2025 NCF-Envirothon Alberta

Current Environmental Issue

ENVIROTHON
ALBERTA 2025

STUDY RESOURCES
Part A

2025 NCF-Envirothon Alberta
Current Issue Study Resources
Part A

Roots and Resiliency: Fostering Forest Stewardship in a Canopy of Change

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Current Issue Part A Study Resources

Key Topic #1: Climate Change Projections

1. Describe the causes of climate change, including the greenhouse effect.
2. Explain the impacts of climate change on the environment, as well as social and economic impacts both locally and globally.
3. Explain the concept of Canada's Representative Concentration Pathway models and what they imply for the future climate.
4. Differentiate types of climate models and the various components that enable models to project future conditions.

Study Resources

Resource Title	Source	Located on
Basics of Climate Change	*US Environmental Protection Agency, 2024*	Pages 4 - 6
Climate Change Indicators: Snow and Ice	*US Environmental Protection Agency, 2024*	Pages 7 - 8
Overview of Climate Change in Canada	*Natural Resources Canada, 2015*	Pages 9 - 20
Scenarios and Climate Models	*Environment and Climate Change Canada, 2018*	Pages 21 - 22
Linking Climate and Inequality	*Guivarch, Taconet, and Mejean - International Monetary Fund, 2021*	Pages 23 - 26
Climate Change	*World Health Organization, 2023*	Pages 27 - 30

<u>Study Resources begin on the next page!</u> ➡

Basics of Climate Change

The earth's climate is changing. Multiple lines of evidence show changes in our weather, oceans, and ecosystems, such as:

- Changing temperature and precipitation patterns
- Increases in ocean temperatures, sea level, and acidity.
- Melting of glaciers and sea ice.[3]
- Changes in the frequency, intensity, and duration of extreme weather events.
- Shifts in ecosystem characteristics, like the length of the growing season, timing of flower blooms, and migration of birds.

These changes are due to a buildup of greenhouse gases in our atmosphere and the warming of the planet due to the greenhouse effect.

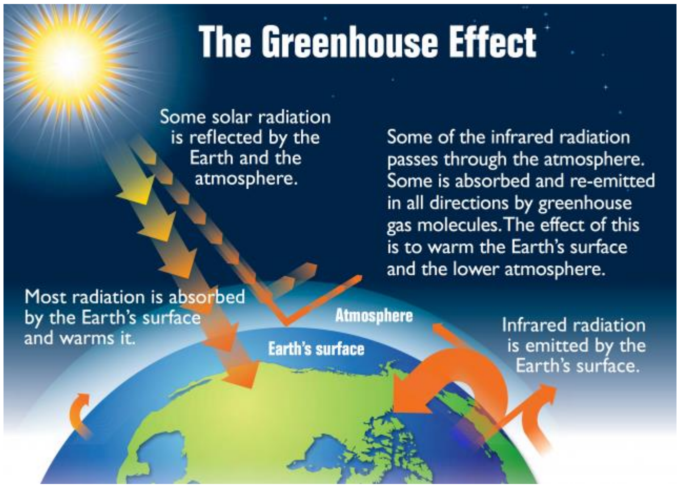

Figure 1) The greenhouse effect helps trap heat from the sun, which keeps the temperature on earth comfortable. But people's activities are increasing the amount of heat-trapping greenhouse gases in the atmosphere, causing the earth to warm up.

The earth's temperature depends on the balance between energy entering and leaving the planet's system. When sunlight reaches the earth's surface, it can either be reflected back into space or absorbed by the earth. Incoming energy that is absorbed by the earth warms the planet. Once absorbed, the planet releases some of the energy back into the atmosphere as heat (also called infrared radiation). Solar energy that is reflected back to space does not warm the earth.

Certain gases in the atmosphere absorb energy, slowing or preventing the loss of heat to space. Those gases are known as "greenhouse gases." They act like a blanket, making the earth warmer than it would otherwise be. This process, commonly known as the "greenhouse effect," is natural and necessary to support life. However, the recent buildup of greenhouse gases in the atmosphere from human activities has changed the earth's climate and resulted in dangerous effects to human health and welfare and to ecosystems.

Key Greenhouse Gases

Most of the warming since 1950 has been caused by human emissions of greenhouse gases.[4] Greenhouse gases come from a variety of human activities, including burning fossil fuels for heat and energy, clearing forests, fertilizing crops, storing waste in landfills, raising livestock, and producing some kinds of industrial products.

Carbon Dioxide

Carbon dioxide is the primary greenhouse gas contributing to recent climate change. Carbon dioxide enters the atmosphere through burning fossil fuels, solid waste, trees, and other biological materials, and as a result of certain chemical reactions, such as cement manufacturing. Carbon dioxide is absorbed and emitted naturally as part of the carbon cycle, through plant and animal respiration, volcanic eruptions, and ocean-atmosphere exchange.

The Carbon Cycle

The carbon cycle is the process by which carbon continually moves from the atmosphere to the earth and then back to the atmosphere. On the earth, carbon is stored in rocks, sediments, the ocean, and in living organisms. Carbon is released back into the atmosphere when plants and animals die, as well as when fires burn, volcanoes erupt, and fossil fuels (such as coal, natural gas, and oil) are combusted. The carbon cycle ensures there is a balanced concentration of carbon in the different reservoirs on the planet. But a change in the amount of carbon in one reservoir affects all the others. Today, people are disturbing the carbon cycle by burning fossil fuels, which release large amounts of carbon dioxide into the atmosphere, and through land use changes that remove plants, which absorb carbon from the atmosphere.

Methane

Both natural and human activities produce methane. For example, natural wetlands, agricultural activities, and fossil fuel extraction and transport all emit methane.

Nitrous Oxide

Nitrous oxide is produced mainly through agricultural activities and natural biological processes. Fossil fuel burning and industrial processes also create nitrous oxide.

F-Gases

Chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, together called F-gases, are often used in coolants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants.

Global Warming Potential

Different greenhouse gases can remain in the atmosphere for different amounts of time, ranging from a few years to thousands of years. In addition, some gases are more effective than others at making the planet warmer. Learn more about Global Warming Potential (GWP), a measure of climate impacts based on how long each greenhouse gas remains in the atmosphere and how strongly it absorbs energy.

Other Greenhouse Gases

Ground-Level Ozone

Ground-level ozone is created by a chemical reaction between emissions of nitrogen oxides and volatile organic compounds from automobiles, power plants, and other industrial and commercial sources in the presence of sunlight. In addition to trapping heat, ground-level ozone is a pollutant that can cause respiratory health problems and damage crops and ecosystems.

Water Vapor

Water vapor is another greenhouse gas and plays a key role in climate feedbacks because of its heat-trapping ability. Warmer air holds more moisture than cooler air. Therefore, as greenhouse gas concentrations increase and global temperatures rise, the total amount of water vapor in the atmosphere also increases, further amplifying the warming effect.[5]

Aerosols

Aerosols in the atmosphere can affect climate. Aerosols are microscopic (solid or liquid) particles that are so small that instead of quickly falling to the surface like larger particles, they remain suspended in the air for days to weeks. Human activities, such as burning fossil fuels and biomass, contribute to emissions of these substances, although some aerosols also come from natural sources such as volcanoes and marine plankton.

Unlike greenhouse gases, the climate effects of aerosols vary depending on what they are made of and where they are emitted. Depending on their color and other factors, aerosols can either absorb or reflect sunlight. Aerosols that reflect sunlight, such as particles from volcanic eruptions or sulfur emissions from burning coal, have a cooling effect. Those that absorb sunlight, such as black carbon (a part of soot), have a warming effect.

Not only can black carbon directly absorb incoming and reflected sunlight, but it can also absorb infrared radiation.[6] Black carbon can also be deposited on snow and ice, darkening the surface and thereby increasing the snow's absorption of sunlight and accelerating melt.[7] While reductions in all aerosols can lead to more warming, targeted reductions in black carbon emissions can reduce global warming. Warming and cooling aerosols can also interact with clouds, changing their ability to form and dissipate, as well as their reflectivity and precipitation rates. Clouds can contribute both to cooling, by reflecting sunlight, and warming, by trapping outgoing heat.

Climate Feedbacks

Climate feedbacks are natural processes that respond to global warming by offsetting or further increasing change in the climate system. Feedbacks that offset the change in climate are called negative feedbacks. Feedbacks that amplify changes are called positive feedbacks.

Water vapor appears to cause the most important positive feedback. As the earth warms, the rate of evaporation and the amount of water vapor in the air both increase. Because water vapor is a greenhouse gas, this leads to further warming.

The melting of Arctic sea ice is another example of a positive climate feedback. As temperatures rise, sea ice retreats. The loss of ice exposes the underlying sea surface, which is darker and absorbs more sunlight than ice, increasing the total amount of warming. Less snow cover during warm winters has a similar effect.

Clouds can have both warming and cooling effects on climate. They cool the planet by reflecting sunlight during the day, and they warm the planet by slowing the escape of heat to space (this is most apparent at night, as cloudy nights are usually warmer than clear nights).

Climate change can lead to changes in the coverage, altitude, and reflectivity of clouds. These changes can then either amplify (positive feedback) or dampen (negative feedback) the original change. The net effect of these changes is likely an amplifying, or positive, feedback due mainly to increasing altitude of high clouds in the tropics, which makes them better able to trap heat, and reductions in coverage of lower-level clouds in the mid-latitudes, which reduces the amount of sunlight they reflect. The magnitude of this feedback is uncertain due to the complex nature of cloud/climate interaction.

Climate Change Indicators: Snow and Ice

The Earth's surface contains many forms of snow and ice, including sea, lake, and river ice; snow cover; glaciers, ice caps, and ice sheets; and frozen ground. Climate change can dramatically alter the Earth's snow- and ice-covered areas because snow and ice can easily change between solid and liquid states in response to relatively minor changes in temperature. This chapter focuses on trends in snow, glaciers, and the freezing and thawing of oceans and lakes.

A Closer Look:

Rising global average temperature is associated with widespread changes in weather patterns. Scientific studies indicate that extreme weather events such as heat waves and large storms are likely to become more frequent or more intense with human-induced climate change. This chapter focuses on observed changes in temperature, precipitation, storms, floods, and droughts.

Why does it matter?

Long-term changes in climate can directly or indirectly affect many aspects of society in potentially disruptive ways. For example, warmer average temperatures could increase air conditioning costs and affect the spread of diseases like Lyme disease, but could also improve conditions for growing some crops. More extreme variations in weather are also a threat to society. More frequent and intense extreme heat events can increase illnesses and deaths, especially among vulnerable populations, and damage some crops. While increased precipitation can replenish water supplies and support agriculture, intense storms can damage property, cause loss of life and population displacement, and temporarily disrupt essential services such as transportation, telecommunications, energy, and water supplies.

Summary of Key Points

- U.S. and Global Temperature. Average temperatures have risen across the contiguous 48 states since 1901, with an increased rate of warming over the past 30 years. Nine of the top 10 warmest years on record have occurred since 1998. Average global temperatures show a similar trend, and all of the top 10 warmest years on record worldwide have occurred since 2005. Within the United States, temperatures in parts of the North, the West, and Alaska have increased the most.
- Seasonal Temperature. As the Earth warms overall, average temperatures increase throughout the year, but the increases may be larger in certain seasons than in others. Since 1896, average winter temperatures across the contiguous 48 states have increased by nearly 3°F. Spring temperatures have increased by about 2°F, while summer and fall temperatures have increased by about 1.5°F.
- High and Low Temperatures. Many extreme temperature conditions are becoming more common. Since the 1970s, unusually hot summer days (highs) have become more common over the last few decades in the United States. Unusually hot summer nights (lows) have become more common at an even faster rate. This trend indicates less "cooling off" at night. Although the United States has experienced many winters with unusually low temperatures, unusually cold winter temperatures have become less common—particularly very cold nights (lows). Record-setting daily high temperatures have become more common than record lows.
- Heat Waves. Heat waves are occurring more than they used to in major cities across the United States. Heat waves are occurring three times more often than they did in the 1960s—about six per year compared with two per year. The average heat wave season is 49 days longer, and individual heat waves are lasting longer and becoming more intense.
- U.S. and Global Precipitation. Total annual precipitation has increased over land areas in the United States and worldwide. Since 1901, precipitation has increased at an average rate of 0.2 inches per decade over the contiguous 48 states. However, shifting weather patterns have caused certain areas, such as the Southwest, to experience less precipitation than usual.

