestration and storage are not being tracked, although the impacts of restoration of coastal ecosystems on climate change mitigation are well known. For example restoring just 20% of the saltmarshes in the Bay of Fundy could sequester an additional 3.55 Mt of CO_2 per year (Chmura and Van Ardenne 2018). Likewise, at the same time that investments are being made to coastal restoration, coastal ecosystems continue to be lost through development projects (*e.g.* The Review Panel for the Roberts Bank Terminal 2 Project 2020).

RECOMMENDATION 5

FINANCIAL RESOURCES

Commit the necessary financial investments to ensure that NCS have a significant impact on both reducing GHG emissions and reversing the loss of biodiversity.

Sharp-tailed Grouse, Alberta grassland. Photo: bgsmith/istock

ANALYSIS

RECOMMENDATION 5: FINANCIAL RESOURCES

Currently investments in NCS are a fraction of those in hard infrastructure or technological fixes such as Carbon Capture and Storage. To make NCS a reality, investments surpassing those on hopeful technological fixes to climate change will be required.

To reach the Paris Agreement targets not only will GHG emissions have to be drastically reduced but long-lived carbon dioxide will have to be removed from the atmosphere, in the order of 100 to 1000 Gt CO_2 over the 21st century. All pathways must be mobilized to attain this level of carbon dioxide removal. IPCC (2018) highlights that the potential of Bioenergy Carbon Capture and Storage (BECCS) and NCS will both fall short of what is needed, by 5 Gt CO_2 and 3.6 Gt CO_2 per year, respectively, at the current potential of technology and effort in NCS (IPCC 2018).

In 2020 Canada announced its first investment of $3 billion over 10 years in NCS (Liberal Party of Canada 2020). While this is an important step, it's worthwhile to put it in context. By 2011 Canada had already committed upwards of $3 billion in public funding for Carbon Capture and Storage (CCS) (Mitrović and Malone 2011), for an anticipated benefit of only 6.4 Mt CO_2 sequestered per year (Canada Energy Regulator 2016), or 3% of the annual emissions reductions needed to reach Canada's current climate change target. While keeping global temperatures to 1.5 °C or 2 °C below pre-industrial levels requires using all solutions, it has been estimated that NCS could account for over 35% of global GHG emissions reductions per year (Griscom et al. 2017), whereas CCS could account for at most 13% of global GHG emission reduction (Natural Resources Canada 2016). Further and larger investments in NCS are urgently needed.

ANNEX I: THE NUMBERS AND METHODS

The numbers in *italics* represent the total for a given category. The numbers in **bold** represent what is under immediate threat, for example by annual logging. Where there are only numbers in italics it was not possible to distinguish immediate threats from longer term threats. Although data for peatlands are provided they were not part of the totals in the text as it was not possible to quantify the effects of short term human impacts on the vast majority of peatlands, mostly because feedbacks from climate change are by far the biggest threat to peatland carbon dynamics.

Initiative	Total Area (ha)	Stored carbon lost to the atmosphere if recommendations are not implemented (Mt C)	Emission reductions from retention of store carbon (Mt CO_2e)[1]	Emissions Reductions from maintaining CO_2 sequestration (Mt) CO_2/year
TARGETED PROTECTION				
Boreal Old-Growth Forests > 100 years **(imminently threatened)**	*144,495,880*[2] **248,090**[2]	*16,403 to 90,980*[3] **29.5**[3]	*60,200 to 333,898* **108**	*925*[4] **1.6**[4]
Boreal Old-Growth Forests > 200 years **(imminently threatened)**	*79,620,178*[2] **136,702**[2]	*9,039 to 50,132*[3] **16.2**[3]	*33,171 to 173,985* **59.6**	*510*[4] **0.9**[4]
Boreal Old-Growth Forests > 300 years **(imminently threatened)**	*47,182,328*[2] **81,009**[2]	*5,356 to 29,708*[3] **9.6**[3]	*19,657 to 109,028* **33.3**	*302*[4] **0.5**[4]
BC old-growth forests on high productivity sites **(imminently threatened)**	*415,000*[5] **192,600**[5]	130[6], 167[7], 207 to 309[8] **78**[7] **to 143**[8]	478[6], 614[7], 758 to 1,338[8] **286**[7] **to 526**[8]	2.7[9], 0.14 to 0.29[10], 0.8[11] **1.23**[12]
Native Prairie Grasslands	*12,700,000*[13]	*381 to 1905*[14]	*1398 to 6991*[12]	*2.41*[15]
Peatlands	*1,136,000,000*[16]	*136,700*[16] *to 154,000*[17]	*501,689*[16] *to 565,180*[17]	*Very small*[18]
Eelgrass	*129,000*[19]	*7.8 to 52.8*[19]	*28.6 to 193.8*[19]	*0.1 to 0.71*[20]
Saltmarshes	*111,274*[21]	*27.3 to 971.1*[22], *1.1 to 18.1*[23]	*100 to 3,564*[22], *4.1 to 66.4*[23]	*1.39 to 2.02*[24], *0.24 to 4.42*[25]
PROFORESTATION WITH PROTECTION				
Growing 30% of Managed forests over 60 years to ecological maturity **(annual logging)**	*246,887,640*[26] **233,910**[27]	*4,836 to 26,830*[28] **34.3**[28]	*17,751 to 98,456*[28] **126**[28]	*474*[29] **1.5**[27]
LENGTHENING HARVEST ROTATION				
For example, on 25% of the harvested area **(annual logging)**	**189,000**[30]			**1.2**[30]
RESTORATION				
Planting 2 billion trees		*400*[31]	1468[31]	*4.1 to 8.0*[31]

1 One tonne of carbon is equivalent to 3.67 tonnes of CO_2. To convert stored carbon into GHG emissions (*i.e* CO_2e), the stored carbon retained was multiplied by 3.67. This is a conservative estimate, considering that in cases where portions of the stored carbon are released as methane, the CO_2e would be much higher. (See definition of carbon dioxide equivalent in Annex II: Definitions).

