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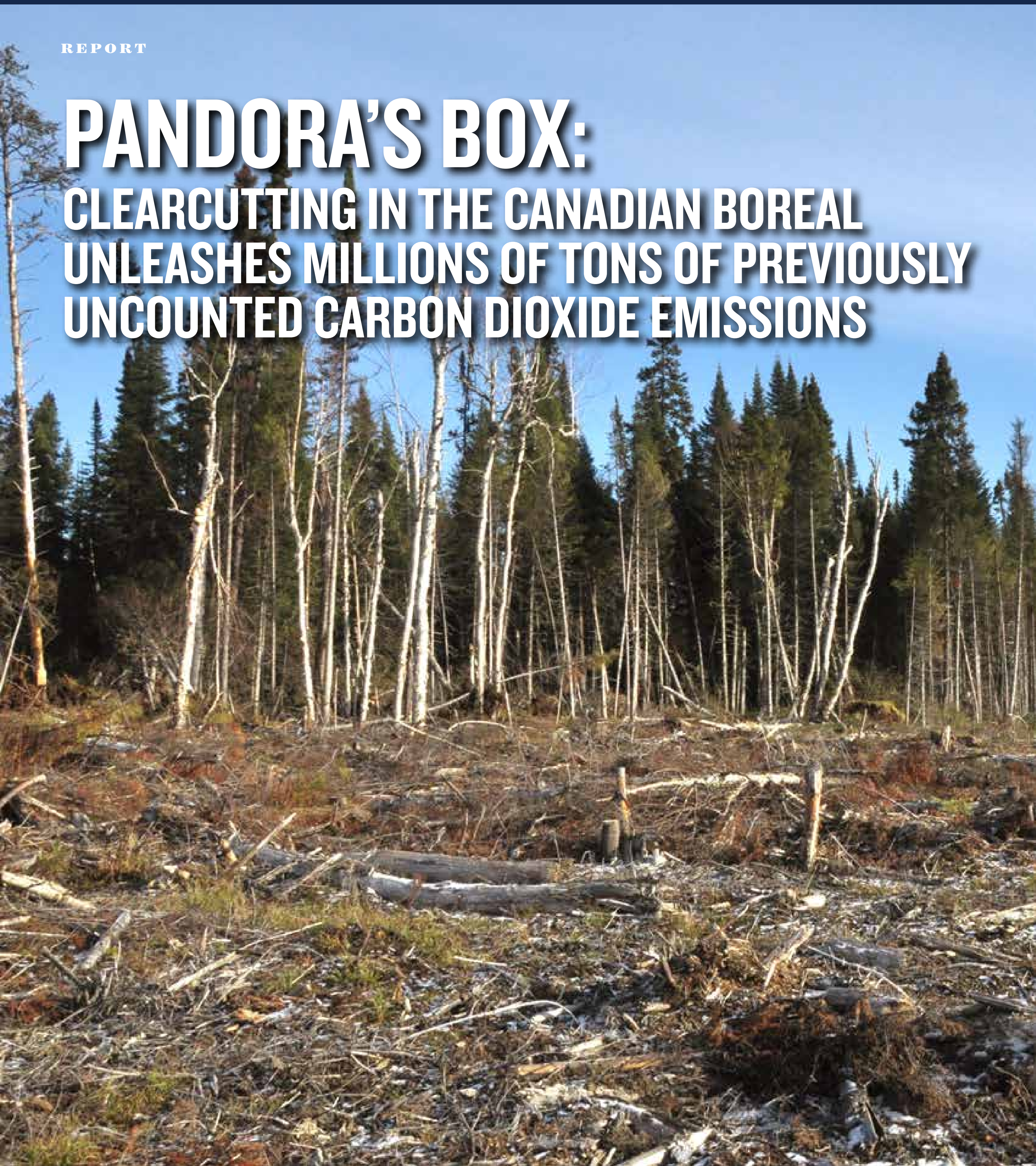
REPORT

PANDORA'S BOX:
CLEARCUTTING IN THE CANADIAN BOREAL UNLEASHES MILLIONS OF TONS OF PREVIOUSLY UNCOUNTED CARBON DIOXIDE EMISSIONS



Acknowledgments

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Special recognition is also due to the Indigenous Peoples across the Canadian boreal forest who are working daily to advocate for their rights and protect their traditional territories from industrial harms inflicted without their consent.

We would also like to thank and acknowledge the many organizations, communities, and individuals working across Canada's boreal forest to conserve, rehabilitate, and preserve this critical global resource.

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Cover image: Boreal forest clearcut south of Waswanipi, Quebec, November 2015. © Joshua Axelrod.

EXECUTIVE SUMMARY

Stretching over 1 billion acres, the Canadian boreal forest is one of the world's most important climate regulators and carbon storehouses. This expanse of trees, lakes, wetlands, and peatlands hosts an astonishing array of biodiversity, the world's largest unbroken areas of primary forest, and hundreds of Indigenous cultures.

But over the past century, the fingerprints of industrial development have slowly invaded this precious ecosystem. Logging, mining, tar sands production, and hydro-electric development have created a checkerboard of clearcuts, open-pit mines, vast reservoirs, and tens of thousands of miles of roads. This activity has denuded landscapes and reversed the course of rivers. Today, these threats and their impacts persist, largely unabated. In just 20 years, an area nearly the size of Ohio has been cut, with a huge portion of this harvested wood converted into pulps that are used to manufacture newsprint, paper, and tissue.

NRDC has conducted a comprehensive review of scientific literature regarding the climate benefits of the boreal forest and potential damage to those benefits caused by industrial logging. This report focuses primarily on quantifying the climate impacts of industrial logging. Our findings give cause for concern.

The current rate of clearcut logging is releasing substantial, unmeasured amounts of carbon dioxide that we estimate to be greater than the annual greenhouse gas emissions of countries like Estonia, Latvia, and Slovenia. Looked at from the Canadian context, we estimate that this unmeasured source of carbon dioxide is equivalent to 37 percent of current production emissions associated with Canada's tar sands industry.[1] In the key boreal forest provinces of Quebec and Ontario, we estimate that annual clearcutting causes the release of nearly 20 million tons of carbon dioxide over the course of the cut forests recovery and regrowth. And while forests' may eventually recover from intensive logging, our results show that current rates of cutting are outpacing the cut forest's natural ability to recover and to sequester more carbon than they release.

Here, we summarize the results of NRDC's modeling based on quantitative data measuring the carbon flux at a variety of boreal forest plots immediately post-harvest, mid-recovery, and post-recovery (i.e., regrown). "Carbon flux" is a measurement of the difference between forest respiration (carbon dioxide entering the area as the trees "exhale" and materials decompose) and forest sequestration (the rate at which the forest and its plants are absorbing and storing carbon dioxide from the atmosphere). These results reveal carbon dioxide emission trends that require serious policy responses, as discussed in this report's final section. These policies should be implemented across Canada's boreal forest to maximize the size and effectiveness of this critical carbon sink.

KEY TERMINOLOGY

This report uses certain key terms, defined below.

CLEARCUT: While clearcutting goes by many names, we use it to refer to the removal of a significant majority of living trees from a given area. It is the preferred harvest method across Canada's boreal forest.

FOREST REGENERATION: The recovery of a forest following harvest. We believe a previously harvested area has successfully regenerated when it has attained as many of its pre-harvest ecological characteristics as biologically possible.

PRIMARY FOREST: A forest that has not been significantly impacted by human activity such as road-building, logging, or mining. Can be synonymous with "old growth," "intact forest," and other terms.

NET ECOSYSTEM PRODUCTIVITY (NEP): A method for quantifying the carbon balance (i.e., carbon dioxide removed and carbon dioxide released) of a given area over time. In other words, it quantifies whether carbon dioxide is being emitted or sequestered within an area, and the changes in concentration of carbon dioxide within that area over time.

EMISSIONS: Greenhouse gas emissions, typically in the form of carbon dioxide.

SEQUESTRATION: The process by which living trees remove carbon dioxide from the air and "lock" it in their wood, root systems, debris, and soils.

CARBON SINK: An area, such as a forest, that sequesters and stores a larger amount of carbon dioxide than it releases through natural processes.

WETLAND: An area of land that is saturated with water, such as a marsh or swamp.

PEATLAND: An area of land containing mostly peat or peat bogs, which are made up primarily of decomposed plant matter accumulated in a water-saturated environment with limited exposure to oxygen.

LIFECYCLE ANALYSIS (LCA): Examination of a product's total carbon footprint from the moment raw material is harvested through the product's eventual use or disposal.

1 Environment and Climate Change Canada, *National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada* (2017), p. 80, unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php.

FIGURE 1: THE AMERICAN AND CANADIAN BOREAL FOREST (GREEN). IN CANADA, THE BOREAL FOREST STRETCHES FROM NEWFOUNDLAND OFF CANADA'S EAST COAST, ALL THE WAY TO CANADA'S WESTERN BORDER WITH THE UNITED STATES IN THE YUKON TERRITORY

I. THE CANADIAN BOREAL FOREST: A VAST CARBON STOREHOUSE

The boreal forest[2] is the world's largest forest, circling the Northern Hemisphere with a green crown that contains nearly 25 percent of the world's remaining primary forests.[3] It covers much of Canada, Alaska, Russia, Finland, Sweden, and Norway, as well as portions of China and Mongolia.[4] Its forest floor is home to a delicate ecosystem of mosses, lichens, and other organisms,[5] and its soils are often extremely carbon-rich.[6] In addition to seemingly endless stretches of closed-canopy forest, large areas are covered by wetlands, rivers, lakes, and peatlands, which are some of the world's most carbon-dense ecosystems.