- Heavy Precipitation. In recent years, a higher percentage of precipitation in the United States has come in the form of intense single-day events. The prevalence of extreme single-day precipitation events remained fairly steady between 1910 and the 1980s but has risen substantially since then. Nationwide, nine of the top 10 years for extreme one-day precipitation events have occurred since 1996. The occurrence of abnormally high annual precipitation totals (as defined by the National Oceanic and Atmospheric Administration) has also increased.
- Tropical Cyclone Activity. Tropical storm activity in the Atlantic Ocean, the Caribbean, and the Gulf of Mexico has increased during the past 20 years. Storm intensity, a measure of strength, duration, and frequency, is closely related to variations in sea surface temperature in the tropical Atlantic and has risen noticeably during that time. However, changes in observation methods over time make it difficult to know for sure whether a longer-term increase in storm activity has occurred. Records collected since the late 1800s suggest that the actual number of hurricanes per year has not increased.
- River Flooding. Increases and decreases in the frequency and magnitude of river flood events vary by region. Floods have generally become larger across parts of the Northeast and Midwest and smaller in the West, southern Appalachia, and northern Michigan. Large floods have become more frequent across the Northeast, Pacific Northwest, and parts of the northern Great Plains, and less frequent in the Southwest and the Rockies.
- Drought. Average drought conditions across the nation have varied over time. The 1930s and 1950s saw the most widespread droughts, while the last 50 years have generally been wetter than average. Specific trends vary by region, as the West has generally experienced more drought while the Midwest and Northeast have become wetter. A more detailed index developed recently shows that over the period from 2000 through 2020, roughly 20 to 70 percent of the U.S. land area experienced conditions that were at least abnormally dry at any given time. However, this index has not been in use for long enough to compare with historical drought patterns.
- A Closer Look: Temperature and Drought in the Southwest. The southwestern United States is particularly sensitive to changes in temperature and thus vulnerable to drought, as even a small decrease in water availability in this already arid region can stress natural systems and further threaten water supplies. Several measures indicate persistent and more severe drought conditions in recent years.

Weather and Climate

Weather is the state of the atmosphere at any given time and place. Most of the weather that affects people, agriculture, and ecosystems takes place in the lower layer of the atmosphere. Familiar aspects of weather include temperature, precipitation, clouds, and wind that people experience throughout the course of a day. Severe weather conditions include hurricanes, tornadoes, blizzards, and droughts.

Climate is the long-term average of the weather in a given place. While the weather can change in minutes or hours, a change in climate is something that develops over longer periods of decades to centuries. Climate is defined not only by average temperature and precipitation but also by the type, frequency, duration, and intensity of weather events such as heat waves, cold spells, storms, floods, and droughts.

The concepts of climate and weather are often confused, so it may be helpful to think about the difference between weather and climate with an analogy: weather influences what clothes you wear on a given day, while the climate where you live influences the entire wardrobe you buy.

Government of Canada Gouvernement du Canada

Overview of Climate Change in Canada

4.1 THE CANADIAN ECONOMY

Current State

Climate change will impact a rapidly evolving Canadian economy, in which demographic, commercial and technological changes will exert strong influences on future outcomes. The magnitude of the impacts of climate change on the Canadian economy is thus difficult to predict. Impact modeling suggests that, although overall economic impacts may be slightly positive in the short term at moderate degrees of warming, further warming and associated changes in climate will overwhelm systems, causing net economic losses (Stern, 2006). It must also be stressed that much of the research to date on the economic impacts of climate change considers only changes in mean conditions, rather than extreme events, despite the fact that natural disasters associated with extreme weather events frequently incur significant short- and longer term costs. Losses to regional and local economies from both extreme weather events and gradual, longer term changes in climate could be severe. At the local scale, communities that are reliant on climate-sensitive natural resources may be particularly vulnerable to climate change .

National-scale roll-ups, where losses or gains are expressed in terms of national GDP, tend to obscure the impacts in smaller provinces and territories. Consider, for example, the collapse of the northern cod fishery in Newfoundland in 1992. This had extreme provincial- and community-level repercussions, including the loss of up to 40 000 jobs (Mason, 2002), and yet was hardly reflected at the scale of national GDP.

Some of the key ways in which climate change will impact the Canadian economy are categorized as follows:

Impacts from extreme events and natural disturbances:

- Economic losses from such events in Canada are often in the hundreds of millions of dollars (e.g. Hurricane Juan, Alberta hailstorms, British Columbia wildfires), and even in the billions (1998 Ice Storm, 1996 Saguenay flood; 2001 -2002 national-scale drought). Insect damage to forests and crops may also be significant.
- Impacts on buildings and infrastructure: Included in this category are increased maintenance and protection costs, total loss or replacement costs, and loss of assets. Winter roads , coastal erosion and permafrost degradation are key concerns in Canada.
- Impacts on the production and prices of, and the demand for, goods and services: These costs will be manifest both within Canada and internationally , and will be both positive and negative.
- Costs related to the impacts on public safety, health and welfare of populations: These costs, although difficult to quantify and predict, may be high. Examples include the effect of vector-borne diseases, the long-term effects of flooding (e.g. mental health, mold issues and financial hardship), and impacts of changing climate on culture and traditional ways of life. Potential benefits may result from less extreme winter weather.
- Impacts resulting from hydrological changes in lakes and streams: Several economic sectors, including energy (e.g. hydroelectricity), tourism and recreation, freshwater fisheries, and transportation will be affected by changing water levels and supply.

Limited data are available on the sensitivity or vulnerability of the services sector in Canada, which now dominates our economy. In the short term, however, it is likely to be less sensitive to slow and/or moderate climate change than the renewable resources sector. For all sectors, continuing climate change means increasing risk that critical thresholds will be reached, triggering long-term future feedbacks (Schneider, 2004) and catastrophic events that would be extremely costly (Stern, 2006).

4.2 POPULATION AND DEMOGRAPHICS

Trends and Projections

The elderly are commonly identified as being among the most vulnerable to climate change, especially with respect to health-related impacts. The proportion of elderly persons (age 65 and over) in Canada increased 3% between 1981 and 2005 (from 10 to 13%), and will continue to increase until 2056 under all projection scenarios (Statistics Canada, 2005). Under medium-growth scenarios, the proportion of elderly is projected to almost double in the next 25 years and, by 2056, half the Canadian population would be over 47 years of age. The proportion of the oldest seniors (80 years and over) also increases sharply in every projection scenario. For example, in the medium-growth scenario, about one in 10 Canadians will be 80 years and over by 2056, compared with about one in 30 in 2005. Other populations considered more vulnerable to climate change include children, Aboriginal people, people with pre-existing health conditions and the poor (Health Canada, 2005).

Canada's population will continue to grow between now and 2056 under most scenarios analyzed by Statistics Canada (see Figure 6; Table 8). The medium-growth scenario would bring a 30% increase in the size of the Canadian population by 2056, whereas the high-growth scenario would yield a 53% increase from present. The low-growth scenario projects an increase to 2039, then a gradual decline to 2056. In all the scenarios considered, natural increase would become negative in the medium or long term and migration would become Canada's only source of population growth.

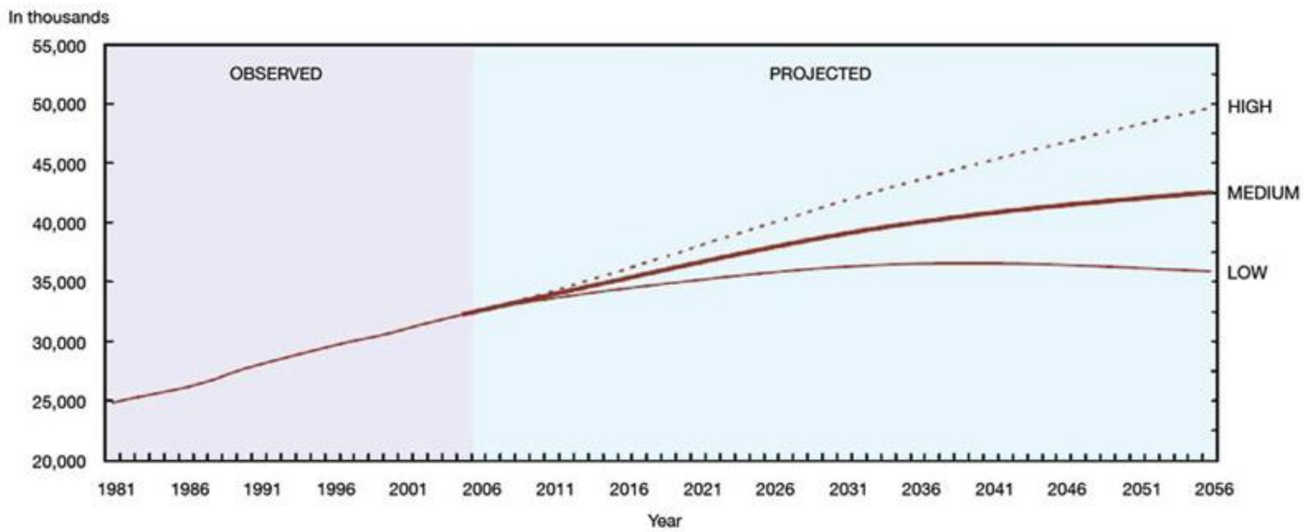

TABLE 8: Population projections for Canada under low-, medium and high-growth scenarios to 2031 and 2056 (compiled from Statistics Canada, 2005).

Scenario	2031	2056
Low growth	36.3 million	35.9 million
Medium growth	39 million	42.5 million
High growth	41.8 million	49.7 million
Population actuelle (2006): 32,6 millions		

4.3 CLIMATE TRENDS AND PROJECTIONS

Observed Trends - Temperature and Precipitation

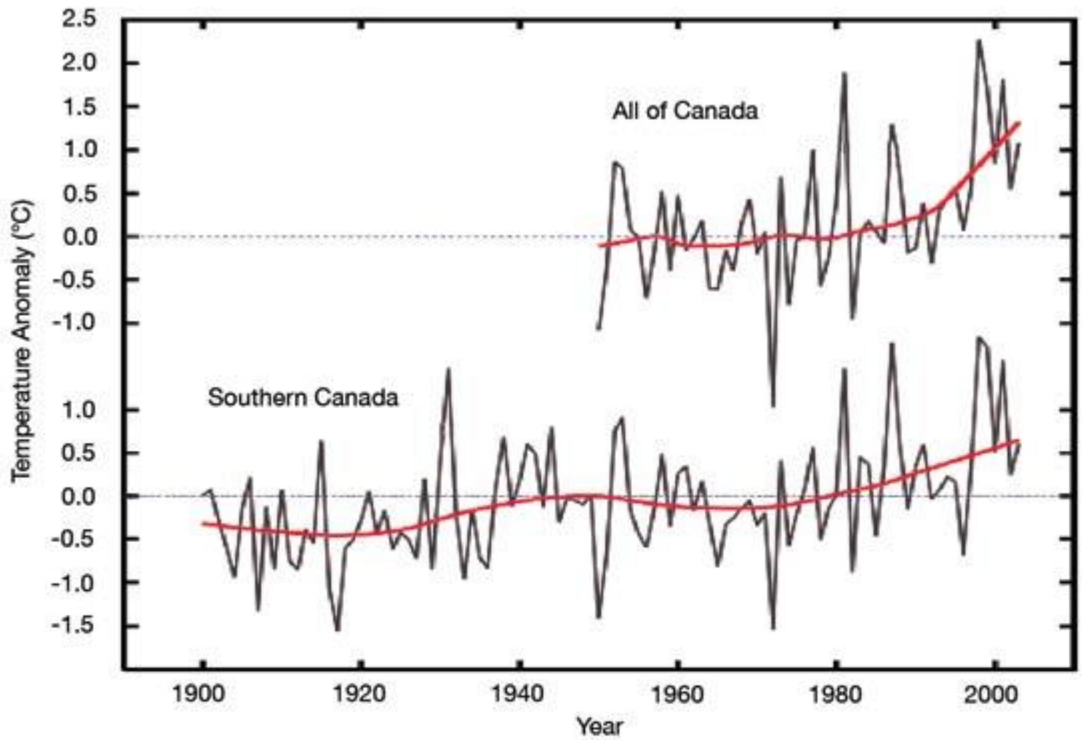

FIGURE 7: Annual national temperature departures and long-term trend, 1948 to 2006 (Environment Canada, 2006).