2 The area of old-growth boreal forests for 100, 200, 300 years was: 144,495,880; 79,620,178; and 47,182,328 hectares, respectively (Bergeron and Fenton 2012). The area logged annually for 100, 200, 300 year boreal forests was estimated as: 258,089; 136,702; 81,009 ha respectively calculated from annual harvest in 2015 by province (Statistics Canada 2018). The total area gives a sense of the potential over the long term for emissions savings from carbon storage. However, the annual logging area represents the imminent threat and so the immediate emissions savings.

3 Anticipated carbon lost to the atmosphere from logging is 66% of total stored carbon (Woods Hole Research Center et al. 2020). For old-growth boreal forests total stored carbon was calculated using estimates for stored carbon without peat soils. Estimates ranged from 24.9-137.9 (>100 years); 22.5-76 (>200 years); 13.3- 45 (>300 years) Gt C. The numbers are significantly higher for peat forests (Chen et al. 2010) but it is difficult to assess which forests are on peat soils from the data available. The annual carbon lost from logging is relevant for immediate emissions savings and is based on the annual boreal forest harvest in 2015 (note 2) and storage of 180 tonnes/ha, which is the average for carbon stored in the Eastern and Western Boreal (Stinson et al. 2011).

4 The area of old-growth boreal forest was as in note 2, the sequestration rate used was 6.4 tonnes/ha/year for mature managed forests in Canada (Canadian Council of Forest Ministers 2018).

5 (Price et al. 2020) have mapped the old-growth forests in BC based on site productivity. The area of old-growth forest on high productivity sites (OGHPS) that grow trees greater than 20 m was 415,000 ha. Although 23% of BC's forests are designated as old-growth most of these are not the big old trees that people think of as old-growth. The OGHPS represent only 3% of BC's remaining old-growth and is not protected. The area threatened by logging is based on the 2015 harvest of 192,600 ha in BC's Montane Cordillera and Pacific Maritime Ecozones (Statistics Canada 2018), where most of the BC's ancient forests are being logged. At the current rate of logging it would take less than 3 years to liquidate BC's ancient forests on these high productivity sites.

6 Estimates of stored carbon in OGHPS in BC vary. For this estimate the stored carbon in the Pacific Maritime Ecozone, where much of the OGHPS remains, of 475 tonnes/ha (Stinson et al. 2011) was used. As with note 3, it was anticipated that 66% of the stored carbon would be lost by logging. As with note 1, it was assumed that most of the stored carbon is released as CO_2 after logging and the factor of 3.67 was used to convert stored carbon lost into CO_2e emitted.

7 For this estimate stored carbon of 611 tonnes/ha from Pacific Northwest old-growth forests was used as a proxy for OGHPS (Mosseler et al. 2003b; Harmon et al. 1990). Other assumptions on the loss of stored carbon after logging and conversion of lost carbon to CO_2 emissions are the same as note 6 and the total area logged was as in note 5.

8 For this estimate stored carbon from Pacific Northwest Coastal Montane of 754 to 1127 tonnes/ha was used as a proxy for OGHPS (Fredeen et al. 2005) . This estimate was similar to carbon stores in Oregon old-growth forests of 724.5 tonnes/ha (Talberth 2017). Other assumptions on the loss of stored carbon after logging and conversion of lost carbon to CO_2 emissions are the same as note 6 and the total area logged was as in note 5.

9 For this estimate carbon sequestration rate of 6.4 tonnes/ha/year was used which is sequestration of mature trees in Canada (Canadian Council of Forest Ministers 2018) and the area of OGHPS in BC and the annual area logged were as in note 5.

10 Calculated using sequestration rate range for 200 to 400-year-old forests in Pacific Northwest of 0.34 to 0.7 tonnes/ha/year (Gray et al. 2016) and the area of OGHPS in BC as in note 5.

11 The higher annual sequestration is based on 1.92 tonnes CO_2/ha/year sequestered in Oregon forests (Talberth 2017) and 415,000 hectares of OGHPS as in note 5.

12 This estimate is based on annual sequestration for mature forests of 6.4 tonnes/ha/year, as in note 9, area logged in BC of 192,600 ha, as in note 5.

13 Area of remaining original prairie grasslands is 11 million ha. The area of native prairie grassland that is currently grazed is 12.7 million ha. The increase is due to conversion of croplands back to grasslands (Wang et al. 2014) .

14 Stored carbon in uncultivated prairie grasslands is estimated, using data from (Wang et al. 2014), to be 1270 to 3810 Mt C. Estimates of carbon lost without implementation of the recommendations is based on losses of 30 to 50% of the soil organic carbon with conversion to cultivated agriculture (Agricultural Producers Association of Saskatchewan 2017). Other estimates of total carbon in prairie grasslands fall within this range. For example, (Agricultural Producers Association of Saskatchewan 2017) estimates stored carbon in uncultivated prairie grasslands is 2 to 3 billion tonnes (Gt), which calculate to a loss of 600 to 1500 Mt of carbon from conversion of remaining uncultivated prairie grasslands. Similar results are found for stored carbon using (White et al. 2000) estimate 100 to 300 tonnes carbon/ha for prairie grasslands. As with note 1 it was assumed that emissions from stored carbon were as CO_2 and therefore a factor of 3.67 was used to convert carbon lost to CO_2 emissions.