In Canada, the boreal forest covers more than 1 billion acres stretched across the entire country.[7] This vast network of ecosystems provides regional and global benefits, including biodiversity, vast intact habitats, freshwater storage, cultural preservation of Indigenous Peoples' traditional practices, and recreation, among many others.[8,9,10] The forest's ability to produce these benefits depends on a landscape largely protected from major human impacts like industrial development.

Canada's boreal forest is also an extraordinary carbon storehouse. It plays a critical role in the fight against climate change via three key processes: storing carbon above ground in its trees, storing carbon below ground in its soils, and continuing to absorb carbon dioxide out of the atmosphere and "sequester" it in both these carbon pools. Due to its cold temperatures and extensive peatlands, the Canadian boreal forest is extremely effective at storing atmospheric carbon within its biomass and soils for long periods.[11] Over time, carbon accumulates above and below ground, with much

2 Faculty of Natural Resources Management, "Overview," Lakehead University, www.forest.org/index.php?category=world_boreal_forest (accessed August 30, 2017).

3 Boreal Songbird Initiative, "Boreal Forest," www.borealbirds.org/boreal-forest (accessed August 31, 2017).

4 Ibid.

5 Hinterland Who's Who, "Boreal Forest," Canadian Wildlife Federation, www.hww.ca/en/wild-spaces/boreal-forest.html (accessed August 31, 2017).

6 Corey J.A. Bradshaw and Ian G. Warkentin, "Global Estimates of Boreal Forest Carbon Stocks and Flux," *Global and Planetary Change*, 128, no. 27 (May 2015): p. 24.

7 Arun K. Bose, et al., "Constraints to Partial Cutting in the Boreal Forest of Canada in the Context of Natural Disturbance-Based Management: A Review," *Forestry* 87, no. 1 (January 2014): p. 12.

8 Hinterland Who's Who, "Boreal Forest." PEW Environment Group, *A Forest of Blue: Canada's Boreal* (2011), p. 7, www.pewtrusts.org/~/media/legacy/uploadedfiles/peg/publications/report/pegborealwaterreport11march2011pdf.pdf.

9 Boreal Songbird Initiative, "Indigenous Communities in Canada's Boreal Forest," www.borealbirds.org/indigenous-communities-canada-boreal-forest (accessed August 30, 2017).

10 Sara Teitelbaum, *Building a Green Economy in the Boreal Forest*, Greenpeace (2010), p. 5, www.greenpeace.org/canada/Global/canada/report/2010/11/Building-a-green-economy-in-the-boreal-forest.pdf. Natural Resources Canada, "Boreal Forest," www.nrcan.gc.ca/forests/boreal/13071 (accessed August 30, 2017).

11 International Boreal Conservation Campaign, "Carbon Storage in Canada's Boreal Forest" (June 2012), http://mbwatercaucus.org/wp-content/uploads/2012/06/BorealForest-CarbonMaps.pdf. Matt Carlson, Jeff Wells, and Dina Roberts, *The Carbon the World Forgot: Conserving the Capacity of Canada's Boreal Forest Region to Mitigate and Adapt to Climate Change*, Boreal Songbird Initiative and Canadian Boreal Initiative (2009): p. 8-9, www.borealbirds.org/sites/default/files/pubs/report-full.pdf.

of it becoming locked in permafrost. Northern circumpolar permafrost areas are estimated to hold up to 50 percent of the world's below-ground carbon in place.[12] From a carbon management perspective, it is also important to recognize that healthy boreal forests continue to sequester carbon as they age, with older forests storing more carbon than younger forests.[13] The Canadian boreal forest's soils, plants, and wetlands hold more than 12 percent of the world's land-based carbon stock—an almost unimaginable 306.6 billion tons. That's the equivalent of more than 36 years of global carbon dioxide emissions from burning fossil fuels.[14]

A remarkable share of total forest carbon is stored in the soils of the boreal forest. Compared to tropical forests, which are estimated to hold more than 50 percent of their carbon in trees and other above-ground biomass, boreal forests hold as little as 5 percent of their carbon in trees and other plants.[20] This means that 95 percent of the boreal forest's stored carbon is essentially "locked up" in its soils, wetlands, and peatlands. Absent human intervention, it will largely remain there.[21]

INDIGENOUS PEOPLES AND THE BOREAL FOREST

Though this report focuses on a narrow analysis of measured quantitative data, it is important to acknowledge that the Indigenous Peoples who have inhabited Canada's boreal forest for millennia have much to teach the Western world about the forest and the changes that have taken place there. The forest and its species—such as boreal caribou—are intimately entwined with Indigenous cultures across the region. This relationship between cultures and ecosystems is leading to new and innovative management regimes, designed and led by Indigenous communities, that show promise for addressing many of the impacts and threats explored in this report.[15] The development of these regimes is creating a model for integrating Indigenous and Western knowledge and science in ways that ensure that Indigenous Peoples' intimate and long-term knowledge of the forest is truly integrated into new provincial and federal policies. In the climate policy context, this same integration of Indigenous and Western knowledge and science should be deployed in examining forest management regimes that maximize the forest's ecological health and climate benefit.

THE BOREAL FOREST IS A KEY PILLAR IN THE FIGHT AGAINST CLIMATE CHANGE

In 2015, more than 190 countries came together in Paris for the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC). These nations, including Canada, agreed to act to limit global temperature rise to 2 degrees Celsius above preindustrial levels, and to make every effort to limit this warming to 1.5 degrees Celsius.

The world's forests were identified as a key tool for achieving that goal.[16] As a major carbon reservoir with the ability to remove significant amounts of carbon dioxide from the atmosphere, the Canadian boreal forest is one of our most critical weapons in this fight.

Canada has acknowledged the importance of its forests as carbon sinks that can be further enhanced through smart management. However, its "Pan-Canadian Climate Framework"—the federal government's outline of national and sub-national policies to reduce Canada's greenhouse gas emissions—appears to have adopted forest industry assertions[17] that ignore major knowledge gaps and are overly optimistic about the potential for wood products to store carbon (discussed further in Section III).[18] This could undermine the effectiveness of the country's climate mitigation plans, as it has a 44 million metric ton gap between projected emissions and its greenhouse gas emissions reduction targets that it hopes to fill via "additional measures such as . . . stored carbon (forests, soils, and wetlands)."[19]

12 Carlson, Wells, and Roberts (2009): p. 9.

13 Sebastiaan Luyssaert, et al., "Old-Growth Forests as Global Carbon Sinks," *Nature* 455, no. 7210 (2008): p. 213-215. N.L. Stephenson, et al., "Rate of Tree Carbon Accumulation Increases Continuously with Tree Size," *Nature* 507, no. 7490 (March 6, 2014).

14 The global terrestrial carbon stock is often estimated at 2,500 gigatons. R. Lal, "Soil Carbon Sequestration Impacts on Global Climate Change and Food Security," *Science* 304, no. 1623 (June 2004): p. 1623. Recent studies of the boreal forest carbon stock have found a median value, based on existing research, of 1,095 gigatons. Bradshaw and Warkentin (2015): p. 26. With 28 percent of the boreal located in Canada, we estimate that around 12.3 percent of the global terrestrial sink, or 306.6 gigatons, is located in Canada's boreal forest. Natural Resources Canada, "8 Facts About Canada's Boreal Forest," http://www.nrcan.gc.ca/forests/boreal/17394 (accessed August 30, 2017). Global greenhouse gas emissions from burning fossil fuels totaled just under 8.4 gigatons in 2007, and we have used this number in our calculations. Mark Z. Jacobson, *Air Pollution and Global Warming: History, Science, and Solutions* (New York, NY: Cambridge University Press, 2012), p. 301.

15 Pikangikum First Nation and Red Lake District, Ontario Ministry of Natural Resources, *Keeping the Land: A Land Use Strategy for the Whitefeather Forest and Adjacent Areas* (June 2006), www.whitefeatherforest.ca/wp-content/uploads/2008/08/land-use-strategy.pdf.

16 *See:* UNFCCC, *Paris Agreement*, Article 5 (2015), unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf.

17 *See, e.g.:* Canadian Climate Forum, *Canadian Forest Products: Contributing to Climate Change Solutions* (2015), p. 3, www.fpac.ca/wp-content/uploads/CCF-IP4-Forest-Nov2015-FINAL.pdf. The report claims, "Increasing the use of wood for construction can reduce emissions as the carbon stored in that wood gets locked in for a long period of time." Government of Canada et al., *Pan-Canadian Framework on Clean Growth and Climate Change* (2016), p. 21, www.canada.ca/content/dam/themes/environment/documents/weather1/20170125-en.pdf.