The influence of anthropogenic climate change on Canada is evident in observed trends and temperatures simulated by global climate models (Zhang et al., 2006). These changes are already impacting human and natural systems (cf. Gillett et al., 2004). Observational data have been collected in southern Canada for more than a century and in other parts of Canada since the mid -twentieth century. These data, together with satellite data from the past 25 years or so, provide a detailed picture of how Canadian climate and associated biophysical variables have changed in recent decades. This section provides an overview of the observed changes; for more detailed discussion, readers are referred to Barrow et al. (2004) and Hengeveld et al. (2005).

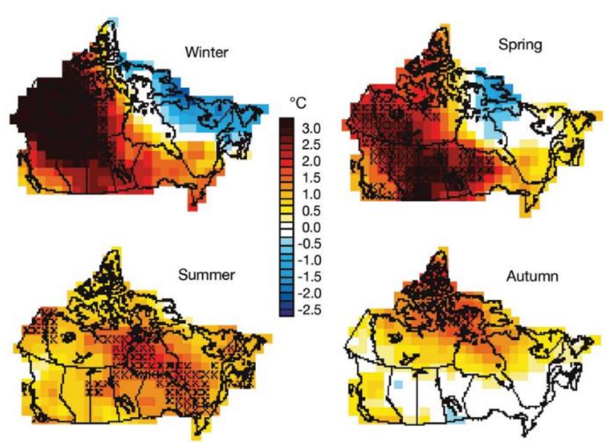

FIGURE 8: Regional distribution of linear temperature trends (°C) observed across Canada between 1948 and 2003, by season. The "X" symbols indicate areas where the trends are statistically significant. Source: Hengeveld et al. (2005).

On average, Canada has warmed by more than 1.3°C since 1948 (Figure 7), a rate of warming that is about twice the global average. During this time period, the greatest temperature increases have been observed in the Yukon and Northwest Territories. All regions of the country have experienced warming during more recent years (1966 -2003; McBean et al., 2005), including the eastern Arctic, where there has been a reversal from a cooling trend to a warming one, starting in the early 1990s (Huntington et al., 2005a; Nickels et al., 2006).

On a seasonal basis (Figure 8), temperature increases have been greater and more spatially variable during the winter and spring months. In northwestern Canada, winter temperatures increased more than 3 °C between 1948 and 2003. During the same period, winter and spring cooling trends (up to -2.5°C) were observed in parts of the eastern Arctic. Summer warming has been both more modest and more uniform in space, whereas warming in the autumn period has been largely confined to Arctic regions and British Columbia (Figure 8).

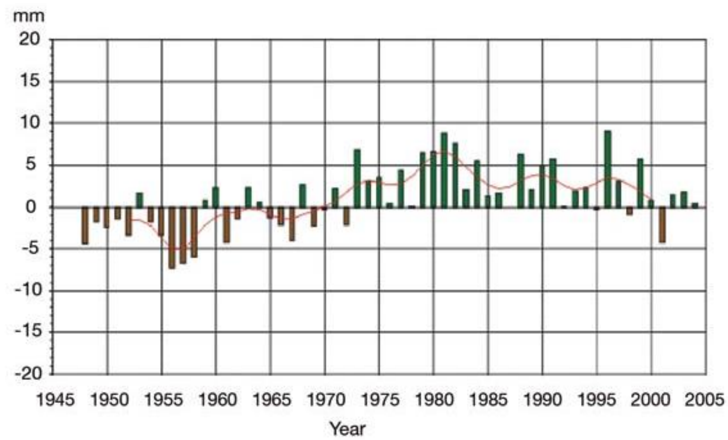

FIGURE 9: Trends in annual departures of average annual precipitation across Canada from the 1951 to 1980 normals, with weighted running mean. Source: Environment Canada.

National trends in precipitation (Figure 9) are more difficult to assess, primarily because of the discontinuous nature of precipitation and its various states (rain, snow and freezing rain). Nevertheless, Canada has, on average, become wetter during the past half century, with mean precipitation across the country increasing by about 12 % (Environment Canada, 2003).

Changes in precipitation have also varied by region and season (Figures 10, 11) since 1950. Annually averaged, the largest percentage increase in precipitation has occurred in the high Arctic, while parts of southern Canada (particularly the Prairies) have seen little change or even a decrease (Figure 10). For example, over most of Nunavut, annual precipitation has increased by 25 to 45%, whereas the average increase in southern Canada has been 5 to 35% (Environment Canada, 2003).

FIGURE 10: Regional distribution of linear annual precipitation trends (% change) observed across Canada between 1948 and 2003. The "X" symbols indicate areas where the trends are statistically significant Source: Zhang et al. (2000), updated in 2005.

Seasonal trends since 1950 indicate that most of the Arctic has become wetter in all seasons. Southern British Columbia and southeastern Canada also show regions with significant increases in precipitation in spring and autumn. In contrast, most of southern Canada except the western part of southern Ontario, which has seen increased lake effect snow (see Chapter 6), has experienced a significant decline in winter precipitation.

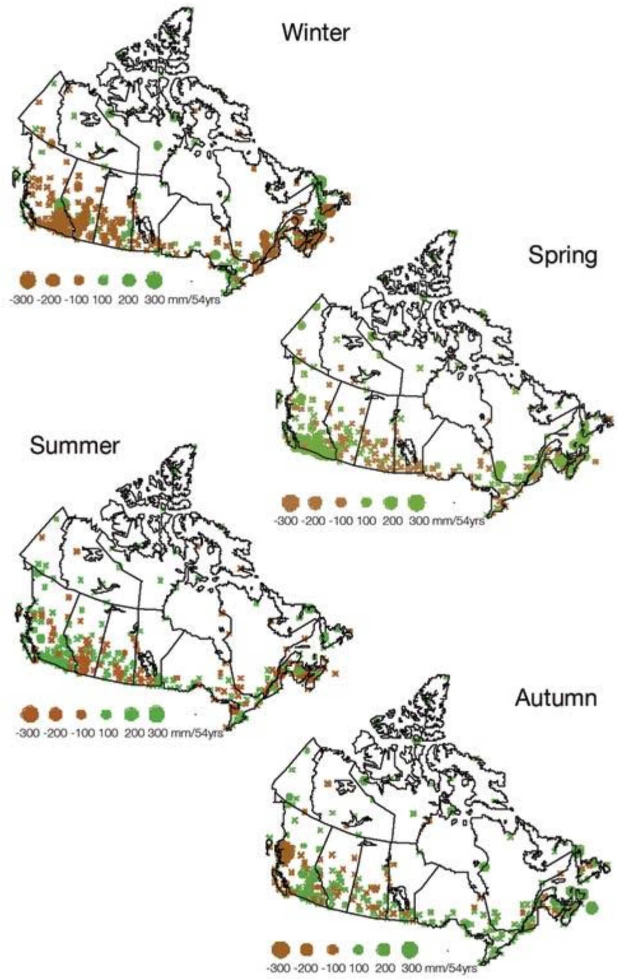

FIGURE 11: Changes in precipitation since 1950, by season. Data are presented as total change over the full 54 years of data, expressed in mm. The magnitude of change is indicated by the size of the circle, with green indicating an increase and brown a decrease. The crosses denote areas where trends are not statistically significant. Source: Environment Canada.

Changes in the frequency of extreme temperature and precipitation events have been observed in Canada from 1950 to 2003, including (from Vincent and Mekis, 2006):

- fewer extreme cold nights,
- fewer extreme cold days,
- fewer frost days,
- more extreme warm nights,
- more extreme warm days,
- more days with precipitation,

- decrease in mean amount of daily precipitation,
- decrease in maximum number of consecutive dry days,
- decrease in annual total snowfall (southern Canada), and
- increase in annual total snowfall (northern and northeastern Canada).

Accompanying these changes has been a significant decline in the number of heating-degree days. There are also significant changes at the regional scale in the numbers of intense precipitation events. On average, the fraction of precipitation falling as intense events (the upper 10%) has been decreasing in southern Canada but increasing in northern Canada, particularly in the northeast. Also, more of the precipitation is falling as rain rather than snow.

Other Observed Changes

Changes in temperature and precipitation during the past 50 to 100 years have led to changes in other variables, including sea ice, snow cover, permafrost, evaporation and sea level. These changes, as well as their implications for the environment, the economy and society, are discussed in detail in the regional chapters of this report. This section simply highlights key observations. The cryosphere has responded to observed warming. For example, the extent of Arctic sea ice during the late summer season has decreased by 8% since 1979 (Figure 12). Snow-cover duration, on average, has decreased by about 20 days in the Arctic since 1950 (Figure 13). Annual total snow amount has increased in some Arctic regions (Taylor et al., 2006), however, because higher temperatures induce higher humidity, which results in more precipitation. A general increase in thaw depth was observed through the 1990s across the Canadian permafrost regions (e.g. Brown et al., 2000; Nixon et al., 2003; Smith et al., 2005). Shallow permafrost temperatures increased during the last two to three decades of the twentieth century by 0.3 to 0.5 °C per decade in the Canadian high Arctic (Taylor et al., 2006), and ranged from no change to almost 1 °C per decade in the western Arctic (Smith et al., 2005).

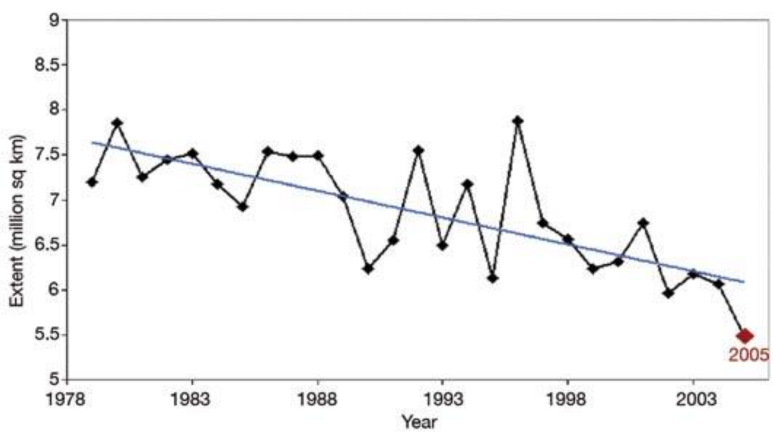

FIGURE 12: Trends in minimum (September) Arctic sea-ice extent from 1978 to 2005, as recorded by NASA satellites. The trend from 1979 to 2005, now showing a decline of more than 8% percent, is shown with a straight blue line. Source: National Snow and Ice Data Center (2005).