15 Calculated from data in (Wang et al. 2014).

16 Area of peatlands and C storage of 136.7 Gt is from Munir et al. (2015). The conversion to CO_2e assumed releases of CO_2. Releases from methane would be higher, as the GWP of methane is 28 times higher than for CO_2 over 100 years (see note on carbon dioxide equivalent in Annex II: Definitions).

17 Carbon storage in Canada's peatlands of 154 Gt from (Henschel and Gray 2007). The conversion to CO_2e assumes releases of CO_2. Releases of methane would be higher, as the GWP of methane is 28 times higher than for CO_2 over 100 years (see note on carbon dioxide equivalent in Annex II: Definitions). Also note that the loss of peatlands, while important to present here, was not considered in the totals for conservation because it is difficult to assess how much of Canada's peatlands are currently threatened. As well, some of the old-growth boreal forest, which was counted, is on peatlands which would result in double counting.

18 Sequestration of carbon from peat is very slow and estimated to be 19-24 g C/m^2/year (Vitt 2016). As a result, it takes a very long time, centuries and longer, to recover the carbon stored in peatlands, when it is lost.

19 Estimates for eelgrass vary largely due to poor information on the extent of eelgrass beds globally and in Canada and the variability in eelgrass carbon dynamics depending on the site and the species of eelgrass. Total area of eelgrass for Canada was estimated as 129,000 ha, which is double the area documented in (CEC 2016), based on the CEC (2016) note that Canada likely has double the area that they were able to document. Estimates of carbon storage were made using global data and translating it to the total area in Canada. Total area of global eelgrass is estimated as 117,700 km^2 to 600,000 km^2 (Duarte et al. 2013) . Global carbon stock in eelgrass beds is estimated to be 4.2 to 8.4 Gt (Duarte et al. 2013). Releases of stored carbon were assumed to be as CO_2 and hence stored carbon was multiplied by 3.67 to obtain CO_2e.

20 This estimate was calculated translating global eelgrass sequestration from (Duarte et al. 2013) of 48 to 112 Mt CO_2 /year into total remaining eelgrass in Canada, as estimated in note 19.

21 Total area of saltmarshes in Canada of 111,274 ha has been calculated by (McOwen et al. 2017).

22 This estimated was calculated using area of saltmarshes in Canada (note 21) and the global carbon stocks in saltmarshes of 9.8 to 19.2 Gt C (Fourqurean et al. 2012). Global area of saltmarshes was taken from (Duarte et al. 2013). CO_2 released from loss of Canadian carbon stocks used conversion of 3.67 C to CO_2e. This is a conservative estimate as methane is also released from loss of saltmarshes, which if included would make the CO_2e higher.

23 Calculated using area of saltmarshes in Canada (note 21), the global area of saltmarshes and the carbon stocks of saltmarshes of 0.4 to 6.5 Gt C (Duarte et al. 2013).

24 Calculated using area of saltmarshes in Canada as 111,274 ha (note 21) and global sequestration of 27.4 to 40 Mt/year (Fourqurean et al. 2012).

25 Calculated using area of saltmarshes in Canada as 111,274 ha (note 21) and global sequestration of 4.8 to 87.3 Mt CO_2/year (Duarte et al. 2013).

26 Managed forest area over 60 years is 246,887,640 ha (Table 5 NFIS 2020).

27 233,910 ha represents 30% of the area harvested in 2015. The total area harvested was 779,700 ha (Statistics Canada 2018). Emissions released from the total area harvested were 4.9 Mt CO_2 per year, using average sequestration of Canada's mature managed forests of 6.4 tonnes CO_2/ha/yr (Canadian Council of Forest Ministers 2018). Emissions released from 30% of the area harvested was calculated as 1.5 Mt CO_2. The harvest for 2015 was used because the area harvested by province was available and that allowed a better estimate for the total carbon stored, as estimates of carbon storage by ecozone were available (Stinson et al. 2011). Area for boreal forest greater than 100, 200 or 300 years was taken from (Bergeron and Fenton 2012).

28 Stored carbon on 30% of the forest area was taken from (Chen et al. 2010), for Ontario boreal forests, making it a low estimate for the more carbon dense forests in British Columbia. It was assumed that 66% of the stored carbon is lost from logging, as in note 3. The CO_2e was calculated using a factor of 3.67, as in note 1.

29 Managed forest over 60 years is 246,887 km^2, or 75% of the managed forest (Table 5 NFIS 2020). Sequestration was taken as 6.4 tonnes CO_2 per ha/year (Canadian Council of Forest Ministers 2018) and the sequestration rate from the proforestation with protection recommendation was for 30% of the forest greater than 60 years.

30 The area harvested in 2017 was 756,000 ha (NRCAN 2020). Total sequestration of CO_2 lost from the harvested area in 2017 was 4.8 Mt CO_2 25% of the area harvested is 189,000 ha. Sequestration was based on 6.4 tonnes CO_2 per ha per year (Canadian Council of Forest Ministers 2018).

31 (Bastin et al. 2019) lower estimate of 1 trillion trees sequestering 2.05 Gt/year and (Vaughan 2020) higher estimate of 1 trillion trees sequestering 4 Gt/year, was extrapolated to 2 billion trees. For carbon storage, it was assumed that the trees would be protected and accumulate carbon for at least 200 years. CO_2e was calculated, as in note 1, by multiplying CO_2 x 3.67.