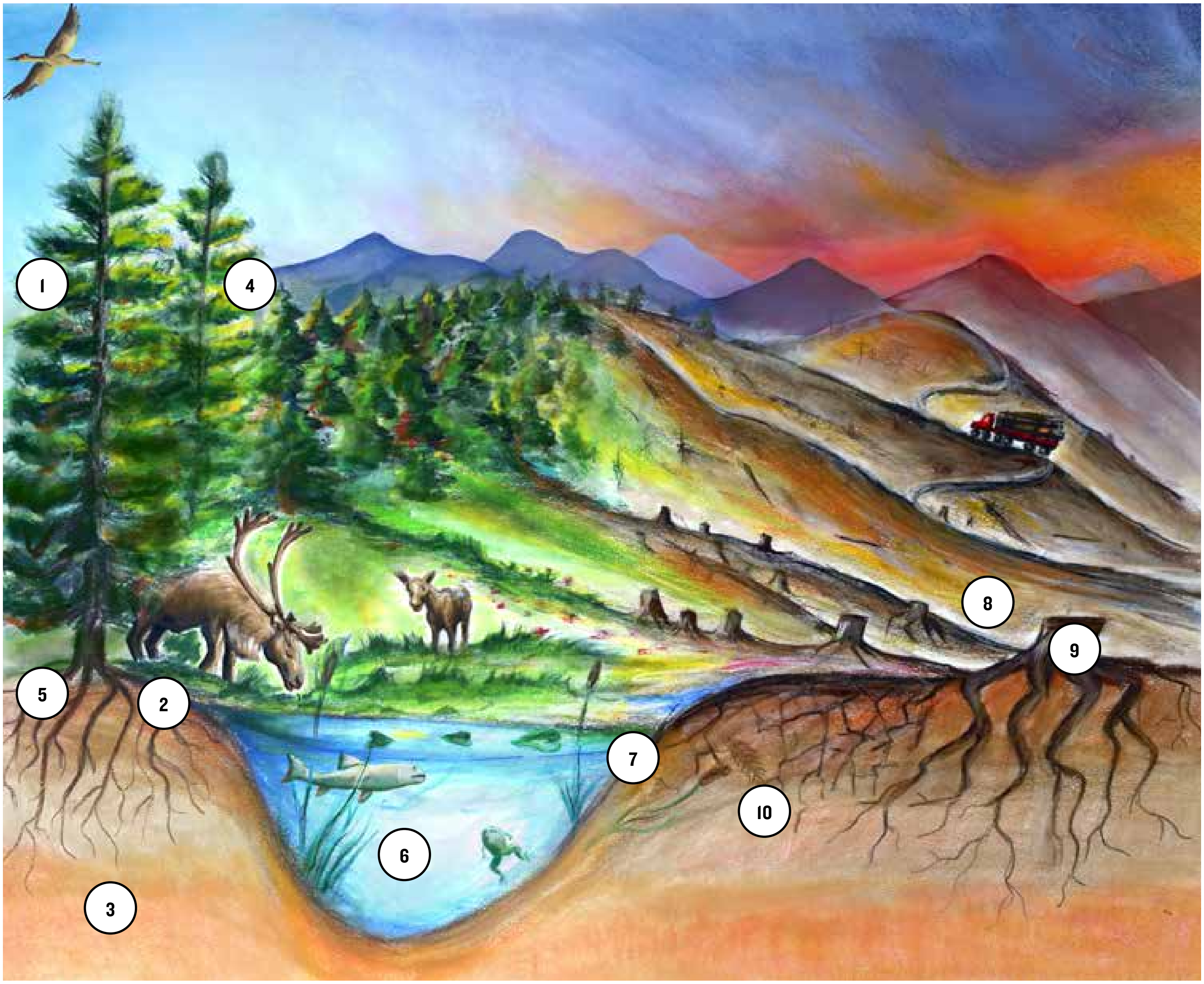
18 Government of Canada et al., *Pan-Canadian Framework on Clean Growth and Climate Change* (2016), p. 21.

19 Ibid., p. 44.

20 Bradshaw and Warkentin (2015), p. 27.

21 *See generally*, Ibid.

FIGURE 2: THE BASICS OF BOREAL FOREST CARBON DYNAMICS



Boreal visual by Courtenay Lewis and Rebeka Ryvola

An undisturbed boreal forest sequesters carbon dioxide via (1) photosynthesis, which moves atmospheric carbon dioxide into a tree or plant's biomass—(2) that is, its leaves, branches, roots. Over time, a good deal of this carbon is moved (3) to the boreal forest's soils as leaves, branches, and roots slowly biodegrade and become part of the ecosystem's soils. Carbon is lost from undisturbed forests via (4) respiration and (5) decomposition. (6) Wetlands and (7) peatlands also contribute to the boreal forest's carbon storage by providing significant water-saturated, oxygen-poor areas that limit decay. When a forest is disturbed by clearcutting, stored carbon in soils and forest floor litter is released via (8) soil disturbance and increased rates of (9) decomposition. (10) Wetlands are often drained or dry up due to a decline in the area's ability to store water, and peatlands also dry up, leading to significant releases of carbon dioxide and methane from now-decaying plant matter.

CANADA'S ASTONISHING ANNUAL BOREAL FOREST CLEARCUTTING

ON AVERAGE, MORE THAN

1 MILLION

NEW ACRES ARE CLEARED IN CANADA'S BOREAL FOREST EVERY YEAR.

SINCE 1996, MORE THAN

28 MILLION ACRES

OF CANADIAN BOREAL FOREST HAVE BEEN LOGGED. THAT'S AN AREA MORE THAN

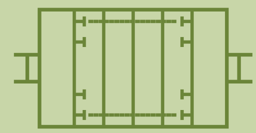
23X

AS BIG AS GRAND CANYON NATIONAL PARK AND NEARLY AS BIG AS THE ENTIRE STATE OF OHIO.

IN CANADA'S BOREAL FOREST, INDIVIDUAL CLEARCUTS SOMETIMES APPROACH

25,000 ACRES

IN SIZE (EQUIVALENT TO 18,000 FOOTBALL FIELDS).



x 18,000

Finally, like all living forests, the Canadian boreal forest extracts carbon dioxide from the atmosphere and holds it in its soils and trees, effectively offsetting greenhouse gas emissions from other sources into the future.[22] This annual removal—which has been estimated for Canada's entire boreal region—is estimated at 113.4 million tons of carbon dioxide, an amount equivalent to emissions from 24 million passenger vehicles.[23] Left undisturbed, the boreal forest can thus act as a long-term carbon sink, making it a powerful resource to help the world meet its goal of keeping average global temperature increases below 2 degrees Celsius in order to avoid the worst consequences of climate change.[24]

II. BOREAL FOREST CLEARCUTTING: AN UNCOUNTED CARBON SOURCE

Since 1996, more than 28 million acres of boreal forest have been logged. That's an area more than 23 times as big as Grand Canyon National Park and nearly as big as the entire state of Ohio.[28] More than ninety percent of this total area was harvested through clearcutting techniques,[29] which are especially destructive to fragile boreal forest ecosystems. In Canada's boreal forest, individual clearcuts sometimes approach 25,000 acres in size—equivalent to 18,000 football fields.[30] On average, more than 1 million new acres

HOW IS CARBON LOST FROM FOREST SOILS?

Carbon sequestration in the boreal forest is influenced by the following factors, among others: (1) the process of photosynthesis, (2) the interaction between fallen organic matter from trees and plants and forest floor bacteria and organisms, and (3) a tree's root system. The entire process can be disrupted when a forest is harvested in a way that severely disrupts these interactions by removing too many trees, disturbing the forest floor, or removing too much of the organic matter beneath trees. Changes in sunlight and temperature suddenly alter the conditions on the forest floor, and these changes can prompt organic carbon to slowly undergo the chemical transition to carbon dioxide, which enters the atmosphere.[25,26,27]

22 Carlson, Wells, and Roberts (2009), p. 7.

23 This boreal region estimation is based on estimates finding that the mean carbon flux for the Canadian boreal region is 0.056 Mg C/hectare per year. Canada's boreal region covers 552 million hectares (slightly more than the area covered by boreal forest), resulting in total positive flux (sequestration) of 30.9 million metric tons of carbon per year. Converted to carbon dioxide, this totals 113.4 million metric tons per year. Bradshaw and Warkentin (2015), p. 29. United States Environmental Protection Agency, "Greenhouse Gas Equivalencies Calculator," www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (accessed August 30, 2017).

24 William S. Keeton, et al., "Late-Successional Biomass Development in Northern Hardwood-Conifer Forests of the Northeastern United States," *Forest Science* 57, no. 6 (2011): p. 499.

25 This summary relies on Natural Resources Defense Council, "Why We Can't Fight Climate Change Without an Intact Boreal Forest," www.nrdc.org/stories/why-we-cant-fight-climate-change-without-intact-boreal-forest (accessed October 20, 2017).

26 Thomas Buchholz, et al., "Mineral Soil Carbon Fluxes in Forests and Implications for Carbon Balance Assessments," *GCB Bioenergy* 6, no. 4 (July 2014): p. 305-11.

27 Hosea Kato Mande, et al., "Forest Logging and It (sic) Impact on Soil Carbon Dioxide Efflux in the Tropical Forest, Peninsular Malaysia," *Journal of Environmental Science, Toxicology and Food Technology* 8, no. 12 (December 2014): p. 69-70.

28 United States Census Bureau, "State Area Measurements and Internal Point Coordinates," www.census.gov/geo/reference/state-area.html (accessed August 30, 2017). National Park Service, "Grand Canyon," www.nps.gov/grca/learn/management/statistics.htm (accessed August 30, 2017).