Recent declines in the volume of glacial meltwater in western Canada (Demuth et al., 2002), and precipitation changes and increased evaporation elsewhere (linked to higher temperatures), have altered water resources across much of Canada (Shabbar and Skinner, 2004). Actual evapotranspiration rates (AET) have, on average, increased in most regions of the country during the last 40 years (Table 10), although the trend is weak or inconsistent in some areas (Fernandes et al., 2007) due to limited availability of water to evaporate. For example, evapotranspiration rates have decreased slightly in the dry regions of the Prairies, where water (to evaporate) is already limited throughout much of the year (Huntington, 2006; Fernandes et al., 2007). Although many areas of the country are expected to experience an increase in precipitation (see Figure 14), this may not be sufficient to offset the AET increase due to temperature rise. In the Great Lakes area, for example, a 1 °C increase in mean annual temperature was associated with a 7 to 8% increase in AET (see Fernandes et al., 2007), resulting in a decrease in water availability.

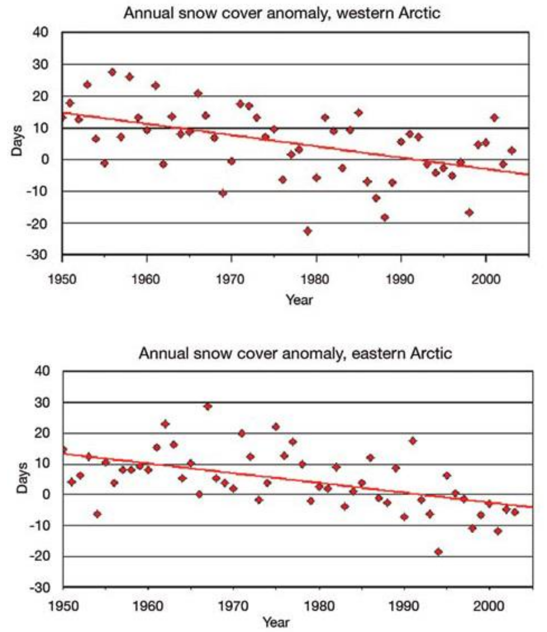

FIGURE 13: Trends in Canadian Arctic snow-cover duration, measured as change in days relative to 1990. Source: Ross Brown, Environment Canada, pers. comm., 2007.

Water levels in lakes across Canada have varied considerably over time, and recent trends toward lower levels in the upper Great Lakes, in association with higher temperatures, have been quite dramatic (Mortsch et al., 2006). Water levels in the Great Lakes are generally projected to continue to drop in the future (see also Chapter 6; Moulton and Cuthbert, 2000; Mortsch et al., 2006; Figure 15).

During the past century, global ocean levels have risen an estimated 0.17 m (range 0.12 -0.22 m; Intergovernmental Panel on Climate Change, 2007a). The magnitude of relative sea-level rise along Canadian coastlines depends upon whether the coast is experiencing crustal (glacioisostatic) rebound or subsidence as a result of the deglaciation that took place thousands of years ago. For example, in some parts of Canada, such as around Hudson Bay, land has continued to emerge despite increasing global sea levels. However, regional land subsidence in other regions, including most of the Atlantic coastline, has doubled the rate of local sea-level rise in some areas (McCulloch et al., 2002). In Charlottetown, for instance, relative sea level rose 32 cm over the twentieth century (Forbes et al., 2004). Additional geophysical factors influencing relative sea-level changes in Canada include tectonic activity along the Pacific coast and subsidence due to extensive sediment deposition, particularly in the Fraser River and Mackenzie River deltas. Along the west coast, relative sea level change has been lower, with sea level rising by 4 cm in Vancouver, 8 cm in Victoria, 12 cm in Prince Rupert and dropping by 13 cm in Tofino over the twentieth century (British Columbia Ministry of Water, Land and Air Protection, 2002). In the north, the Yukon coast and the directly adjacent Northwest Territories coast are subsiding, making relative sea-level rise in these regions greater than along most of the Arctic coast (Barrow et al., 2004).

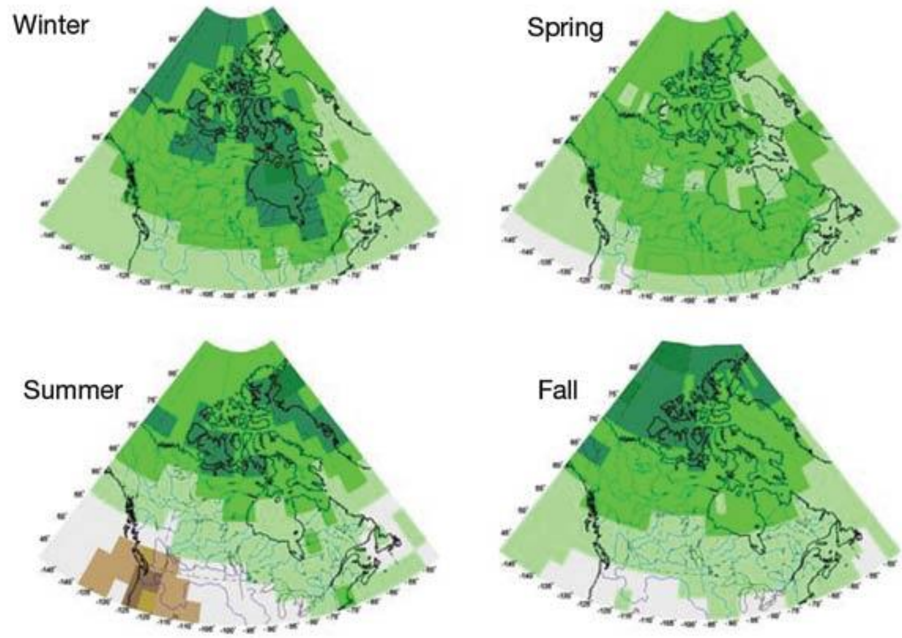

FIGURE 14: Seasonal change in precipitation by the 2050s (relative to 1961-1990), based on the median of seven global climate models and using the emissions scenarios of the Special Report on Emissions Scenarios (SRES).

Projections - Temperature and Precipitation

All of Canada, with the possible exception of the Atlantic offshore area, is projected to warm during the next 80 years. In most cases, future changes in climate will involve a continuation of the patterns, and often an acceleration of the trends, discussed above. Therefore, amounts of warming will not be uniform across the country (see Figure 16). During the present century, temperature increases will be greatest in the high Arctic, and greater in the central portions of the country than along the east and west coasts (Figure 16). Regional differences in temperature projections are also illustrated in Figure 17, which shows historical and projected change in temperature for six cities across Canada.

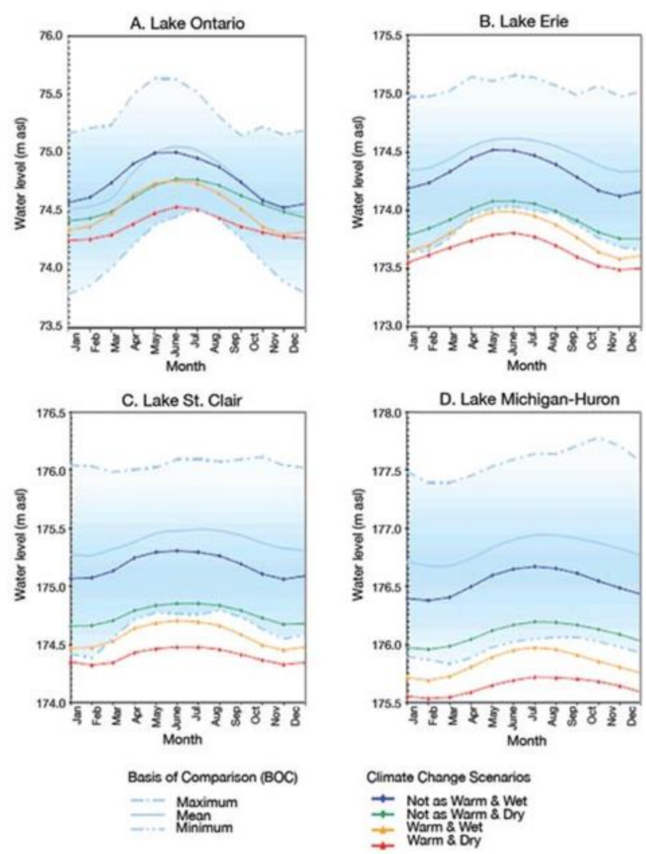

FIGURE 15: Projected changes in water levels for the Great Lakes (Mortsch et al., 2006).

On a seasonal basis, warming is expected to be greatest during the winter months (Figure 16), due in part to the feedback effect that reduced snow and ice cover has on land-surface albedo. Winter warming by the 2050s is expected to be most pronounced in the Hudson Bay and high Arctic areas, and least in southwestern British Columbia and the southern Atlantic region. A decrease in the winter diurnal temperature range across the country indicates that winter nights will likely warm more than winter days (Barrow et al., 2004). This pattern was not found for the other seasons. Rates of warming will be lower in the summer and fall, and summer warming is projected to be more uniform across the country. These patterns are consistent with the observed trends presented above.

The frequency of extreme warm summer temperatures (exceeding 30°C) is expected to increase across Canada (see Figure 18; Kharin et al., 2007). Heat waves are projected to become more intense and more frequent. The health impacts of extreme heat, as well as effective adaptation measures to deal with heat waves, are discussed in several of the regional chapters (e.g. Chapters 5, 6 and 7). At the same time, extreme cold days are projected to decline significantly (Kharin et al., 2007), resulting in an overall reduction in the climate severity index (Barrow et al., 2004).

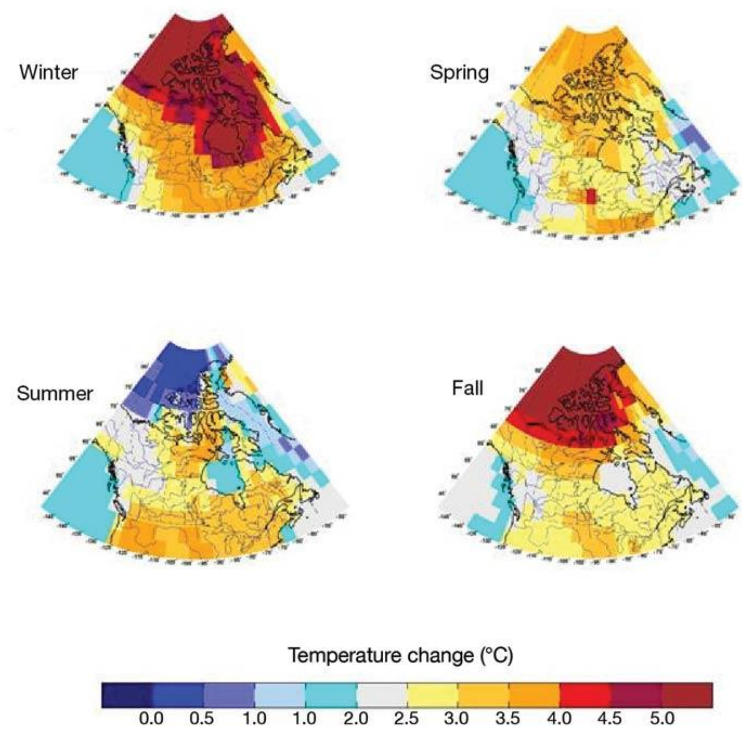

FIGURE 16: Seasonal change in temperature across Canada by 2050 (relative to 1961-1990), based on the median of seven global climate models and using the emissions scenarios of the Special Report on Emissions Scenarios (SRES).

Future precipitation is more difficult to project, and changes are generally of lower statistical significance, than changes in temperature (Barrow et al., 2004). This is reflected in the wide range in model results for projected precipitation (see Figure 19). Annual total precipitation is projected to increase across the country during the current century. By the 2080s, projected precipitation increases range from 0 to 10% in the far south up to 40 to 50% in the high Arctic. Due to enhanced evapotranspiration, driven by higher temperatures, many regions will experience a moisture deficit despite greater amounts of precipitation.