ANNEX II: DEFINITIONS

Nationally Determined Contributions (NDCs) are the mitigation and adaptation actions and targets, defined by each country, that all Parties to the Paris Agreement on Climate Change are required to submit. NDCs are to be revised every five years, and they must demonstrate increased ambition over time.

Paris Agreement on Climate Change is an agreement by most Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to hold the increase in global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change. It came into effect November 2016.

Natural Climate Solutions (NCS) refers to leveraging the properties of healthy ecosystems to address both climate change mitigation and adaptation, while also enhancing biodiversity. NCS are a sub-set of what is often referred to as Natural Solutions (NS) or Nature-Based Solutions (NbS). NbS are "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN Resolution: World Conservation Congress: WCC-2016-Res-069-EN).

Carbon Sequestration refers to the rate at which carbon dioxide is removed from the atmosphere by carbon sinks, such as oceans, forests and soils. As natural ecosystems both absorb and release carbon dioxide (CO_2), through photosynthesis and respiration, carbon sequestration includes the rate of absorption of CO_2 minus the rate of release of CO_2. Globally it is measured as Megatonnes (Mt) or millions of tonnes of CO_2 sequestered per year. It is sometimes measured as Teragrams (Tg) or trillion grams of carbon per year. A Tg equals a Mt.

Carbon Store is a natural reservoir of carbon that absorbs and holds more carbon than it releases. Carbon stores are usually measured in billions of tonnes (Gt). The largest carbon stores on earth are fossil pools (~10,000 Gt), soil (~2300 Gt), plant biomass (~550 Gt), the ocean surface (~1000 Gt) and deep oceans (~37,000 Gt). The CO_2 absorbed from the atmosphere through carbon sequestration is stored in natural ecosystems as carbon.

Carbon Sink refers to any reservoir that absorbs more carbon than it releases, thereby lowering the concentration of CO_2 in the atmosphere. In the context of NCS a carbon sink is a natural system that holds carbon stores. Examples of carbon sinks are oceans, forests, peatlands, soils and grasslands.

A Carbon Source releases carbon dioxide (CO_2) into the atmosphere. The primary sources of CO_2, which are responsible for most of the increases in CO_2 concentrations in the atmosphere since the industrial revolution, are the burning of fossil fuels and deforestation. Globally 87% of all human-produced CO_2 emissions come from the burning of fossil fuels (CO_2 Human Emissions (CHE) 2017). In Canada, the burning of fossil fuels for energy and transportation are responsible for about 82% of GHG emissions (ECCC 2020).

Land Use, Land Use Change and Forestry (LULUCF) refers to the human activities that impact terrestrial carbon sinks through land use, changes in land use or forestry. A feature of LULUCF is that activities can increase or decrease the removals of greenhouse gases (GHGs) from the atmosphere, thereby playing an important role in mitigation of climate change (UNFCCC 2020b). In Canada LULUCF is used as a proxy for carbon fluxes from natural systems, although at this point Canada does not measure the fluxes from all of the ecosystems that are important for climate change mitigation and adaptation.

Primary Forests "are naturally regenerated forests of native tree species, including mangroves and peat forests, whose structure and dynamics are dominated by ecological and evolutionary processes, including natural disturbance regimes, and where if there has been significant prior human intervention it was long enough ago to have enabled an ecologically mature forest ecosystem to be naturally re-established" (IUCN 2020). As used in this document, it includes the term old-growth forest.

Carbon dioxide (CO_2) and CO_2-equivalents (CO_2e). CO_2 is one of several gases in the atmosphere which absorb and re-emit heat, keeping the Earth's atmosphere warmer than it would otherwise be. Human activities, such as the burning of fossil fuels, are increasing the levels of the gases, known as greenhouse gases (GHGs) in the atmosphere. Although CO_2 is the most common GHG emitted through human activities, other GHGs are also emitted, each with its own global warming potential (GWP), with the CO_2 GWP as a reference set as 1. CO_2-equivalent (CO_2e) translates all GHGs into one common unit based on their GWP. For example, methane (CH_4) has a GWP of 28, meaning 1 kg of methane causes 28 times more warming over a 100-year period than 1 kg of CO_2 , which can be expressed as 28 kg of CO_2e (Brander 2012; IPCC 2019). It is worth noting that GWP is a bit more complex than described, as some gases are short-lived in the atmosphere (e.g. methane) and others are long-lived (e.g. CO_2). Measured over 20 years methane has a GWP of 87 (IPCC 2019).

Only CO_2 is sequestered from the atmosphere through the process of photosynthesis, and therefore all measures of carbon sequestration can be given as CO_2. Releases of GHGs from carbon stores can be in the form of several different GHGs so they are usually expressed as CO_2e.