29 National Forestry Database, "A. Area Harvested: Clearcut (ha)*c," nfdp.ccfm.org/data/compendium/html/comp_61e.html (accessed August 20, 2017). Greenpeace, *Consuming Canada's Boreal Forest: The Chain of Destruction from Logging Companies to Consumers* (2007), p. 19, www.greenpeace.org/canada/Global/canada/report/2007/9/consuming-the-boreal-forest-t.pdf. "Clearcutting" refers to a logging practice that removes most, if not all, trees from a given area during harvest. Andrew Park, et al., *A Cut Above: A Look at Alternatives to Clearcutting in the Boreal Forest*, Wildlands League (February 2005), p. 9, wildlandsleague.org/attachments/A%20Cut%20Above.pdf.

30 Catherine Grant, et al., *Boreal Alarm: A Wake Up Call for Action in Canada's Endangered Forests*, Greenpeace (2012), p. 9, www.greenpeace.org/canada/Global/canada/report/2013/01/HotSpotReport.pdf.

are cleared in Canada's boreal forest every year.[31] It is not easy to mitigate many of the impacts of clearcutting, which include increased runoff from denuded soil, degraded peatlands and wetlands, and damage to the fragile forest floor from use of heavy equipment.

In addition to the enormous ecological impacts of this industrial activity, one major impact has gone largely unmeasured and unreported: the dramatic degradation of the boreal forest carbon sink and the associated carbon dioxide emissions linked to boreal forest clearcutting. In fact, each of the impacts listed above further damages the boreal forest's ability to keep as much carbon and other potent greenhouse gases locked within its soils and peatlands as possible.

To begin to grasp the implications of these missing and unaccounted for carbon dioxide emissions, NRDC surveyed data applicable specifically to the Canadian boreal forest and created a model to estimate per-acre[32] emissions associated with boreal forest clearcutting. This model and its outputs are discussed in detail below.[33]

II.a. Counting Boreal Forest Carbon: Modeling Carbon Dioxide Emissions from Boreal Forest Clearcutting

We quantified the carbon dioxide emissions for a given clearcut acre from the moment of harvest until full regeneration was achieved. Under this scenario, the acre in question hypothetically grows back and once again stores as much carbon as it did before the initial harvest.[34]

Our analysis relies on studies that examined forest sites in Saskatchewan and Quebec representing a variety of forest conditions, including unharvested and clearcut parcels and areas that were in the process of post-harvest regeneration.[35] The species composition, understory, and soil type differed between Saskatchewan and Quebec sites—factors that impact the results discussed below. Saskatchewan was dominated by Jack pine, bearberry, green alder, and feathermoss, and Quebec by black spruce with some Jack pine, blueberry, laurel, and sphagnum.[36]

We used data from these studies to develop a model[37] to estimate the long-term carbon impact of clearcutting in the boreal forest. Secondarily, we looked at the carbon dioxide emissions associated with average annual clearcuts in the Canadian boreal forest by province.[38] A discussion of the model and our methods can be found in a paper titled "Accounting for Carbon Dioxide Emissions from Clearcut Logging in the Canadian Boreal Forest."[39]

We found that a clearcut acre of boreal forest is a net carbon dioxide source for decades of post-harvest recovery, depending on species and geography. This is because there is a large initial release of carbon dioxide at the moment of harvest, followed by gradually decreasing emissions from processes like decomposition, all of which exceed the amount of carbon the harvested site sequesters as plants and trees begin to reappear.

We also found that just a single acre of clearcut boreal forest releases an estimated 18 to 27.5 tons of carbon dioxide over a period of 13 years in a Jack pine-dominated boreal forest and 27 years in a black spruce-dominated boreal forest, compared to similar undisturbed forests with similar biological characteristics.[40] This range is likely due to compositional and geographic differences between the sites studied, as noted above. These findings are alarming and clearly point to boreal forest clearcutting as a significant source of anthropogenic carbon emissions in Canada.

31 National Forestry Database, "A. Area Harvested: Clearcut (ha)*c." This estimate is based on total harvesting in done provinces where most logging activity takes place in the boreal forest. These are Newfoundland and Labrador, Quebec, Ontario, Manitoba, Saskatchewan, Alberta, the Yukon Territory, and the Northwest Territories. Measured units were in hectares and have been converted to acres. Average clearcut area is based on 20 years of data.

32 Because the data used in our model was presented in terms of hectares, our model output uses those units. However, as presented here, we have converted our findings to acres.

33 Lance Larson, "Accounting for Carbon Emissions from Clearcut Logging in the Canadian Boreal Forest," Natural Resources Defense Council, (2017), https://www.nrdc.org/sites/default/files/accounting-emissions-clearcut-canadian-boreal-wp.pdf.

34 Under Canada's Forestry Act regulations, "If . . . the forestry officer includes terms or conditions in a permit or gives instructions for the protection of the forest area, those terms, conditions or instructions shall be to encourage regeneration and reforestation, to avoid damage to vegetation or to the timber that is not covered by the permit, and to avoid damage to the cutting and removal site and any animal habitats." Forestry Act, Timber Regulations of 1993, SOR/94-118, §8, laws-lois.justice.gc.ca/eng/regulations/SOR-94-118/page-1.html#docCont. Despite this apparently discretionary power to require regeneration, Canada touts forest regeneration in its forest industry marketing materials, claiming, "[t]he regeneration rate on harvested Crown lands in Canada is nearly 100% when artificial and natural regeneration rates are combined." Natural Resources Canada, *The State of Canada's Forests: Annual Report 2016* (2016), p. 24, cfs.nrcan.gc.ca/pubwarehouse/pdfs/37265.pdf. However, there is insufficient quantitative study of forest regeneration in Canada's boreal forest to evaluate this claim and thus improve upon the assumptions made in this brief.

35 R.F. Grant, et al., "Net Ecosystem Productivity of Temperate and Boreal Forests after Clearcutting—A "Fluxnet-Canada Measurement and Modelling Synthesis," *Tellus B* 62, no. 5 (2010): p. 475-496. Onil Bergeron, et al., "How Does Forest Harvest Influence Carbon Dioxide Fluxes of Black Spruce Ecosystems in Eastern North America?" *Agricultural and Forest Meteorology* 148, no. 4 (2008): p. 537-548.

36 Grant, et al., (2010), p. 480.

37 Larson (2017).

38 To reach our boreal clearcut number, NRDC used government-provided clearcut data from provinces where the majority of forest harvest takes place in the boreal forest. These include Alberta, Saskatchewan, Manitoba, Ontario, Quebec, and Newfoundland and Labrador. British Columbia, one of Canada's major forest products producers, is not included because most of its logging takes place outside of the province's limited boreal zone.

39 Larson (2017).

40 This time frame is based on our model's output of the period of time it takes for a clearcut acre of boreal forest to make the transition from a net carbon source (immediately following cut) to a net carbon sink. The measurements we relied on showed faster forest recovery in Jack pine-dominated forests (13 years) versus black spruce-dominated forests (27 years).

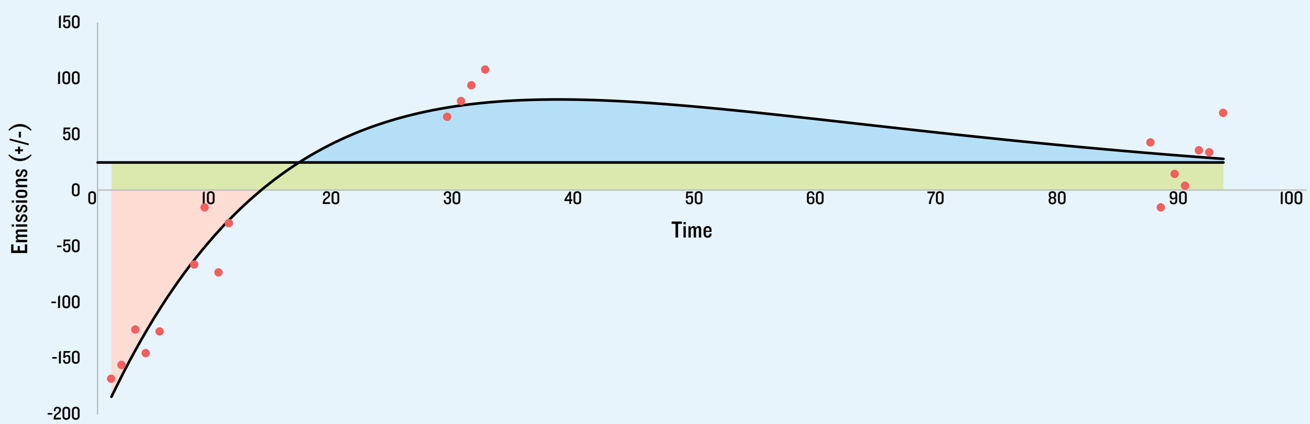
THE BASICS OF NRDC'S CLEARCUT EMISSIONS ACCOUNTING MODEL

To estimate the carbon dioxide emission impacts of clearcutting in the Canadian boreal forest, we developed a model that compares measurements of net ecosystem productivity (NEP) taken at boreal forest clearcut sites, sites recovering from clearcuts, and maturing boreal forest sites (sites where disturbance took place 75+ years ago).[41] We then plotted this data against the number of years that had elapsed post-clearcut, and fit a curve to it to determine both the amount of carbon dioxide released following a clearcut, and the length of time it might take for the clearcut forest to return to being either carbon neutral (i.e. breaking even in terms of carbon stored and carbon dioxide released versus its pre-cut state) or a net carbon sink (i.e., having made up its carbon debt and continuing to sequester additional carbon dioxide).