Seasonal changes in precipitation will generally have greater regional-scale impacts than the annual totals. Throughout most of southern Canada, precipitation increases are projected to be low (0 -10% by the 2050s) during the summer and fall months. In some regions, especially the south-central Prairies and southwestern British Columbia, precipitation is even expected to decline in the summer (Figure 14). This means less available precipitation during the growing season in important agricultural regions. Other important changes in precipitation include an increase in the percentage of precipitation falling as rain rather than snow, and an increase in extreme daily precipitation (Figure 20; Kharin and Zwiers, 2000)

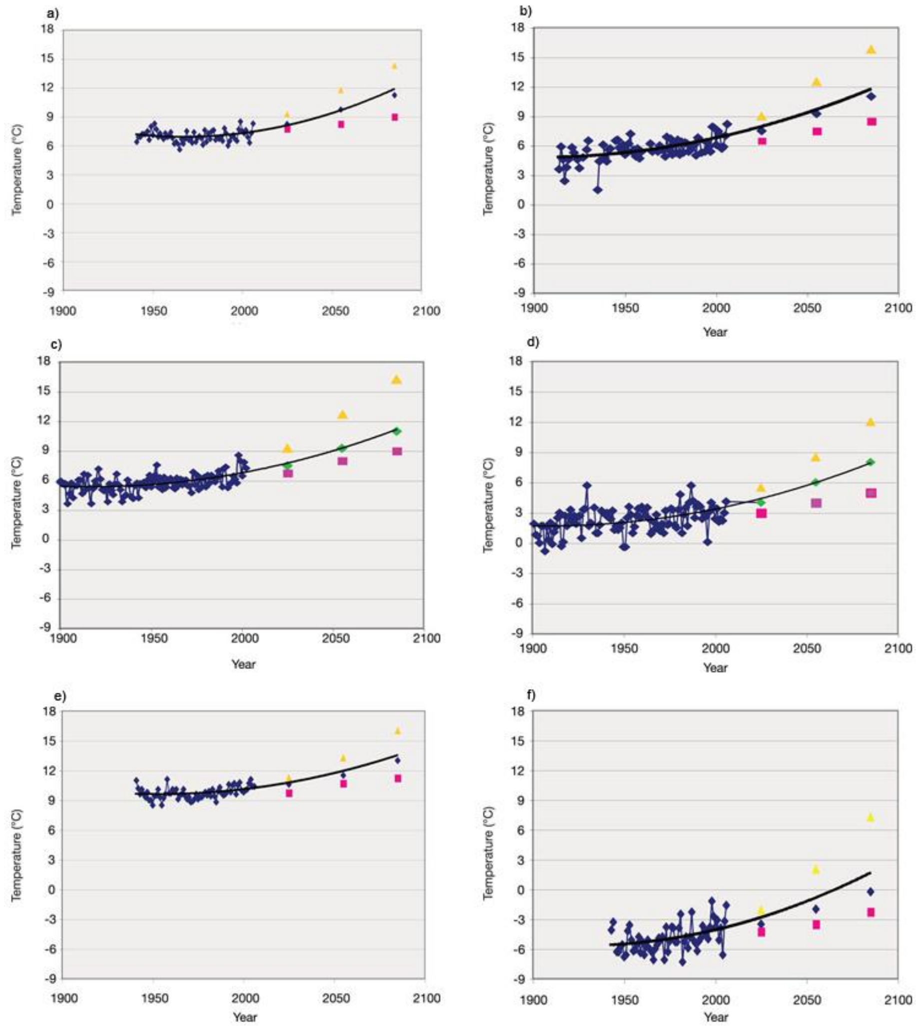

FIGURE 17: Historical trends (blue diamond) and projected maximum (yellow triangle), median (green diamond) and minimum (pink square) annual mean temperature scenarios for the 2020s, 2050s and 2080s for six cities across Canada: a) Yarmouth, NS; b) Drummondville, QC; c) Ottawa, ON; d) Regina, SK; e) Victoria, BC; and f) Yellowknife, NT. Note historical data presented are limited by data availability, and projected changes are derived from a range of global climate models using the emissions scenarios of the Special Report on Emissions Scenarios (SRES).

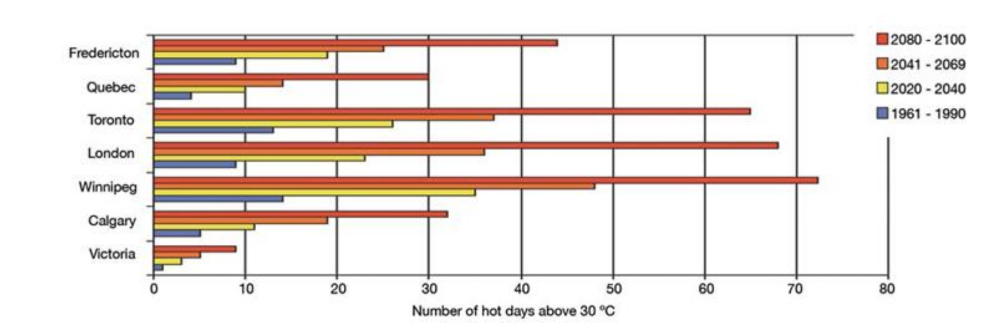

FIGURE 18: Number of days with temperatures exceeding 30ºC, during observed (1961-1990) and future (2020-2040; 2041-2069; and 2080-2100) time periods (Hengeveld et al., 2005)

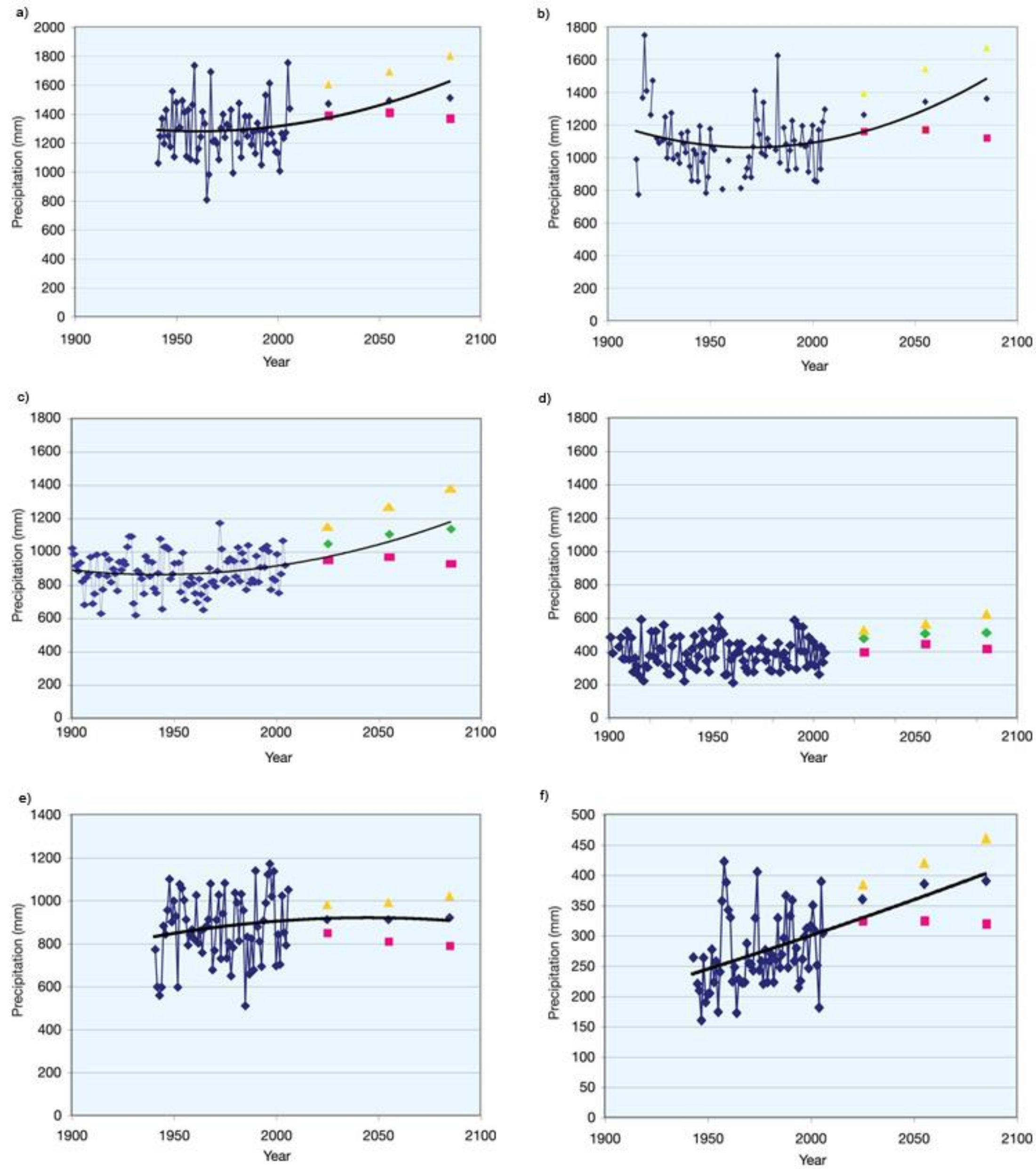

FIGURE 19: Historical trends (blue diamond) and projected maximum (yellow triangle), median (green diamond) and minimum (pink square) total annual precipitation scenarios for 2020s, 2050s and 2080s for six cities across Canada: a) Yarmouth, NS; b) Drummondville, QC; c) Ottawa, ON; d) Regina, SK; e) Victoria, BC; and f) Yellowknife, NT. Note historical data presented are limited by data availability, and projected changes are derived from a range of global climate models using the emissions scenarios of the Special Report on Emissions Scenarios (SRES).

Other Projected Changes

Sea level will continue to rise during the current century, with global projections of 0.18 to 0.59 m by 2100 (Intergovernmental Panel on Climate Change, 2007a). Relative sea-level changes in Canada will continue to exhibit similar patterns to those observed during the twentieth century. Therefore, regions of rebound (e.g. Hudson Bay, parts of the British Columbia coast and the Labrador coast) will generally experience lesser impacts as a result of sea-level change than areas that are currently subsiding (e.g. Beaufort Sea coast, much of the Atlantic coast and the Fraser River delta). The influence of sea-level rise on coastal communities and activities such as shipping and tourism are discussed in detail in Chapters 3, 4, 5 and 8. As sea level rises, the risk of storm-surge flooding increases. Such flooding will likely occur more frequently in the future, particularly in areas already impacted by these events. For example, storm-surge flooding in Charlottetown, which occurred six times between 1911 and 1998, is likely to occur every year by 2100 unless significant adaptation measures are implemented to protect the city (McCulloch et al., 2002).

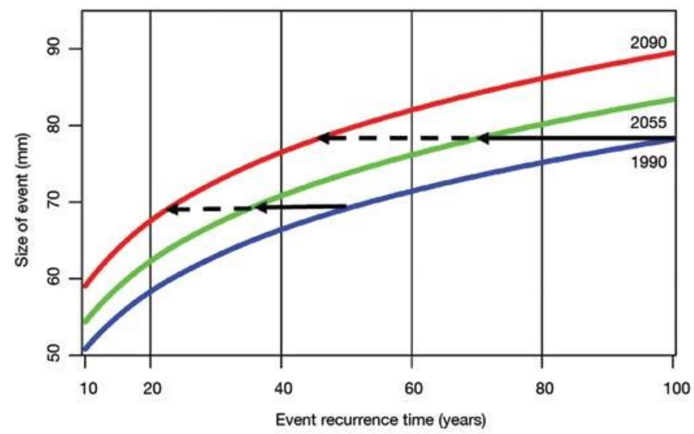

FIGURE 20: Projected changes in extreme 24-hour precipitation events, North America between latitudes 25°N and 65°N (based on Kharin and Zwiers, 2000). Source: Environment Canada.