REFERENCES

Abraham KF, McKinnon LM, Jumean Z, Tully SM, Walton LR, Stewart HM (2011) Hudson Plains Ecozone+ Status and Trends Assessment. In: Canadian Council of Resource Ministers (ed) Canadian Biodiversity: Ecosysatem Status and Trends 2010. Technical Ecozone+ Report. Canadian Council of Resource Ministers, Ottawa, Canada, p xxi + 445pp

Agricultural Producers Association of Saskatchewan (2017) Growing Sustainability: A report on the APAS prairie agriculture carbon summit. Regina, Canada

Anderson CM, DeFries RS, Litterman R, Matson PA, Nepstad DC, Pacala S, Schlesinger WH, Shaw MR, Smith P, Weber C (2019) Natural climate solutions are not enough. Science 363 (6430):933-934

Arabian J, Currie J, Snider J (2019) Wildlife Protection Assessment: A national habitat crisis. Toronto, Canada. doi: https://doi.org/10.13140/RG.2.2.22764.62089

Artelle KA, Zurba M, Bhattacharyya J, Chan DE, Brown K, Housty J, Moola F (2019) Supporting resurgent Indigenous-led governance: A nascent mechanism for just and effective conservation. Biological Conservation 240:108284. doi:https://doi.org/10.1016/j.biocon.2019.108284

Baez S (2020) Seagrass Protections Can Lead to Big Wins for Our Ocean, People, and Governments. PEW Charitable Trusts. https://www.pewtrusts.org/en/research-and-analysis/articles/2020/05/20/seagrass-protections-can-lead-to-big-wins-for-our-ocean-people-and-governments. Accessed June 29 2020

Baldocchi D, Penuelas J (2019) Natural carbon solutions are not large or fast enough. Global Change Biology 25 (7):e5-e5. doi:10.1111/gcb.14654

Bastin J-F, Finegold Y, Garcia C, Mollicone D, Rezende M, Routh D, Zohner CM, Crowther TW (2019) The global tree restoration potential. Science 365 (6448):76. doi:10.1126/science.aax0848

Bergeron Y, Fenton NJ (2012) Boreal forests of eastern Canada revisited: old growth, nonfire disturbances, forest succession, and biodiversity. Botany 90 (6):509-523. doi:10.1139/b2012-034

Biello D (2008) Old-Growth Forests Help Combat Climate Change. Scientific American Sept. 11

Böttcher H, Lindner M (2010) Manging forest plantations for carbon sequestration today and in the future. In: Bauhus J, van der Meer P, Kanninen M (eds) Ecosystem goods and services from plantation forests. Earthscan, London and Washington DC, pp 43-76

Bradshaw CJ, Warkentin IG (2015) Global estimates of boreal forest carbon stocks and flux. Global and Planetary Change 128:24-30. doi:https://doi.org/10.1016/j.gloplacha.2015.02.004

Brander M (2012) Greenhouse Gases, CO_2, CO_2e and Carbon: What do all these terms mean? Ecometrica August

Canada Energy Regulator (2016) Canadian carbon capture and storage projects will soon sequester up to 6.4 million tonnes of CO_2 per year. https://www.cer-rec.gc.ca/nrg/ntgrtd/mrkt/snpsht/2016/09-01cndncrbncptr-eng.html. Accessed August 24 2020

Canadian Council of Forest Ministers (2018) Canada's Forests: CO_2 Sink or Source? CCFM. https://www.sfmcanada.org/images/Publications/EN/C02_Sink_EN.pdf.

Carlson M, Wells J, Roberts D (2009) The Carbon the World Forgot: Conserving the Capacity of Canada's Boreal Forest Region to Mitigate and Adapt to Climate Change. Seattle, WA and Ottawa Canada

CEC (2016) North America's Blue Carbon: Assessing Seagrass, Salt Marsh and Mangrove Distribution and Carbon Sinks. Commission for Environmental Cooperation, Montreal, Canada

Chastain S (2017) Carbon Stocks and Accumulation Rates in Salt Marshes of the Pacific Coast of Canada. Simon Fraser, Vancouver

Chen J, Colombo SJ, Ter-Mikaelian MT, Heath LS (2010) Carbon budget of Ontario's managed forests and harvested wood products, 2001–2100. Forest Ecology and Management 259 (8):1385-1398. doi:https://doi.org/10.1016/j.foreco.2010.01.007

Chmura GL, Van Ardenne LB (2018) The Bay of Fundy Blue Carbon Story. Montreal, QC

CO_2 Human Emissions (CHE) (2017) Main Sources of Carbon Dioxide Emissions. CHE. https://www.che-project.eu/news/main-sources-carbon-dioxide-emissions. Accessed May 25 2020

Crowther TW, Glick HB, Covey KR, Bettigole C, Maynard DS, Thomas SM, Smith JR, Hintler G, Duguid MC, Amatulli G (2015) Mapping tree density at a global scale. Nature 525 (7568):201-205. doi:https://doi.org/10.1038/nature14967

Dass P, Houlton BZ, Wang Y, Warlind D (2018) Grasslands may be more reliable carbon sinks than forests in California. Environmental Research Letters 13 (7):074027

DellaSala DA (2018) Conservation Issues: Temperate Rainforests. In: Dellasala DA, Goldstein MI (eds) Encyclopedia of the Anthropocene. Elsevier, Oxford, pp 185-191. doi:https://doi.org/10.1016/B978-0-12-809665-9.09041-8

Didion M, Fortin MJ, Fall A (2007) Forest age structure as indicator of boreal forest sustainability under alternative management and fire regimes: a landscape level sensitivity analysis. Ecological Modelling 200 (1-2):45-58. doi:https://doi.org/10.1016/j.ecolmodel.2006.07.011

Duarte CM, Losada IJ, Mazarrasa I, Hendriks IE, Marbà N (2013) The role of coastal plant communities for climate change mitigation and adaptation. Nature Climate Change 3 (11):961-968. doi:http://www.nature.com/doifinder/10.1038/nclimate1970

ECCC (2020) Canada's Fourth Biennial Report on Climate Change, 2019. Govt. of Canada, Ottawa, Canada