Our model conservatively assumes that a recently clearcut boreal forest site will eventually regrow into a hypothetical mature forest—that is, a forest with similar biological characteristics to the forest that was cut—with a comparable carbon sequestration value to that which was lost with the initial cut. However, replanting and natural reseeding efforts often fail to fully restore clearcut forests to their pre-harvest conditions.[42] Aside from complete canopy recovery, the challenges to full recovery include redeveloping biodiversity,[43] mimicking forest composition,[44] and restoring carbon sequestration potential.[45] Thus, our emissions estimates are likely lower than actual emissions, since anecdotal evidence suggests that forest regeneration in Canada's boreal forest is far less successful than claimed.

FIGURE 3: CONCEPTUAL DEPICTION OF NRDC'S BOREAL FOREST CLEARCUTTING EMISSIONS MODEL

The curve represents a forest site's response to clearcutting over time, with the curve fitted to measured data points (red dots). At harvest, there is a large initial release of carbon dioxide at the site, followed by a gradual decrease in the rate of release while the site recovers. The red area shows the period when the site is a net source of carbon dioxide. The green area shows the assumed sequestration potential of an unharvested site. The blue area shows the period when the site is a net sink of carbon dioxide. Importantly, the "carbon debt" created by the initial harvest is not "paid off" when the curve crosses the x-axis (red area becomes blue area). Our modeling suggests this does not occur for more than 60 years—meaning carbon neutrality at the site is not achieved until after that time.



To capture the magnitude of annual clearcutting, we examined clearcutting at current rates over a period of 85 years. This period represents the rotation length—or anticipated time between first and second harvests of a given acre of forest—currently mandated by Quebec in the boreal zone.[46] Our results provide a projection of annual carbon dioxide emissions associated with clearcut logging and show how cumulative cutting of large areas leads to a net release of sequestered carbon that forest regeneration alone cannot mitigate.

41 Measurements were expressed in terms of "net ecosystem production" (NEP). NEP quantifies the direction and magnitude of carbon dioxide emissions by comparing the CO_2 absorbed by the boreal to CO_2 emitted through respiration.

42 S. Gauthier, et al., "Boreal Forest Health and Global Change," *Science* 349, no. 6250 (Aug. 21, 2015): p. 820.

43 Ibid.

44 D.J. McRae, et al., "Comparisons Between Wildfire and Forest Harvesting and their Implications in Forest Management," *Environmental Reviews* 9, no. 4 (2001): p. 237.

45 Christopher Reyer, Martin Guericke, and Pierre L. Ibisch, "Climate Change Mitigation Via Afforestation, Reforestation and Deforestation Avoidance: And What About Adaptation to Environmental Change?" *New Forests* 38, no. 1 (July 2009): p. 28. Thuy Nguyen-Xuan, et al., "The Importance of Forest Floor Disturbance in the Early Regeneration Patterns of the Boreal Forest of Western and Central Quebec: A Wildfire Versus Logging Comparison," *Canadian Journal of Forest Research* 30, no. 9 (2000): p. 1353-1364. Karen Harper and S. Ellen Macdonald, "Structure and Composition of Edges Next to Regenerating Clear-Cuts in Mixed-Wood Boreal Forest," *Journal of Vegetation Science* 13, no. 4 (Aug. 2002): p. 535-546. Christopher M. Gough, et al., "The Legacy of Harvest and Fire on Ecosystem Carbon Storage in a North Temperate Forest," *Global Change Biology* 13 (2007): p. 1935-1949.

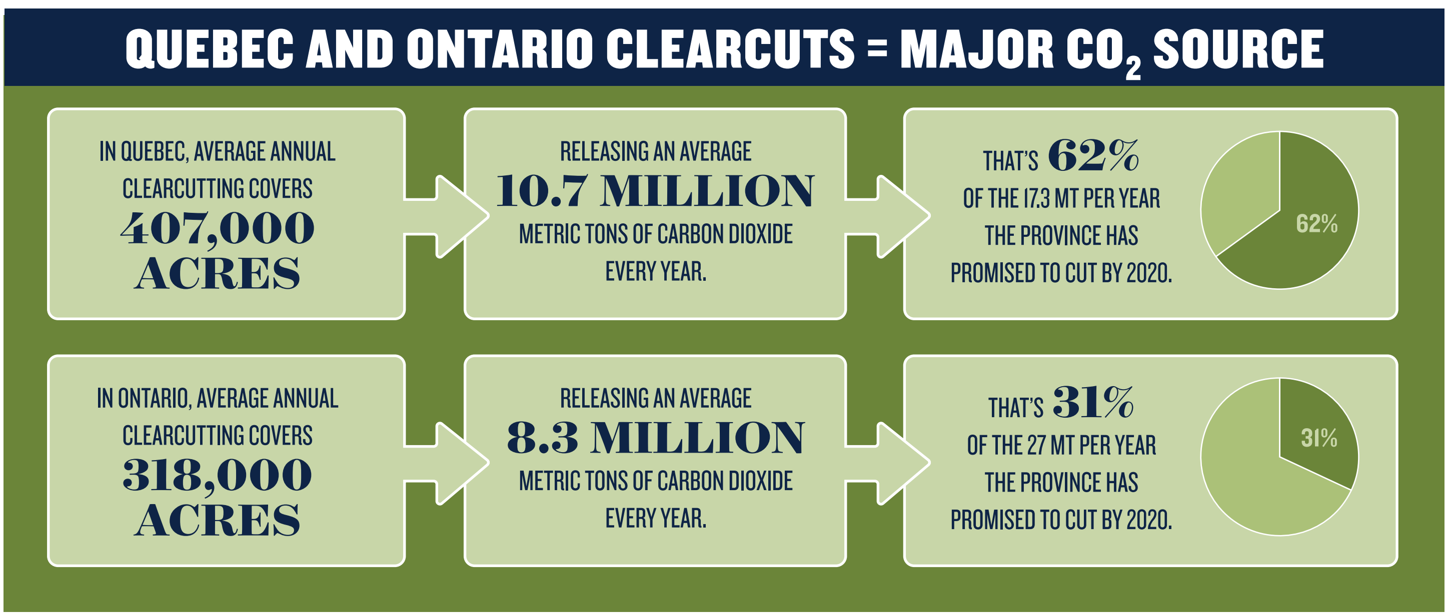
46 We chose this 85-year period because of its current use in a province's boreal forest timber management policy. It does not necessarily represent the time needed for a harvested area in Canada's boreal forest to reach maturity as we define that term.

TABLE 1: AVERAGE ANNUAL AREA CLEARCUT WITH ESTIMATED CO_2 EMISSIONS ASSOCIATED WITH THAT CUTTING							
PROVINCE	**QUEBEC**	**ONTARIO**	**ALBERTA**	**NEWFOUNDLAND**	**SASKATCHEWAN**	**MANITOBA**	**TOTALS**
Annual Harvested Area (acres)[49]	407,000	318,000	190,000	32,000	35,000	25,000	1,007,000
CO_2 Emissions Associated with Annual Harvest (million metric tons)[50]	11.2	8.7	3.4	0.9	0.6	0.5	25.3

When we applied our per-acre findings to annual average clearcutting by province, it became evident that clearcutting causes the emission of a significant quantity of carbon dioxide from disturbed sites that is currently unaccounted for. These emissions are from soil and forest floor disturbance and increased decomposition. This is important since many in the forest industry[47]—and in government[48]—currently claim that intensive forest harvest has a net climate benefit because it keeps carbon that could be lost to natural disturbances, like fire and insects, stored within harvested wood products. There are many problems with this assumption, as discussed in Section III.

As countries and sub-national entities around the world aspire to quickly reduce their greenhouse gas emissions, it is particularly important for Canada's two largest boreal forest harvesters—Quebec and Ontario—to measure and address boreal forest logging emissions as part of their climate plans. Looking at these two provinces closely, the challenge facing them is clarified:

In Quebec, with average annual clearcutting of nearly 407,000 acres,[51] the yearly cut can be expected to release at least 11.2 million metric tons (Mt) of carbon dioxide over the next 27 years.[52] When cumulative cutting impacts are analyzed across an 85-year period—Quebec's current harvest rotation length—these emissions equate to 10.7 Mt/year, on average; this is equal to 13 percent of total provincial emissions in 2015[53] and nearly 62 percent of the 17.3 Mt in annual emissions the province has promised to cut by 2020.[54] In other words, uncounted emissions from clearcut logging on public lands may be erasing two-thirds of the province's promised emissions reductions.



47 *See, e.g.:* Canadian Climate Forum, *Canadian Forest Products: Contributing to Climate Change Solutions*, p. 3.

48 *See, e.g.:* Ontario Ministry of Natural Resources and Forestry, *Ontario's Crown Forests: Opportunities to Enhance Carbon Storage?*, p. 8, apps.mnr.gov.on.ca/public/files/er/mnrf-16-244-discussion-paper.pdf (accessed August 31, 2017).

49 These figures have been rounded to the nearest 1,000 acres.

50 These are not "yearly" CO_2 emissions, but represent the total amount of CO_2 released over a 13- to 27-year period, for a single year of clearcut disturbances. The Jack pine boreal forest model was used for MB, SK, and AB. The Black spruce borealforestmodel was used for NL, QC, and ON.

51 Figure is based on a ten-year average from 2005-2014. National Forestry Database, "A. Area Harvested: Clearcut (ha)*c."

52 Based on the finding that a single clearcut acre can emit an estimated 18.0 – 27.5 tons of CO_2 and that emissions would occur over the course of forest regeneration.