There is not a simple direct relationship between sea ice and temperature because complex interactions, associated with changes in atmospheric and ocean circulation patterns (e.g. the Arctic and North Atlantic oscillations), strongly influence sea-ice patterns (Barrow et al., 2004). Patterns of sea-ice reduction will therefore continue to vary locally and regionally, as they have during the past century (Barrow et al., 2004). Arctic sea-ice extent will, however, decrease during the twenty-first century, and summer ice extent will change more than winter ice extent (Intergovernmental Panel on Climate Change 2007a; Anisimov et al., 2007). Although climate models vary in estimating the rate of ice decline (see Chapter 3), several scenarios indicate that large areas of the Arctic Ocean will be seasonally ice free before the end of the twenty-first century (Solomon et al., 2007).

Sea-level rise, storms and decreases in sea ice will all increase the rate of coastal erosion (see also Chapters 3 and 4; Manson et al., 2005). In northern regions, permafrost degradation will make coastal areas further susceptible to erosion.

4.4 CONCLUSIONS

Canada's climate is changing, and projections show that it will continue to change in the future. In addition to gradual shifts in average temperature and precipitation, changes in temperature and precipitation extremes, sea level, storm surges, sea ice and other climate and climate-related parameters have been both observed and projected. These changes will continue to occur across a backdrop of social and economic changes, which will greatly influence net impacts. Regional differences in projected climate, sensitivity and factors influencing adaptive capacity (e.g. access to economic resources, population demographics) mean that vulnerability varies greatly across the country, both within and between regions. These differences are highlighted throughout the regional chapters of the report.

Scenarios and Climate Models

Emissions scenarios

Human activity is causing climate change. However, we don't know exactly how humans will behave in the future. Nor can we know how emissions of greenhouse gases will change. Emissions scenarios are a way to help us understand what the future could look like. These scenarios provide a range of possible futures, based on a range of future emissions.

A set of scenarios referred to as Representative Concentration Pathways (RCPs) are in common use to study future climate change. RCPs are designed to provide plausible future scenarios of human emissions patterns. These include consideration of future greenhouse gas emissions, deforestation, population growth and many other factors.

Based on best practices in the global science community, the Government of Canada usually presents 3 RCPs (Figure 1):

- RCP8.5: high global emission scenario. This scenario indicates global average warming levels of 3.2 to 5.4°C by 2090.
- RCP4.5: medium global emission scenario, includes measures to limit (mitigate) climate change. This scenario indicates global average warming levels of 1.7 to 3.2°C by 2090.
- RCP2.6: low emission global scenario, requires strong mitigation actions. This scenario indicates global average warming levels of 0.9 to 2.3°C by 2090.

Other futures are also possible, but limiting consideration to a few RCPs is easier for research and communication. The pathway that unfolds in reality will depend on societies' choices.

Figure 1: Change in global average temperature relative to the 1986-2005 reference period

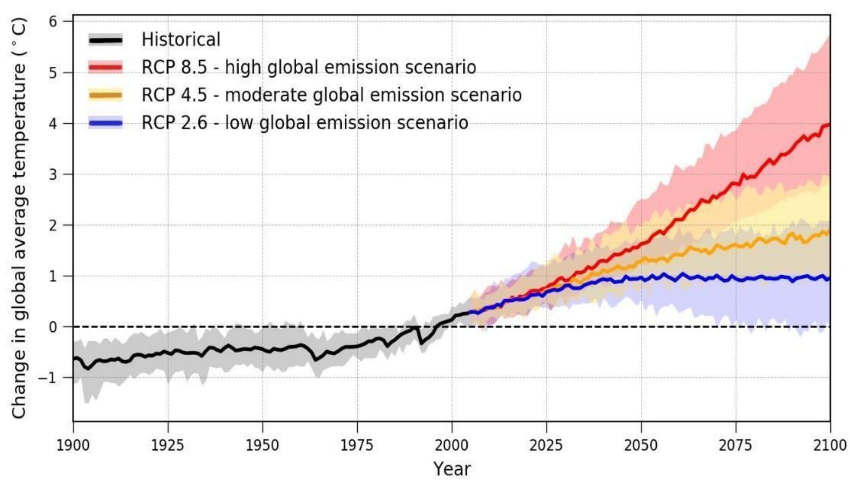

Figure 1. This figure shows changes in global average temperature, relative to the 1986 to 2005 reference period, simulated by 29 global climate models from the Coupled Model Intercomparison Project, Phase 5 (CMIP5).

Climate models and projections

The climate is affected by many elements, including ocean temperatures, clouds, rainfall and vegetation growth. Each of these processes can be simulated in a climate model. These models are so complex it can take weeks to run one simulation, even with supercomputers. To decrease computing time as much as possible, climate models divide the Earth up into large grid cells. For global climate models (GCMs) that cover the globe, grid cells are often larger than 100 kilometres (km).

For impact, vulnerability or adaptation studies, you may need data from grid cells smaller than 100 km. For example, precipitation extremes often occur on much smaller scales than 100 km. Also, local temperatures can be affected by local landscape features. One way to get finer resolution data (smaller grid cells) is from dynamic or statistical downscaling.

Dynamically downscaled models are also known as regional climate models (RCMs). RCMs simulate the climate of a smaller region, relying on information provided by GCMs. RCMs' grid cells are usually from 10 to 50 km in size. RCMs use the laws of physics to simulate the local climate.

Statistically downscaled models use statistical relationships between local climate variables (such as precipitation) and large-scale variables (such as atmospheric pressure). The relationship is then applied to projections from GCMs to simulate local climate.

Climate models project future climate conditions based on the assumptions in the RCPs (Representative Concentration Pathways). In other words, a climate projection shows how certain elements of climate, such as the average temperature in a region, could change based on one RCP. Although climate models are based on the laws of physics, different climate models can use different methods to simulate these laws when simulating the climate. So, even for the same RCP, projections from different climate models can differ.

Managing uncertainty in climate projections

We can't say for certain how the climate will change in the future. This is because:

- we can't predict the exact amount of greenhouse gasses future human activity will produce
- we can't perfectly model the Earth's climate system

Use of different scenarios or RCPs help deal with the first issue. For the second issue, multiple climate models, each constructed somewhat differently, are used. There is no one best climate model. Plus, some models are better at capturing different aspects of the climate than others. Dealing with all these results can be daunting. Fortunately, we can account for the range of model results in a simpler way.

The results from many climate models are grouped to create a "multi-model ensemble." Then, percentiles (from statistics) are used to summarize the range of results from that ensemble. A percentile is the maximum value of a percentage of all results. To summarize the range of results, the 25th and 75th percentiles are commonly used, along with the median (50th percentile). For example, the 25th percentile for temperature increase means that 25% of individual model results show the same or less warming.

Linking Climate and Inequality

CÉLINE GUIVARCH, NICOLAS TACONET, AURÉLIE MÉJEAN

International Monetary Fund, September 2021

In recent decades, global economic growth has lifted millions out of extreme poverty and reduced inequalities between countries. But unmanaged climate change threatens to set back that progress by damaging poverty eradication efforts worldwide, and disproportionately affecting the poorest regions and people.

The evidence is mounting: a World Bank report estimated that an additional 68 to 135 million people could be pushed into poverty by 2030 because of climate change. Our own research shows that if the most dire projections of future economic damages in the current scientific literature hold true, climate change would reverse the gains of the past few decades and cause inequality between countries to rise again. Within countries, the impacts of climate change also risk worsening inequality.

At the same time, actions taken to curb warming could have an unwelcome effect on inequality, if climate policies prove too burdensome for poor countries. Such actions need to be complemented by measures to offset the costs on the poor and vulnerable across and within countries.

We view mitigating climate change as a necessary condition for sustainably improving living standards around the world. At the same time, we maintain that distributive and procedural justice must be at the forefront of every stage of environmental policymaking. In planning, development, and implementation, the effort to reduce emissions must be at the service of broader objectives of development, such as poverty and inequality reduction, the creation of decent jobs, improvement of air quality, and improvement of public health.

Risk to health and livelihoods

Since the Industrial Revolution, emissions of greenhouse gases due to human activities have increased from a negligible level to more than 40 billion tons a year. As these emissions have accumulated in our atmosphere, they have increased the average annual temperature by about 1 degree Celsius compared with the pre-industrial era. Temperature increases have led to glaciers and ice caps melting, sea levels rising, and more frequent and extreme meteorological events, such as heat waves and droughts, with cascading effects on ecosystems, agricultural yields, human health, and livelihoods.

While the effects of climate change are global, and their projected impacts concern every area in the world, a wide scientific literature suggests that climate risks disproportionately affect the poorest countries and people, who are more exposed and more vulnerable to their impacts.

In the poorest economies, a large part of the population depends directly on activities that may be the most affected by climate change, notably, the agricultural, forestry, and fisheries sectors. People with the lowest incomes are the most likely to depend for their survival on resources provided by nature. Rising temperatures are exacerbating preexisting disparities in access to clean water and affordable food. Most of the time, the poorest populations do not benefit from insurance mechanisms or have access to basic health services, making them particularly vulnerable to any shock hitting their assets and income streams.

Rich countries and people

And it is the populations of these economies most vulnerable to climate change who contribute the least to the accumulation of greenhouse gases.

Greenhouse gas emissions today are mainly linked to the level of a nation's wealth: the richest countries represent only 16 percent of the world population but almost 40 percent of CO_2 emissions. The two categories of the poorest countries in the World Bank classification account for nearly 60 percent of the world's population, but for less than 15 percent of emissions. On a per capita basis, emissions are about 20 metric tons of CO_2-equivalent a person a year in the United States—approximately double the amount per person in the European Union or in China, and almost 10 times the amount in India.

This cross-country inequality is rooted in history: the contribution of the developed economies to global warming is greater than their share of current emissions because they have added to the accumulation of greenhouse gases in the atmosphere for a longer period. For example, the contribution of the United States to cumulative emissions is 25 percent of the total, the European Union's 22 percent, China's 13 percent, and India's 3 percent.

Reducing inequalities

Without action to limit and adapt to climate change, its environmental impact will continue to amplify inequalities and could undermine development and poverty eradication. While inequality refers to differences in income or wealth across the whole range distribution, poverty concerns individuals below a given income threshold, or lacking access to basic needs. By hitting the poorest hardest, climate change risks both increasing existing economic inequalities and causing people to fall into poverty.

Limiting the global temperature increase to 1.5°C requires reaching net zero CO_2 emissions by 2050 and reducing global emissions by approximately 50 percent in 2030, compared with 2010 levels. Limiting the increase in temperature to 2°C means net zero CO_2 emissions should be reached by 2070, and global emissions should be reduced by 25 percent by 2030. Every fraction of a degree counts because the impacts of climate change increase with rising temperature in a nonlinear way. For instance, while an increase of 1.5°C would expose 245 million people to a new or aggravated water shortage, this number becomes 490 million at +2°C.

The need is urgent for policies to transform rapidly and profoundly the way we use energy and transportation, produce and consume food as well as other goods, and shelter ourselves. The question is how to design these policies.

Mitigation efforts

Reducing emissions will ultimately limit climate change impacts and their unequal effects; however, mitigation policies must not neglect their own impacts on inequalities. As they affect energy or food prices, mitigation policies may also slow down progress in energy access and affect the poorest, who spend a higher share of income on these goods.

Thus, mitigation efforts should be shared fairly to ensure they serve the broader objectives of development, poverty and inequality reduction, improvement of air quality, health, and so forth. Given their greater historical contribution and greater ability to pay for mitigation, rich countries should pave the way by taking ambitious climate action. Financial transfers between countries can also reduce the burden of mitigation for poorer countries and increase participation in mitigation efforts.