European Commission (2020) EU Biodiversity Strategy for 2030: Bringing nature back into our lives. European Commission, Brussels, Belgium

Executive Secretary of Convention on Biological Diversity (2019) Biodiversity and Climate Change. Montreal, Canada

FAO (2015) Forest Resources Assessment Working Paper 180: Terms and Definitions. Rome, Italy

Federal Provincial and Territorial Governments of Canada (2010a) Coastal. In: Eamer J, Hayes T, Smith R (eds) Canadian Biodiversity: Ecosystem Status and Trends 2010. Canadian Councils of Resource Ministers, Ottawa, Canada, p 32

Federal Provincial and Territorial Governments of Canada (2010b) Forests. In: Eamer J, Hayes T, Smith R (eds) Canadian Biodiversity: Ecosystem Status and Trends 2010. Canadian Councils of Resource Ministers, Ottawa, Canada, pp 14-17

Federal Provincial and Territorial Governments of Canada (2010c) Grasslands. In: Eamer J, Hayes T, Smith R (eds) Canadian Biodiveristy: Ecosystem Status and Trends 2010. Canadian Councils of Resource Ministers, Ottawa, Canada, pp 18-19

Fisheries and Oceans Canada (2019) Overview of funded projects (Coastal Restoration Fund). DFO. http://dfo-mpo.gc.ca/oceans/crf-frc/overview-apercu-eng.html. Accessed April 4 2019

Fourqurean JW, Duarte CM, Kennedy H, Marbà N, Holmer M, Mateo MA, Apostolaki ET, Kendrick GA, Krause-Jensen D, McGlathery KJ (2012) Seagrass ecosystems as a globally significant carbon stock. Nature geoscience 5 (7):505-509. doi:https://doi.org/10.1038/ngeo1477

Fredeen AL, Bois CH, Janzen DT, Sanborn PT (2005) Comparison of coniferous forest carbon stocks between old-growth and young second-growth forests on two soil types in central British Columbia, Canada. Canadian Journal of Forest Research 35 (6):1411-1421. doi:10.1139/x05-074

Gorley A, Merkel G (2020) A New Future for Old Forests: A Strategic Review of How British Columbia Manages for Old Forests Within Its Ancient Ecosystems. Victoria, Canada

Gray A, Whittier T (2017) There's Carbon in Them Thar Hills: But How Much? Could Pacific Northwest Forest Store More? Science Findings, vol 195. USDA Forest Service

Gray AN, Whittier TR, Harmon ME (2016) Carbon stocks and accumulation rates in Pacific Northwest forests: role of stand age, plant community, and productivity. Ecosphere 7 (1):e01224

Griscom BW, Adams J, Ellis PW, Houghton RA, Lomax G, Miteva DA, Schlesinger WH, Shoch D, Siikamäki JV, Smith P (2017) Natural climate solutions. Proceedings of the National Academy of Sciences 114 (44):11645-11650. doi:https://doi.org/10.1073/pnas.1710465114

Harmon ME, Ferrell WK, Franklin JF (1990) Effects on carbon storage of conversion of old-growth forests to young forests. Science 247 (4943):699-702. doi:https://doi.org/10.1126/science.247.4943.699

Henry M (2020) Algonquin's Old Forests. Ontario's Old-Growth Forests. http://www.oldgrowth.ca/algonquin/. Accessed March 29 2020

Henschel C, Gray T (2007) Forest Carbon Sequestration and Avoided Emissions. Toronto, Canada

Holtsmark B (2012) Harvesting in boreal forests and the biofuel carbon debt. Climatic change 112 (2):415-428. doi:https://doi.org/10.1007/s10584-011-0222-6

IPCC (2018) Summary for Policymakers. In: Masson-Delmotte V, Zhai P, Pörtner H-O et al. (eds) Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland, pp 1-26

IPCC (2019) Summary for Policy Makers. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. In: Climate Change and Land. WMO and UNEP, Bonn, Germany, pp 1-41

IUCN (2020) IUCN Policy Statement on Primary Forests Including Intact Forest Landscapes. IUCN, Gland, Switzerland

Keith H, Mackey BG, Lindenmayer DB (2009) Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proceedings of the National Academy of Sciences 106 (28):11635. doi:10.1073/pnas.0901970106

Kneeshaw D, Gauthier S (2003) Old growth in the boreal forest: A dynamic perspective at the stand and landscape level. Environmental Reviews 11 (S1):S99-S114. doi:https://doi.org/10.1139/a03-010

Kurz WA, Beukema SJ, Apps MJ (1998) Carbon budget implications of the transition from natural to manged disturbance regimes in forest landscapes. Mitigation and Adaptation Strategies for Global Change 2 (4):405-421

Lewis SL, Wheeler CE, Mitchard ETA, Koch A (2019) Restoring natural forests is the best way to remove atmospheric carbon. Nature 568:25-28

Liberal Party of Canada (2019) Natural Climate Solutions. Liberal.ca https://liberal.ca/liberals-move-forward-to-plant-two-billion-trees/

Lorenz K, Lal R (2018) Carbon Sequestration in Grassland Soils. In: Lorenz K, Lal R (eds) Carbon Sequestration in Agricultural Ecosystems. Springer International Publishing, Cham, pp 175-209. doi:https://doi.org/10.1007/978-3-319-92318-5_4

McOwen CJ, Weatherdon LV, Van Bochove J-W, Sullivan E, Blyth S, Zockler C, Stanwell-Smith D, Kingston N, Martin CS, Spalding M (2017) A global map of saltmarshes. Biodiversity data journal (5). doi:https://doi.org/10.3897%2FBDJ.5.e11764