53 Cumulative analysis of emissions curves generated by the BSp model with a moderate forest recovery assumption was done for an 85-year period (Quebec's current harvest rotation period), resulting in 907 Mt of emissions. This equates to 10.7 Mt/year, on average, over that time period. Quebec's reported annual greenhouse gas emissions were 80.1 Mt in 2015. Environment and Climate Change Canada, "Greenhouse Gas Emissions by Province and Territory," www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=18F3BB9C-1 (accessed August 31, 2017).

54 Government of Quebec, *Quebec in Action: Greener by 2020* (2012), p. 48, www.mddelcc.gouv.qc.ca/changements/plan_action/pacc2020-en.pdf.

In Ontario, with average annual clearcutting of 318,000 acres,[55] the yearly cut can be expected to release at least 8.7 Mt of carbon dioxide over the same 27 years.[56] When cumulative cutting impacts are analyzed across 85 years, these emissions equate to 8.3 Mt/year, on average, or 31 percent of the 27 Mt in annual emissions the province has promised to cut by 2020.[57] In other words, uncounted emissions from clearcut logging on public lands may be erasing nearly one-third of the province's promised emissions reductions. This finding should be of interest to Ontario decision-makers who recently showed North American leadership on climate change by successfully phasing out coal-fired electricity in 2014.[58]

HOW CANADA CURRENTLY HANDLES FOREST EMISSIONS

Canada does not currently include emissions from the "Land Use, Land-use Change and Forestry" (LULUCF) sector in its national greenhouse gas inventory (GHGI) provided to the UNFCCC.[59] Instead, it provides an estimate of the figure and notes, in its latest submission, that if it were included in the country's overall accounting, that the LULUCF sector would remove 34 Mt (4.7 percent) from its currently reported emissions.[60] This figure is based on measurements derived from "managed lands,"[61] which account for 67 percent of Canada's forested area.[62] Importantly, while Canada estimates a net carbon benefit from its managed forests, it excludes emissions associated with natural disturbances (primarily wildfire),[63] potentially creating a reporting imbalance given that the benefit measured also comes via natural processes. In addition, two important considerations remain unclear. First, in refining its reporting practices for GHGIs, Canada may begin treating harvested wood products differently in the future.[64] And second, it is unclear whether Canada is considering the emissions associated with interim fluxes in forest carbon—caused, for example, by extensive clearcutting[65]—which NRDC has found to be quite substantial.

Because these emissions take place over the entire regeneration period, we annualized them by measuring the cumulative emissions associated with average boreal forest harvest levels. Harvest rates and associated emissions currently outpace the recovery of carbon sequestration potential, meaning that each year, the Canadian boreal forest's "carbon debt" associated with logging increases. This means that carbon dioxide emissions associated with clearcutting Canada's boreal forest are greater than the carbon dioxide absorbed by areas that were clearcut in the past and are in the process of regenerating.

In average terms, this means that each year, clearcutting across the boreal forest releases more than 26 million metric tons (Mt) of carbon dioxide into the atmosphere—more than the annual emissions of countries like Estonia, Latvia, and Slovenia,[66] or the annual emissions of nearly 5.5 million passenger vehicles.[67] These estimated annual emissions are equivalent to 3.6 percent of Canada's total emissions in 2015[68] and 12 percent of the emissions Canada must cut according to its commitment under the Paris Agreement.[69] That means boreal forest clearcutting produces more emissions than Canada's reported annual aviation, rail, and marine freight sectors (12.7Mt), combined with its aviation, bus, rail, and motorcycle passenger sectors (7.6Mt).[70]

III. PIECES OF THE CARBON PUZZLE: THERE'S A LOT GOING ON IN THE FOREST

While we mainly focus on anthropogenic greenhouse gas sources in this report, we should also acknowledge the multiple other factors that may result in both carbon storage and carbon release in Canada's boreal forest. Some of these factors are natural and have taken place over the entire history of the forest's existence, independent of human interventions. Other dynamics exist precisely because of human activity in the forest or around the globe. The factors

55 Figure is based on a ten-year average from 2005-2014. National Forestry Database, "Area Harvested: Clearcut (ha)*c."

56 Based on the results of NRDC's Black spruce model.

57 The analysis used for Quebec above (see note 53) was applied to Ontario, resulting in 708 Mt of emissions over the 85-year period analyzed. This equates to 8.3 Mt/year, on average, over that time period. Ontario committed to reducing greenhouse gas levels 15% from 1990 emissions levels by 2020 – from 177 million tons to 150 million tons. Ontario Ministry of the Environment, Go Green: Ontario's Action Plan on Climate Change (August 2007), p. 7, www.climateontario.ca/doc/workshop/2011LakeSimcoe/Ontarios%20Go%20Green%20 Action%20Plan%20on%20Climate%20Change.pdf.

58 Christina Marshall, "Ontario Phases Out Coal-Fired Power," *Scientific American*, (January 11, 2013), www.scientificamerican.com/article/ontario-phases-out-coal-fired-power.

59 Ministry of Environment and Climate Change Canada, "National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada – Executive Summary," www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=662F9C56-1#land (accessed October 23, 2017).

60 Ibid.

61 Ibid.

62 Sandro Federici, et al., *GHG Fluxes From Forests: An assessment of national GHG estimates and independent research in the context of the Paris Agreement,* Climate and Land Use Alliance, (June 2017), p. 10, Table 1, www.climateandlandusealliance.org/wp-content/uploads/2017/07/GHG_forest_fluxes-main-paper.pdf.

63 Donna Lee and Maria J. Sanz, *UNFCCC Accounting for Forests: What's in and what's out of NDCs and REDD+,* Climate and Land Use Alliance, (June 2017), p. 11, Table 6, www.climateandlandusealliance.org/wp-content/uploads/2017/07/Policy_brief-NDCs-and-REDD.pdf.

64 Ibid., p. 9, 11.

65 W.A. Kurz, et al., "Carbon in Canada's boreal forest – a synthesis," *Environmental Reviews* (2013), 21, no. 4: p. 271.

66 OECD.Stat, "Greenhouse Gas Emissions," Organisation for Economic Co-operation and Development, stats.oecd.org/Index.aspx?DataSetCode=AIR_GHG (October 20, 2017).

67 This figure should be treated as an estimate to guide future inquiry into average annual emissions attributable to intensive boreal forest logging. It was reached by summing the cumulative impact of 85 years of logging in the Quebec boreal forest based on our Black spruce model and then extrapolating that number out for the entire boreal forest. This equated to 2.245 billion metric tons of carbon dioxide released over an 85-year period, or 26.4 million metric tons per year. Larson (2017). United States Environmental Protection Agency, "Greenhouse Gas Equivalencies Calculator."

68 Environment and Climate Change Canada, "Canadian Environmental Sustainability Indicators: Greenhouse Gas Emissions," www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=F60DB708-1 (accessed October 20, 2017).

69 UNFCCC, *Canada's 2017 Nationally Determined Contribution Submission to the United Nations Framework Convention on Climate Change*, www4.unfccc.int/ndcregistry/PublishedDocuments/Canada%20First/Canada%20First%20NDC-Revised%20submission%202017-05-11.pdf.

70 Ibid., p. 22.

include harvested wood products, forest regeneration, climate change, and wildfires.

Wood Products: Carbon Stored or Carbon Lost?

Federal and provincial governments, along with Canada's forest industry, appear on the verge of taking an extreme and unnuanced position on the climate benefits of harvested wood products. Citing various published studies, they make blanket claims such as, "when carbon stored in harvested wood products is factored into carbon accounting, sustainably managed forests are always a carbon sink."[71] From a scientific and policy perspective, this blatant over-simplification of the complexity of the carbon balance issue could seriously damage Canada's boreal forest and its ability to act as a global carbon sink. It could also cast doubt on Canada's avowed commitment to fight climate change. One paper succinctly summarized the issue: "Scientists have yet to demonstrate that there is a net [carbon] storage in forest products if a complete [life cycle analysis], from cradle to grave, is completed,"[72] adding that "important emissions associated with the production, transport, and utilization of the forest products have been excluded, leading to erroneous conclusions about net [carbon] storage in forest products."[73]

Throughout the literature on harvested wood products (HWPs), an important note of caution is constantly sounded about depending on these products as a climate solution: HWPs only have a climate benefit under strict conditions.[74] This caution even appears in the studies cited by governments to support their claims that HWPs can "always" be carbon sinks.[75] For example, the Intergovernmental Panel on Climate Change (IPCC) states that HWPs can act as carbon pools if their wood is harvested "equal to or below the annual forest increment," reinforcing the necessity of reducing deforestation and forest degradation while increasing forest areas in a given region.[76] (Annual forest increment is essentially a forest's natural growth rate over the course of a year.) However, provinces like Ontario have used these studies to push the narrative that increased use of wood products (and thus, increased forest harvest) has a net-positive climate effect. While current literature concludes that HWPs can provide benefits under narrow conditions,[77] those conditions are not currently met in large parts of Canada's boreal forest.