Within regions and countries, policy design is key to making sure climate policies do not hurt the poorest. For instance, redistribution plans for the revenues generated by carbon prices can offset the negative impacts on poor people and even lead to net benefits for the poorest. Conversely, concerns about the regressive effects of policies have prevented strengthening existing carbon tax levels, for instance in France following the Yellow Vest movement. Other policies, such as investment in low-carbon technologies or building standards, can also have unequal effects on individuals, depending on their design.

Promoting adaptation and resilience

In parallel to reducing emissions, adaptation policies must be put in place to decrease the exposure of the most vulnerable populations to climate change impacts. This means devising rules regulating construction in risky areas, such as flood zoning, land entitlement, and building standards. The poorest communities must be provided with better health services and new insurance mechanisms.

As the poorest tend to be excluded from the decision-making process, there is always a risk of underinvestment in actions that would be particularly beneficial to them. Policies need to be tailored to ensure they do not impose undue financial constraints on those who have the fewest resources. Policymakers must guarantee that adaptation policies will actually benefit those most in need and will not be hijacked by the wealthiest or by political interests.

Another idea of interest is the creation of adaptation funds that would ensure technological transfers from rich countries, which produce most patents, to poorer ones.

Increasing countries' mitigation ambitions will be the main topic of the United Nations Climate Change Conference of the Parties (COP26) November 1–12. The success of those negotiations is a precondition to limiting inequality-exacerbating climate change. At the same time, careful attention to the equity and fairness of actions for vastly unequal countries will be key for the success of the negotiations themselves.

Jointly tackling climate change and inequality reductions requires paying attention to the intricate links between these issues. Limiting climate change is essential to reduce the risks it would impose, notably on the poorest. However, to design climate policies, the recognition that individuals and countries differ in their ability to mitigate emissions and to cope with climate change impacts is essential. Poorly designed policies risk amplifying existing inequalities, but just transitions to low carbon and more resilient economies can foster more equal societies.

This article is based on the paper "Influence of Climate Change Impacts and Mitigation Costs on Inequality between Countries" published in the journal Climatic Change in February 2020.

Climate change

World Health Organization - 12 October 2023

Key facts

- Climate change is directly contributing to humanitarian emergencies from heatwaves, wildfires, floods, tropical storms and hurricanes and they are increasing in scale, frequency and intensity.
- Research shows that 3.6 billion people already live in areas highly susceptible to climate change. Between 2030 and 2050, climate change is expected to cause approximately 250 000 additional deaths per year, from undernutrition, malaria, diarrhoea and heat stress alone.
- The direct damage costs to health (excluding costs in health-determining sectors such as agriculture and water and sanitation) is estimated to be between US$ 2–4 billion per year by 2030.
- Areas with weak health infrastructure – mostly in developing countries – will be the least able to cope without assistance to prepare and respond.
- Reducing emissions of greenhouse gases through better transport, food and energy use choices can result in very large gains for health, particularly through reduced air pollution.

Overview

Climate change presents a fundamental threat to human health. It affects the physical environment as well as all aspects of both natural and human systems – including social and economic conditions and the functioning of health systems. It is therefore a threat multiplier, undermining and potentially reversing decades of health progress. As climatic conditions change, more frequent and intensifying weather and climate events are observed, including storms, extreme heat, floods, droughts and wildfires. These weather and climate hazards affect health both directly and indirectly, increasing the risk of deaths, noncommunicable diseases, the emergence and spread of infectious diseases, and health emergencies.

Climate change is also having an impact on our health workforce and infrastructure, reducing capacity to provide universal health coverage (UHC). More fundamentally, climate shocks and growing stresses such as changing temperature and precipitation patterns, drought, floods and rising sea levels degrade the environmental and social determinants of physical and mental health. All aspects of health are affected by climate change, from clean air, water and soil to food systems and livelihoods. Further delay in tackling climate change will increase health risks, undermine decades of improvements in global health, and contravene our collective commitments to ensure the human right to health for all.

Climate change impacts on health

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) concluded that climate risks are appearing faster and will become more severe sooner than previously expected, and it will be harder to adapt with increased global heating.

It further reveals that 3.6 billion people already live in areas highly susceptible to climate change. Despite contributing minimally to global emissions, low-income countries and small island developing states (SIDS) endure the harshest health impacts. In vulnerable regions, the death rate from extreme weather events in the last decade was 15 times higher than in less vulnerable ones.

Climate change is impacting health in a myriad of ways, including by leading to death and illness from increasingly frequent extreme weather events, such as heatwaves, storms and floods, the disruption of food systems, increases in zoonoses and food-, water- and vector-borne diseases, and mental health issues. Furthermore, climate change is undermining many of the social determinants for good health, such as livelihoods, equality and access to health care and social support structures. These climate-sensitive health risks are disproportionately felt by the most vulnerable and disadvantaged, including women, children, ethnic minorities, poor communities, migrants or displaced persons, older populations, and those with underlying health conditions.

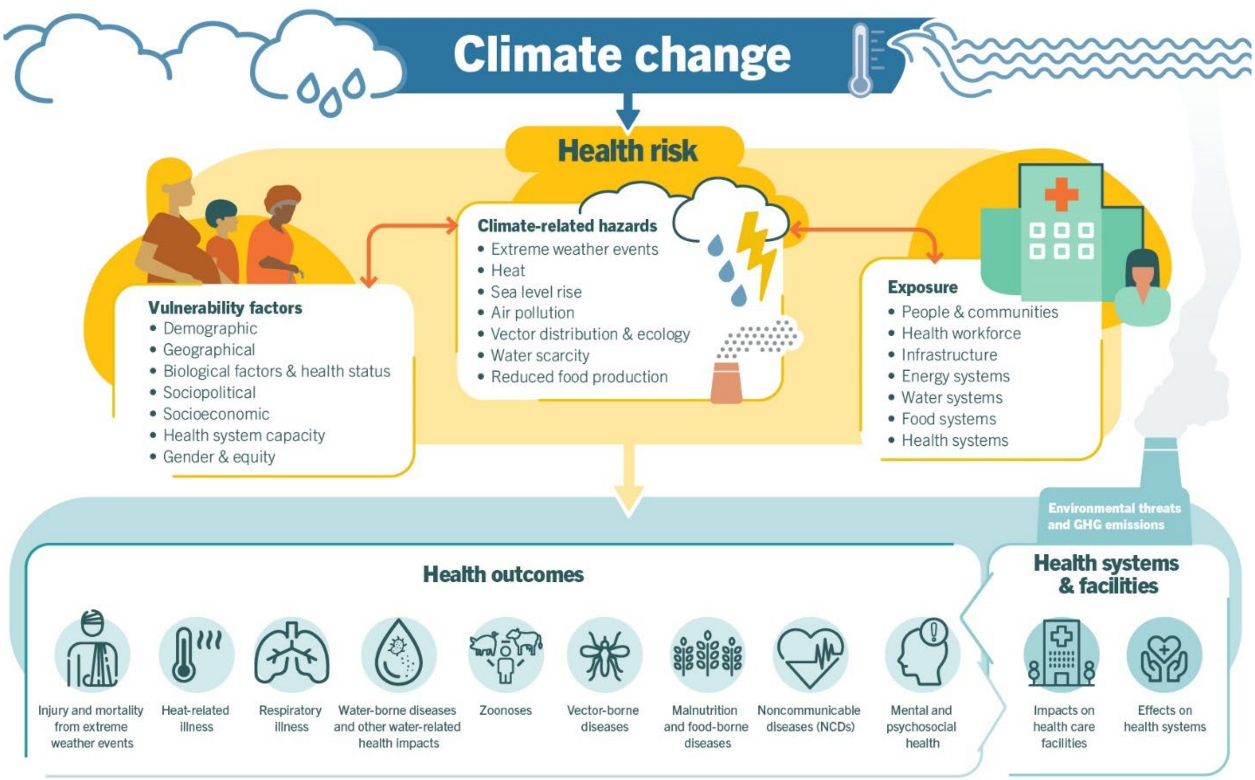

Figure: An overview of climate-sensitive health risks, their exposure pathways and vulnerability factors. Climate change impacts health both directly and indirectly, and is strongly mediated by environmental, social and public health determinants.

Although it is unequivocal that climate change affects human health, it remains challenging to accurately estimate the scale and impact of many climate-sensitive health risks. However, scientific advances progressively allow us to attribute an increase in morbidity and mortality to global warming, and more accurately determine the risks and scale of these health threats.

WHO data indicates 2 billion people lack safe drinking water and 600 million suffer from foodborne illnesses annually, with children under 5 bearing 30% of foodborne fatalities. Climate stressors heighten waterborne and foodborne disease risks. In 2020, 770 million faced hunger, predominantly in Africa and Asia. Climate change affects food availability, quality and diversity, exacerbating food and nutrition crises.

Temperature and precipitation changes enhance the spread of vector-borne diseases. Without preventive actions, deaths from such diseases, currently over 700 000 annually, may rise. Climate change induces both immediate mental health issues, like anxiety and post-traumatic stress, and long-term disorders due to factors like displacement and disrupted social cohesion.

Recent research attributes 37% of heat-related deaths to human-induced climate change. Heat-related deaths among those over 65 have risen by 70% in two decades. In 2020, 98 million more experienced food insecurity compared to the 1981–2010 average. The WHO conservatively projects 250 000 additional yearly deaths by the 2030s due to climate change impacts on diseases like malaria and coastal flooding. However, modelling challenges persist, especially around capturing risks like drought and migration pressures.

The climate crisis threatens to undo the last 50 years of progress in development, global health and poverty reduction, and to further widen existing health inequalities between and within populations. It severely jeopardizes the realization of UHC in various ways, including by compounding the existing burden of disease and by exacerbating existing barriers to accessing health services, often at the times when they are most needed. Over 930 million people – around 12% of the world's population – spend at least 10% of their household budget to pay for health care. With the poorest people largely uninsured, health shocks and stresses already currently push around 100 million people into poverty every year, with the impacts of climate change worsening this trend.

Climate change and equity

In the short- to medium-term, the health impacts of climate change will be determined mainly by the vulnerability of populations, their resilience to the current rate of climate change and the extent and pace of adaptation. In the longer-term, the effects will increasingly depend on the extent to which transformational action is taken now to reduce emissions and avoid the breaching of dangerous temperature thresholds and potential irreversible tipping points.

While no one is safe from these risks, the people whose health is being harmed first and worst by the climate crisis are the people who contribute least to its causes, and who are least able to protect themselves and their families against it: people in low-income and disadvantaged countries and communities.

Addressing climate change's health burden underscores the equity imperative: those most responsible for emissions should bear the highest mitigation and adaptation costs, emphasizing health equity and vulnerable group prioritization.

Need for urgent action

To avert catastrophic health impacts and prevent millions of climate change-related deaths, the world must limit temperature rise to 1.5°C. Past emissions have already made a certain level of global temperature rise and other changes to the climate inevitable. Global heating of even 1.5°C is not considered safe, however; every additional tenth of a degree of warming will take a serious toll on people's lives and health.

WHO response

WHO's response to these challenges centres around 3 main objectives:

- **Promote actions that both reduce carbon emissions and improve health:** supporting a rapid and equitable transition to a clean energy economy; ensuring that health is central to climate change mitigation policy; accelerating mitigation actions that bring the greatest health gains; and mobilizing the strength of the health community to drive policy change and build public support.
- **Build better, more climate-resilient and environmentally sustainable health systems:** ensuring core services, environmental sustainability and climate resilience as central components of UHC and primary health care (PHC); supporting health systems to leapfrog to cheaper, more reliable and cleaner solutions, while decarbonizing high-emitting health systems; and mainstreaming climate resilience and environmental sustainability into health service investments, including the capacity of the health workforce.
- **Protect health from the wide range of impacts of climate change**: assessing health vulnerabilities and developing health plans; integrating climate risk and implementing climate-informed surveillance and response systems for key risks, such as extreme heat and infectious disease; supporting resilience and adaptation in health-determining sectors such as water and food; and closing the financing gap for health adaptation and resilience.