Mitrović M, Malone A (2011) Carbon capture and storage (CCS) demonstration projects in Canada. Energy Procedia 4:5685-5691. doi:https://doi.org/10.1016/j.egypro.2011.02.562

Moomaw W, Masino S, Faison E (2019) Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good. Frontiers in Forests and Global Change 2 (Article 27):1-10. doi:10.3389/ffgc.2019.00027

Moomaw WR, Chmura GL, Davies GT, Finlayson CM, Middleton BA, Natali SM, Perry JE, Roulet N, Sutton-Grier AE (2018) Wetlands in a changing climate: science, policy and management. Wetlands 38 (2):183-205. doi:https://doi.org/10.1007/s13157-018-1023-8

Morales-Hidalgo D, Oswalt SN, Somanathan E (2015) Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015. Forest Ecology and Management 352:68-77. doi:https://doi.org/10.1016/j.foreco.2015.06.011

Mosseler A, Thompson I, Pendrel B (2003a) Old-Growth Forests in Canada - A Science Perspective. Paper presented at the XII World Forestry Congress, Quebec City, Canada,

Mosseler A, Thompson I, Pendrel BA (2003b) Overview of old-growth forests in Canada from a science perspective. Environmental Reviews 11 (S1):S1-S7. doi:10.1139/a03-018

Munir TM, Perkins M, Kaing E, Strack M (2015) Carbon dioxide flux and net primary production of a boreal treed bog: Responses to warming and water-table-lowering simulations of climate change. Biogeosciences 12:1091-1111. doi:https://doi.org/10.5194/bg-12-1091-2015

Natural Resources Canada (2016) Carbon Capture and Storage. Oil Sands. Government of Canada, Ottawa, Canada

Canada's National Forest Inventory (2020) NFI. https://nfi.nfis.org/en/data_and_tools. Accessed July 26

North American Bird Conservation Initiative Canada (2019) State of Canada's Birds 2019. Ottawa, Canada

NRCAN (2020) State of Canada's Forests: Annual Report 2019. Ottawa

Ouyang X, Lee SY (2020) Improved estimates on global carbon stock and carbon pools in tidal wetlands. Nature Communications 11 (1):317. doi:10.1038/s41467-019-14120-2

Pan Y, Birdsey RA, Fang J, Houghton R, Kauppi PE, Kurz WA, Phillips OL, Shvidenko A, Lewis SL, Canadell JG (2011) A large and persistent carbon sink in the world's forests. Science 333 (6045):988-993

Price K, Holt R, Daust D (2020) BC's Old Growth Forest: A Last Stand for Biodiversity. British Columbia

Rijal B, LeBel L, Martell DL, Gauthier S, Lussier J-M, Raulier F (2018) Value-added forest management planning: A new perspective on old-growth forest conservation in the fire-prone boreal landscape of Canada. Forest Ecology and Management 429:44-56. doi:https://doi.org/10.1016/j.foreco.2018.06.045

Rogelj J, Shindell D, Jiang K, Fifita S, Forster PM, Ginzburg V, Handa C, Kheshgi H, Kobayashi S, Kriegler E, Mundaca L, Séférian R, Vilariño MV (2018) Mitigation pathways compatible with 1.5°C in the context of sustainable development. In: Masson-Delmotte V, Zhai P, Pörtner HO et al. (eds) Global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathwyas, in the context of strengtehing the global response to the threat of climate change, sustainable development and efforts to eradicate poverty. WMO and UNEP, Saint Aubain, France

Rooney RC, Bayley SE, Schindler DW (2012) Oil sands mining and reclamation cause massive loss of peatland and stored carbon. Proceedings of the National Academy of Sciences 109 (13):4933. doi:10.1073/pnas.1117693108

Schulze E-D, Wirth C, Heimann M (2000) Managing forests after Kyoto. Science 289 (5487):2058-2059. doi:https://doi.org/10.1126/science.289.5487.2058

Seddon N, Chausson A, Berry P, Girardin CAJ, Smith A, Turner B (2020) Understanding the value and limits of nature-based solutions to climate change and other global challenges. Philosophical Transactions of the Royal Society B: Biological Sciences 375 (1794):20190120. doi:10.1098/rstb.2019.0120

Shea T, Woodley A, Lindsay K, Lourds J, Worbets B, St-Hilaire A, Locke H, Black D, Crowshoe R, Lopoukhine N, Porta L, Dragon-Smith C, Supernault C, Sumner J (2018) Canada's Conservation Vision: A report of the national advisory panel. Ottawa, Canada

Smith R, Cannizzo ZJ, Belle E, Wenzel L (2020) Role of Protected Areas in Climate Change Mitigation, Adaptation and Disaster Risk Reduction. In: Filho WL, Azul A, Brandli L, Özuyar PG, Wall T (eds) Climate Action. Encylopedia of the UN Sustainable Development Goals. Springer, Cham,

Smyth C, Stinson G, Neilson E, Lemprière T, Hafer M, Rampley G, Kurz W (2014) Quantifying the biophysical climate change mitigation potential of Canada's forest sector, vol 11. doi:10.5194/bg-11-3515-2014

Soto-Navarro C, Ravilious C, Arnell A, de Lamo X, Harfoot M, Hill SLL, Wearn OR, Santoro M, Bouvet A, Mermoz S, Le Toan T, Xia J, Liu S, Yuan W, Spawn SA, Gibbs HK, Ferrier S, Harwood T, Alkemade R, Schipper AM, Schmidt-Traub G, Strassburg B, Miles L, Burgess ND, Kapos V (2020) Mapping co-benefits for carbon storage and biodiversity to inform conservation policy and action. Philosophical Transactions of the Royal Society B: Biological Sciences 375 (1794):20190128. doi:https://doi.org/10.1098/rstb.2019.0128