Furthermore, if we are to consider HWPs as climate change mitigation tools, we must also consider these products' full lifecycle greenhouse gas impacts. In other words, to create a net climate benefit, the amount of carbon present in a finished product must be greater than the inputs (from harvest, processing, transport, etc.) needed to create and dispose of that product. In addition, the lost sequestration potential of the once-living tree and the amount of carbon released from soils following harvest may severely undermine HWPs' supposed climate "benefit." Issues of material substitution (i.e., using wood in place of concrete and/or steel, which both produce significant greenhouse gas emissions during production[78]) may also impact this analysis, and the viability of meaningful substitution has data gaps that require study as well.[79]

Because of the lack of lifecycle analyses for boreal forest HWPs, estimates and conclusions of the carbon pool created by wood products in use today can be used for misleading policy proposals. Scientific studies estimate that wood products in use or in landfills can provide a large, somewhat stable carbon sink and, therefore, have potential as climate change mitigation tools.[80] However, this conclusion is contingent on those products continuing to hold that carbon in place, and these same studies note that measuring the methane emissions associated with HWPs in landfills may in fact "eat up" the climate benefit that a stable, non-emitting sink would provide. Other recent studies indicate that, over the long term, a variety of factors make it unlikely that HWPs in landfills or in use store significant amounts of carbon for long periods.[81]

Furthermore, the conclusion that HWPs provide a stable, net carbon sink also assumes that the carbon contained in those products is greater than the carbon that was expended to produce, distribute, and dispose of them. Scientists emphasize that this lifecycle analysis has not yet been done and is needed if HWPs are to be pushed in any way as a climate solution.[82]

71 Ontario Ministry of Natural Resources and Forestry, *Ontario's Crown Forests: Opportunities to Enhance Carbon Storage?* p. 8 (emphasis added). See also: Québec Ministère des Ressources Naturelles et de la Faune, *Forests: Building a Future for Quebec* (2008), p. 18, mern.gouv.qc.ca/english/publications/forest/consultation/green-paper.pdf. Canadian Climate Forum, *Canadian Forest Products: Contributing to Climate Change Solutions*, p. 5.

72 Stith T. Gower, "Patterns and Mechanisms of the Forest Carbon Cycle," *Annual Review of Environment and Resources* 28 (Nov. 2003):, p. 194.

73 Ibid., p. 169.

74 *See, e.g.:* Gert Jan Nabuurs, et al., "Forestry," in *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (B. Metz et al., eds) (New York, NY: Cambridge University Press, 2007), p. 550. F. Werner, et al., "National and Global Greenhouse Gas Dynamics of Different Forest Management and Wood Use Scenarios: A Model-Based Assessment," *Environmental Science and Policy* 13 (2010): p. 72. Gower (2003), p. 194. Ann Ingerson, "Carbon Storage Potential of Harvested Wood: Summary and Policy Implications," *Mitigation and Adaptation Strategies for Global Change* 16, no. 3 (2011): 307–323.

75 Michael T. Ter-Mikaelian, Stephen J. Colombo, and Jiaxin Chen, "Effects of Harvesting on Spatial and Temporal Diversity of Carbon Stocks in a Boreal Forest Landscape," *Ecology and Evolution* 3, no. 11 (2013): p. 3738-3750 (cited in: Ontario Ministry of Natural Resources and Forestry, "Ontario's Crown Forests: Opportunities to Enhance Carbon Storage?" pg. 9). *See also:* Québec Ministère des Ressources Naturelles et de la Faune, *Forests: Building a Future for Quebec*, p. 25.

76 Nabuurs (2007), p. 550.

77 Ibid.

78 Ibid.

79 Ingerson (2011).

80 Ter-Mikaelian, Colombo, and Chen (2013).

81 Ingerson (2011).

82 Gower (2003), p. 172.

How Well Do Forests Regrow?

"Carbon neutrality" of timber harvest and consumption of wood products assumes that harvested trees will eventually grow back and reabsorb the carbon lost during harvest, as well as the carbon that would have been sequestered had that tree continued to grow. In Canada, this assumption is prevalent. In fact, the annual federal reports on Canada's forests claim that "[t]he regeneration rate on harvested [public] lands in Canada is nearly 100 percent when artificial and natural regeneration rates are combined."[83] However, there is an extreme dearth of scientific observation regarding post-harvest conditions in the Canadian boreal forest.

Ideally, harvested boreal forests would regrow to mirror their pre-harvest state: similar species of vegetation, similar canopy density, and a return of displaced wildlife. The limited scientific literature examining post-harvest outcomes in the boreal forest, however, paints a much different picture.

FOREST DEGRADATION VERSUS DEFORESTATION

Canada's governments and industry associations tend to focus their reporting on the state of Canada's forests on the minimal amount of deforestation currently taking place.[84] However, little to no attention is paid to forest degradation.[85] Deforestation is the permanent change of previously forested land to some other use like farming or roads or settlements.[86] Forest degradation, on the other hand, is more complex in that it results in a loss of overall biomass and species diversity—among other impacts.[87] Because of Canada's significant area of annual clearcutting, there is serious concern that tens of millions of acres of its forests (with the majority located in the boreal region) are degraded and thus further undermining the region's capacity as a global carbon sink.[88]

Because clearcutting does not mimic the complexity of natural disturbances (i.e., wildfires) and has been shown to negatively affect biodiversity and other complex ecosystem services, its impacts are likely far more significant than traditionally thought.[89] This is particularly relevant to current forest policies, which equate clearcutting and wildfire as interchangeable disturbances. However, research has found that forests that regenerate after intensive harvesting "retain less biological and structural diversity than those originating from natural disturbances in which rapidly changing habitats and high species turnover enhance the adaptation potential to new environmental conditions."[90] This suggests that, contrary to claims that replanting can aid in ecosystem adaptation to stressors like climate change,[91] industrial wood production in the boreal forest has in fact "reduced forest biodiversity and resilience."[92]

The bottom line is that if blocks of clearcut forest are growing back in altered states lacking original species complexity, age diversity, and density, the assumption of carbon neutrality of forest products is deeply flawed. If governments are overestimating the success of current post-harvest activities (including seeding, replanting, and chemical applications), the climate and ecological impacts of aggressive clearcutting are far greater than Canada and many in its forest industry claim.

Wildfires: Complex Natural Disturbances in the Boreal Ecosystem

One of the most complex and scientifically contentious issues impacting Canada's boreal forest is the annual occurrence of wildfires, which have burned large swathes of the boreal forest for time immemorial. They are a natural and important part of the disturbance cycle to which the forest and its species have adapted over millennia. Nonetheless, wildfires release carbon dioxide and, in an era of accelerating climate change, they are often perceived as harmful. However, this perception is overly simplistic, as the causes and impacts (both positive and negative) of fires vary wildly. There is general agreement that some forestry activity can help forests better withstand wildfires by removing buildups of flammable materials that can increase the intensity of fires.[93] But intensive logging methods like clearcut logging and monoculture replanting practices are often associated with more frequent and intense fires.[94]

83 Natural Resources Canada, *The State of Canada's Forests: Annual Report 2016*, p. 24.
84 *See, e.g.:* Natural Resources Canada, *The State of Canada's Forests: Annual Report 2016*.
85 Ibid.
86 Schoene, Dieter, et al., "Forests and Climate Change Working Paper 5: Deforestation," Food and Agriculture Organization of the United Nations (2007), http://www.fao.org/docrep/009/j9345e/j9345e07.htm (accessed October 20, 2017).
87 Ibid.
88 Axelrod, Josh, "Forest Degradation: Canada's Skeleton in the Closet," Natural Resources Defense Council (Sept. 21, 2017), https://www.nrdc.org/experts/josh-axelrod/forest-degradation-canadas-skeleton-closet (accessed October 20, 2017).
89 Yves Bergeron and Nicole J. Fenton, "Boreal Forests of Eastern Canada Revisited: Old Growth, Nonfire Disturbances, Forest Succession, and Biodiversity," *Botany* 90, no. 66 (2012): p. 509-523.
90 Gauthier, et al., (2015), p. 820.
91 *See, e.g.:* Natural Resources Canada, *The State of Canada's Forests: Annual Report 2016*, pg. 12.
92 Gauthier, et al., (2015), p. 820.
93 *See generally:* James K. Agee and Carl N. Skinner, "Basic Principles of Forest Fuel Reduction Treatments," *Forest Ecology and Management* 211, no. 1-2 (2005): p. 84. Scott L. Stephens, et al., "The Effects of Forest Fuel-Reduction Treatments in the United States," *BioScience* 2, no. 6 (June 2012): p. 549. But see: Stephen R. Mitchell, Mark E. Harmon, and Kari E. B. O'Connell, "Pacific Northwest Ecosystems," *Ecological Applications* 19, no. 3 (2009): p. 653-54. Dylan W. Schwilk, et al., "The National Fire and Fire Surrogate Study: Effects of Fuel Reduction Methods on Forest Vegetation Structure and Fuels," *Ecological Applications* 19, no. 2 (2009): p. 301 (suggesting that fuel reduction treatments, while useful for reducing risk of severe wildfires, can have unintended or undesired impacts on net carbon balance and introduction of invasive species).
94 Carter Stone, Andrew Hudak, and Penelope Morgan, "Forest Harvest Can Increase Subsequent Forest Fire Severity," *Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View* (2004): p. 532. Jonathan R. Thompson, Thomas A. Spies, and Lisa M. Ganio, "Reburn Severity in Managed and Unmanaged Vegetation in a Large Wildfire," *Proceedings of the National Academy of Sciences* 104, no. 25 (June 19 2007): p. 10746.

Climate Change: A Forest Stressor

The boreal forest is also on the frontline of some of the earliest and most dramatic impacts of climate change. Temperatures in the boreal forest are expected to increase more than any other forest biome, resulting in drier weather.[95] Drier weather and earlier snowmelt will likely increase the frequency and severity of fires across the boreal forest,[96] and there are indications that this is already occurring.[97] Peatlands are beginning to thaw and dry as well, releasing their vast stores of carbon dioxide and methane into the atmosphere.[98] Unfortunately, industrial logging often further exacerbates these impacts by increasing the frequency and intensity of fires,[99] decreasing forest resilience,[100] and exposing once protected soils to the elements.[101] These shifting realities illustrate that whatever we do, we should not exacerbate climate change with counterproductive logging practices.

IV. RECOMMENDATIONS FOR PRESERVING CANADA'S BOREAL FOREST AS A VITAL CARBON SINK

Disturbance of the Canadian boreal forest's soils, peatlands, wetlands, and permafrost demands serious attention as the world looks to rapidly curb emissions and the need for stable and growing carbon sinks becomes more pressing. Thus, protecting the Canadian boreal forest is in the interest of policymakers in Canada and around the world as we seek to achieve the goals of the Paris Agreement.

Unfortunately, the debate about how to best manage the boreal forest for maximum climate benefit has been overwhelmed by a misinformation campaign led by some in the Canadian logging industry who aim to convince policymakers that destructive forestry practices are beneficial to the global climate. The specter of wildfires and insect infestations, the promise of HWPs, and the blanket assumption of forest regeneration are all red herrings. These issues are being used to divert attention from controllable on-the-ground impacts that are degrading the Canadian boreal forest's effectiveness in the global fight against climate change.

Instead, Canadian policymakers should follow the best available science and devote resources to immediately address the gaps therein. NRDC recommends several common-sense approaches that preserve the Canadian boreal forest's important economic contributions and its critical global function. Our recommendations target Canadian federal and provincial decision-makers, as well as industry players.

Change Existing Forest Practices to Maximize the Boreal Forest's Climate Change Mitigation Potential

Work with Indigenous Peoples to develop forest management practices that keep unharvested areas not only intact, but also healthy; maximize in-place carbon storage; and preserve ecological benefits.

Indigenous Peoples have lived throughout the boreal forest for thousands of years and their cultures are intimately intertwined with the forest. As such, Indigenous Peoples must play pivotal roles in increasing understanding of the boreal forest and the best ways that humans can coexist with this critical ecosystem. In terms of climate change mitigation, Indigenous Peoples' knowledge and science can help federal and provincial policymakers better understand industrial impacts and develop approaches to avoid or minimize the damage.

Reexamine forest practices applicable to Crown Lands (i.e., public lands) and institute "climate-safe forest practices" that minimize disturbances in areas logged; preserve primary forest; and return harvested areas to resilient, long-lived, and complex stands.

As mentioned earlier, current harvest practices across Canada's boreal forest favor clearcutting, which creates large openings in the forest's canopy and is well-known for its major ecosystem impacts. On the other hand, "climate-safe" forestry would limit the use of clearcutting, minimize the impacts of ongoing harvest through careful planning, and include practices that leave more carbon in the forest. These practices could include selective harvesting, primary forest conservation, longer harvest rotations, and protecting forest areas greater than 10,000 km^2 to keep more carbon stored in place.[102] Policymakers must also ensure that new and diverse economic opportunities are created for northern communities who have depended largely on intensive forestry for the past half-century.

95 Gauthier, et al., (2015), p. 820. B.M. Wotton, M.D. Flannigan, and G.A. Marshall, "Potential Climate Change Impacts on Fire Intensity and Key Wildfire Suppression Thresholds in Canada," *Environmental Research Letters* 12 (August 2017): p. 1-12.

96 M.D. Flannigan, et al., "Fuel Moisture Sensitivity to Temperature and Precipitation: Climate Change Implications," *Climate Change* 134, no. 1-2 (January 2016): p. 59-71. Amber J. Soja, et al., "Climate-induced Boreal Forest Change: Predictions versus Current Observations," *Global and Planetary Change* 56, no. 3-4 (April 2007): p. 274-296. B.M. Wotton, et al., (2017), p. 1.

97 Soja, et al., (2007), p. 281. Justin Gillis and Henry Fountain, "Global Warming Cited as Wildfires Increase in Fragile Boreal Forest," *New York Times* (May 10, 2016), https://www.nytimes.com/2016/05/11/science/global-warming-cited-as-wildfires-increase-in-fragile-boreal-forest.html?hp&action=click&pgtype=Homepage&clickSource=story-heading&module=photo-spot-region&region=top-news&WT.nav=top-news&_r=2.

98 David T. Price, et al., "Anticipating the Consequences of Climate Change for Canada's Boreal Forest Ecosystems," *Environmental Review* 21 (2013): p. 322-365. Takeshi Ise, et al., "High Sensitivity of Peat Decomposition to Climate Change through Water-Table Feedback," *Nature Geoscience* 1 (Oct. 2008): p. 763-766.

99 Stone, Hudak, and Morgan (2004), p. 532. Thompson, Spies, and Ganio (2007), p. 10746.

100 Yan Boucher, et al., "Cumulative Patterns of Logging and Fire (1940-2009): Consequences on the Structure of the Eastern Canadian Boreal Forest," *Landscape Ecology* 32, no. 2 (February 2017): p. 361-375. Maude Perrault-Hébert, et al., "Ecological Drivers of Post-Fire Regeneration in a Recently Managed Boreal Forest Landscape of Eastern Canada," *Forest Ecology and Management* 399 (September 2017): p. 74-81.

101 Buchholz, et al., (2014). Mande, et al., (2014), p. 73.

102 These areas are often referred to as "intact forest landscapes" or "intact forest areas."

Prioritize Filling Gaps in Scientific Knowledge Regarding the Boreal Forest to Support Changes in Forest Policy Aimed at Maximizing the Boreal Forest's Climate Change Mitigation Potential

Fill major informational gaps regarding forest regeneration outcomes, greenhouse gas emissions linked to forest harvest, and changes in important ecosystems across Canada.

Forest regeneration is essential from an ecological, economic, and climate perspective. Canada currently claims that all forests harvested are 100 percent regenerated, as required by law.[103] However, there is little evidence this requirement is being met. To overcome this lack of information, a few key steps must be taken:

- First, the condition of harvested forests must be surveyed so that policymakers can adjust course to address potential problems created by historic harvest practices and levels. Such surveys would include capturing changes in species composition, canopy density and structure, and overall biomass present.
- Second, we need further research focused on post-harvest changes occurring on and below the forest floor. Thus, further study of carbon fluxes occurring in harvested areas is needed to build on the work we have presented here.

Support the study of boreal forest HWP lifecycles and carbon storage potential that accurately account for all inputs possible, including recycling and eventual production of methane in landfills.

The policy framework that favors HWPs as effective, stable carbon storage solutions requires scrutiny and significant additional study. We need robust, peer-reviewed analysis of the full carbon lifecycle of Canadian boreal forest wood products. Without it, government decision-makers cannot accurately assess the efficacy or impact of HWP carbon storage on overall boreal forest carbon balance or HWPs' viability as climate change mitigation tools. We also need an in-depth review of North American construction trends and forecasts, including building material usage and related regulations. This analysis would provide critical context for industry arguments that wood and concrete can often be interchanged in construction.

Conduct a comprehensive inventory of carbon in boreal forest soils across Canada and study the impact of industrial activity on this vital carbon store.

While the Canadian government and several scientists have estimated and modeled the terrestrial carbon stock of the global and Canadian boreal forest, we need a wide-scale inventory of the forest's soil carbon. This information would provide critical context for decisions that could impact this important global carbon storehouse.

Improve the Measurement and Reporting of Greenhouse Gas Emissions Associated with Industrial Activity in Canada's Boreal Forest

Develop transparent methods to measure and report greenhouse gas emissions associated with industrial forest activities and include this data in provincial and national greenhouse gas inventories and climate plans.

Canada and its provinces should build on existing work regarding LULUCF emissions reporting to ensure three important factors are considered. First, if Canada chooses to measure and report a "removal" of greenhouse gas emissions (in essence, an annual credit that lowers its internationally reported emissions) due to the extent of its forests, it must also measure and report emissions associated with natural disturbances within those same forests. Second, it must ensure that emissions associated with the country's significant annual timber harvest are quantified and reported. And third, it must ensure that the way it measures the climate impact of HWPs does not ignore the carbon intensity of these products' production, consumption, and eventual decay.

THE BOREAL FOREST CAN'T WAIT, AND CLIMATE CHANGE WON'T

The Canadian boreal forest is one of the planet's greatest carbon storehouses. But its effectiveness is under threat from industrial activity. As our findings show, clearcut logging across Canada's boreal forest is a major, unmeasured source of anthropogenic carbon dioxide emissions. This source must be measured and reported, as understanding and addressing these emissions will be important to the global fight against climate change. Similarly, assumptions and knowledge gaps must be filled before provincial and federal policymakers make decisions based on sweeping generalizations about HWPs' ability to store carbon and lower overall anthropogenic emissions.

And while the carbon that remains beneath the Canadian boreal forest is critical to the future of our planet's climate, the entire forest—its trees, plants, animals, insects, and waters—must be rehabilitated and protected to ensure the survival of the many Indigenous cultures that have thrived in this forest for millennia and an ecosystem that contributes essential benefits to the entire planet.

103 Natural Resources Canada, *The State of Canada's Forests: Annual Report 2016* (2016), p. 22.