Statistics Canada (2017) Forests in Canada. Statistics Canada. https://www150.statcan.gc.ca/n1/pub/16-201-x/2018001/sec-2-eng.htm. Accessed August 16 2020

Statistics Canada (2018) Human Activity and the Environment. Ottawa, Canada

Stinson G, Kurz WA, Smyth CE, Neilson ET, Dymond CC, Metsaranta JM, Boisvenue C, Rampley GJ, Li Q, White TM (2011) An inventory based analysis of Canada's managed forest carbon dynamics, 1990 to 2008. Global change biology 17 (6):2227-2244. doi:https://doi.org/10.1111/j.1365-2486.2010.02369.x

Strassburg BBN, Kelly A, Balmford A, Davies RG, Gibbs HK, Lovett A, Miles L, Orme CDL, Price J, Turner RK, Rodrigues ASL (2010) Global congruence of carbon storage and biodiversity in terrestrial ecosystems. Conservation Letters 3 (2):98-105. doi:10.1111/j.1755-263X.2009.00092.x

Talberth J (2017) Oregon Forest Carbon Policy: Scientific and technical brief to guide legislative intervention. Portland, Oregon

The Review Panel for the Roberts Bank Terminal 2 Project (2020) Roberts Bank Terminal 2 Project. Federal Review Panel Report. Ottawa, Canada

Thomas T, Pidgeon E, von Unger M, Crooks S, Durham C, Herr D, Hicky T, Martini C, Sandoval M, Murray LS, Sinclar Z (2020) Blue Carbon and Nationally Determined Contributions: Guildelines on Enhanced Action. The Blue Carbon Initiative

Tubiello FN, Salvatore M, Golec RDC, Ferrara A, Rossi S, Viancalani R, Federici S, Jacobs H, Flammini A (2014) Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks (trans: Division FS). Working Paper Series, vol ESS/14-02. Rome, Italy

Turetsky MR, Abbott BW, Jones MC, Anthony KW, Olefeldt D, Schuur EAG, Grosse G, Kuhry P, Hugelius G, Koven C, Lawrence DM, Gibson C, Sannel ABK, McGuire AD (2020) Carbon release through abrupt permafrost thaw. Nature Geoscience 13 (2):138-143. doi:10.1038/s41561-019-0526-0

UNFCCC (2020a) Chile Madrid Time for Action. vol Report of the Conference of the Parties on its twenty-fifth session, held Madrid from 2 to 15 December 2019. Part two: Action taken by the Conference of the Parties at its twenty-fifth session

UNFCCC (2020b) Land Use, Land Use Change and Forestry (LULUCF). UNFCCC. https://unfccc.int/topics/land-use/workstreams/land-use--land-use-change-and-forestry-lulucf. Accessed July 31 2020

Vaughan A (2020) How everyone decided trees will save the planet - and why they won't. The Guardian. The Guardian, UK

Vitt DH (2016) Peatlands of Continental North America. In: Finlayson C, Milton G, Prentice R, Davidson N (eds) The Wetland Book. Springer, Dordrecht. doi:https://doi.org/10.1007/978-94-007-6173-5_105-2

Wang X, VandenBygaart AJ, McConkey BC (2014) Land management history of Canadian grasslands and the impact on soil carbon storage. Rangeland Ecology & Management 67 (4):333-343. doi:http://dx.doi.org/10.2111/REM-D-14-00006.1

Watson JEM, Evans T, Venter O, Williams B, Tulloch A, Stewart C, Thompson I, Ray JC, Murray K, Salazar A, McAlpine C, Potapov P, Walston J, Robinson JG, Painter M, Wilkie D, Filardi C, Laurance WF, Houghton RA, Maxwell S, Grantham H, Samper C, Wang S, Laestadius L, Runting RK, Silva-Chávez GA, Ervin J, Lindenmayer D (2018a) The exceptional value of intact forest ecosystems. Nature Ecology & Evolution 2 (4):599-610. doi:10.1038/s41559-018-0490-x

Watson JEM, Venter O, Lee J, Jones KR, Robinson JG, Possingham HP, Allan JR (2018b) Protect the last of the wild. Nature 563:27-30

White R, Murray S, Rohweder M (2000) PIlot Analysis of GLobal Ecosystems: Grassland Ecosystems. Washington DC, USA

Wiken EB, Gauthier D, Marshall I, Lawton K, Hirvonen H (1996) A Perspective on Canada's Ecosystems: An Overview of the Terrestrial and Marine Ecozones. CCEA Occasional Paper No. 14. Ottawa, Canada

Wollenberg JT, Ollerhead J, Chmura GL (2018) Rapid carbon accumulation following managed realignment on the Bay of Fundy. PLOS ONE 13 (3):e0193930. doi:10.1371/journal.pone.0193930

Woods Hole Research Center, Wild Heritage, IntAct, Griffith University, GEOS Institute, Australian Rainforest Conservation Society, Frankfurt Zoological Society (2020) Policy Briefs: Primary Tropical, Temperate and Boreal Forests: Critical Stores of Carbon, Biodiversity and Freshwater.

World Economic Forum (2020) 1t.org. A platform for the trillion tree community. World Economic Forum. https://www.1t.org/. Accessed July 26 2020