Leadership and Raising Awareness: WHO leads in emphasizing climate change's health implications, aiming to centralize health in climate policies, including through the UNFCCC. Partnering with major health agencies, health professionals and civil society, WHO strives to embed climate change in health priorities like UHC and target carbon neutrality by 2030.

Evidence and Monitoring: WHO, with its network of global experts, contributes global evidence summaries, provides assistance to nations in their assessments, and monitors progress. The emphasis is on deploying effective policies and enhancing access to knowledge and data.

Capacity Building and Country Support: Through WHO offices, support is given to ministries of health, focusing on collaboration across sectors, updated guidance, hands-on training, and support for project preparation and execution as well as for securing climate and health funding. WHO leads the Alliance for Transformative Action on Climate and Health (ATACH), bringing together a range of health and development partners, to support countries in achieving their commitments to climate-resilient and low carbon health systems.

2025 NCF-Envirothon Alberta

Current Issue Part A Study Resources

Key Topic #2: Forest Health in a Changing Climate

5. Explain how globalization has enabled the spread of invasive insect species and impacted the world's forests.
6. Describe how wildfire impacts the hydrology, wildlife, and soils of forest communities.
7. Describe the conditions of drought as it relates to forest ecosystems, and identify how increasing drought severity and frequency impacts global forests.
8. Explain the biology and impacts of typical forest insect pests such as Mountain pine beetle, Spruce beetle, Spruce budworm, Forest tent caterpillar, Emerald ash borer, and Asian longhorn beetle.
9. Describe biology and impacts of typical forest diseases such as Western gall rust, Armillaria root rot, needle casts and needle rusts.
10. Describe how the prevalence and spread of forest pests and diseases are expected to shift with climate change.

Study Resources

Resource Title	Source	Located on
Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts	*Ramsfield et al. - Forestry: An International Journal of Forest Research, 2016*	Pages 32 - 33
How Does Wildfire Impact Wildlife and Forests	*Meghan Snow – US Fish and Wildlife Service, 2022*	Page 34
Forest Pest Management	*Natural Resources Canada, 2015*	Pages 35-42
Biotic Pathogens	*Natural Resources Canada, 2015*	Pages 43-46
Forest Pests and Climate Change	*Climate Atlas of Canada, 2024*	Pages 47-48
Shape-shifting forests: A tale of climate, wildfires, and surprising outcomes	*Natural Resources Canada, 2024*	Pages 49-50
Drought	*Natural Resources Canada, 2024*	Pages 51-53

<u>Study Resources begin on the next page!</u> ➡

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Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts

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Forests and trees throughout the world are increasingly affected by factors related to global change. Expanding international trade has facilitated invasions of numerous insects and pathogens into new regions. Many of these invasions have caused substantial forest damage, economic impacts and losses of ecosystem goods and services provided by trees. Climate change is already affecting the geographic distribution of host trees and their associated insects and pathogens, with anticipated increases in pest impacts by both native and invasive pests. Although climate change will benefit many forest insects, changes in thermal conditions may disrupt evolved life history traits and cause phenological mismatches. Individually, the threats posed to forest ecosystems by invasive pests and climate change are serious. Although interactions between these two drivers and their outcomes are poorly understood and hence difficult to predict, it is clear that the cumulative impacts on forest ecosystems will be exacerbated.

Introduction

There is growing recognition among the scientific community and policy makers that sustainable forest management is affected by multiple factors associated with global change. Exponential population growth has resulted in the addition of 1 billion people between 1999 and 2012, leading to a global population of over 7 billion people that must be sustained by Earth's resources. Forests are of vital importance to humanity as they provide a wide range of essential ecosystem services (e.g. fuelwood, fibre, carbon sequestration etc., see Thompson et al., 2011) but the ongoing loss of forest cover means the increasing demand must be met from an ever shrinking resource (Brockerhoff et al., 2013). Concomitant with population growth has been the expansion of global trade networks and an increase in the volume of traded goods (e.g. Hulme, 2009). This has led to a considerable increase in the establishment of populations of non-native species in virtually all parts of the world (e.g. Roques et al., 2009; Aukema et al., 2010; Wingfield et al., 2015). While many of these species appear to be relatively benign, some have major deleterious impacts on trees in natural and managed ecosystems, as well as urban environments. For example, the invasive emerald ash borer has been devastating ash trees in North America (Poland and McCullough, 2006) and *Phytophthora ramorumis* causing dieback and mortality of a wide range of tree species in Europe and North America (Gru¨ nwald et al., 2012). Climate change can exacerbate invasions of forest pests as well as impacts of native pests. For example, climate change can facilitate the range expansion of both native and exotic pests (insects and pathogens), or affect tree resistance to pests (Jactel et al., 2012a), and there is increasing evidence that this is a widespread phenomenon (Battisti et al., 2005; Marini et al., 2012; Anderegg et al., 2015). Using the planetary boundaries approach of Steffen et al. (2015), Trumbore et al. (2015) identified that the main stressors of the world's forests today are invasive species and diseases as well as climate change, along with deforestation and the increasing demand for forest resources. An additional contributor to forest health problems is the ongoing intensification and mechanization of forest management which has increased the vulnerability of forests to disturbance from biological invasions, climate change and other stressors (Seidl et al., 2011). However, there is increasing recognition that forest management can be adapted to increase the resistance and resilience of forests to disturbance (Jactel et al., 2012b; DeRose and Long, 2014; Bahamondez and Thompson, 2016, this issue).

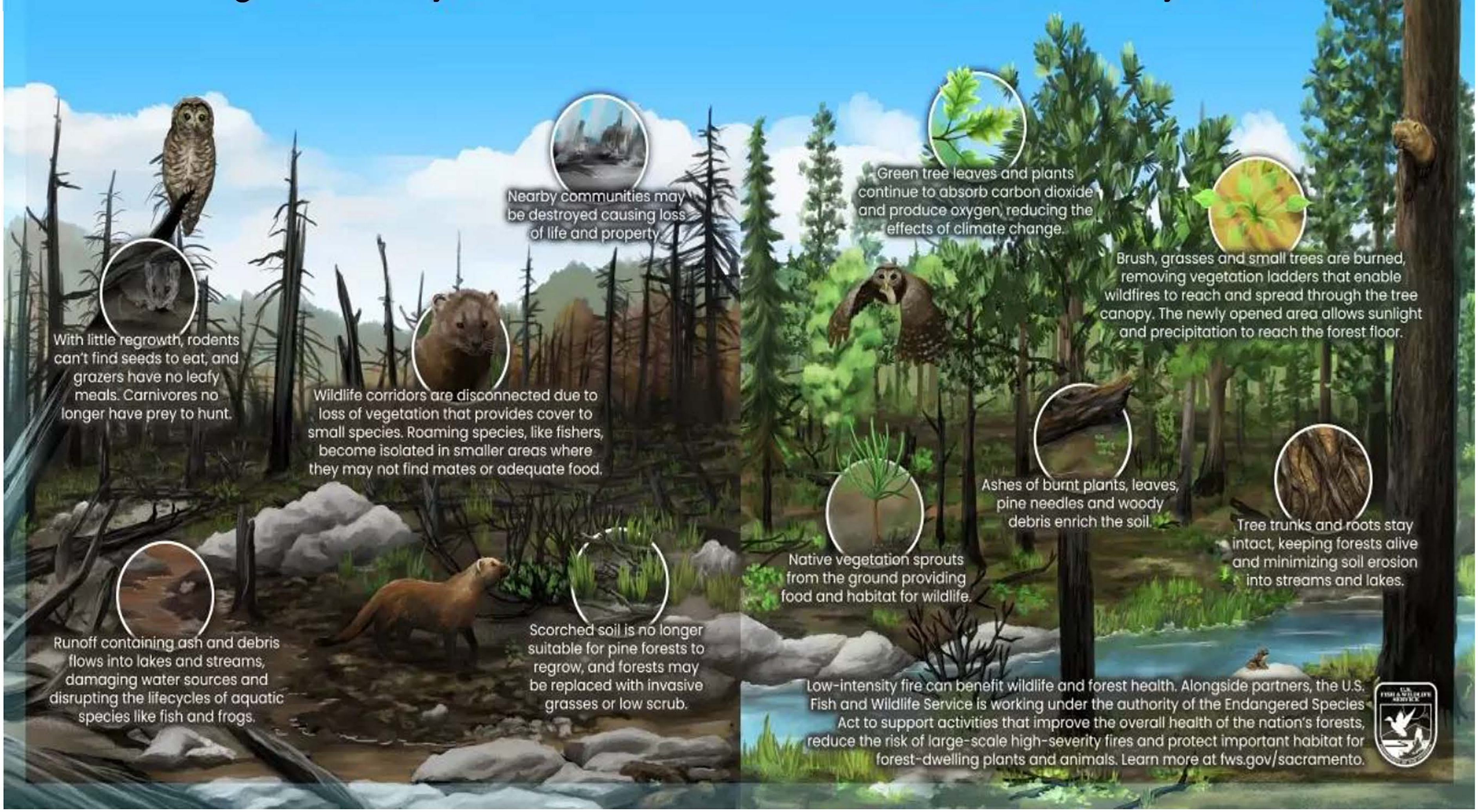
How does fire impact forests and wildlife?

Wildfires are inevitable, but not all fire is harmful to forests. Low-intensity fires can naturally "clean" and thin the forest by removing flammable and thick vegetation on the forest floor. The result is improved habitat for wildlife, healthier soil and new growth of native plants.

It also helps reduce the risk of large-scale high-severity fires that burn through the forest—from the floor to the canopy—with intense heat. High-severity fires across large landscapes can be devastating for wildlife, habitat and surrounding communities.

High-Severity Fire

Low-Intensity Fire



Government of Canada Gouvernement du Canada

Forest pest management

Native insects and diseases play an essential ecological role in Canada's forests.

By consuming trees and other plant material, forest insects and micro-organisms contribute to healthy change and regeneration in forest ecosystems. They help renew forests by removing old or otherwise susceptible trees, recycling nutrients and providing new habitat and food for wildlife.

However, it's not for their ecological benefits that forest insects and diseases sometimes make national news. When infestations are so severe they destroy or damage large areas of commercially valuable forest, or infest Canadian forest products bound for export, then insects and diseases—whether native or alien—become "pests."

Mountain pine beetle, spruce budworm, and Dutch elm disease are all examples of well-known forest pests that have led to significant losses in value of Canadian forests.

What's what: native, alien, invasive

Forest insects and diseases in Canada are typically classified into three broad categories:

- Native: Indigenous species that have existed in Canada for thousands of years. Outbreaks occur periodically. Examples are spruce budworms and mountain pine beetle.
- Alien: Species introduced into Canada's forests within recent history. They are also referred to as "exotic," "non-native" and "foreign." Examples include emerald ash borer, brown spruce longhorn beetle and Dutch elm disease.
- Invasive: Insects and diseases that spread beyond their known usual range.

Both terms, "alien" and "invasive," refer to shifts from one ecosystem to another, not to shifts across national borders. So, even organisms that move into new ecosystems within the same country can be considered alien and invasive if they extend beyond their usual geographic range. The spread of mountain pine beetle from British Columbia's lodgepole pine forests to Alberta's jack pine forests is an example of a native forest insect behaving invasively.

From friend to foe

Native forest insects and diseases are generally of little concern when they exist at non-damaging population levels.

It is when populations of these native species increase beyond an acceptable threshold, or when alien or native species behave invasively that concerns arise. If ecological or economic damage results in measurable impacts—such as a decline in ecosystem health or large reduction in the available wood fibre—then the insect or disease outbreak is seen as being a disturbance and active management intervention may be considered.

The challenge for forest resource managers is therefore two-fold. First is to assess the risks posed by potential and actual outbreaks and spread. Second is to apply risk-based decision-making to manage forest ecosystems in a way that minimizes the negative impacts of outbreaks and maximizes the positive impacts.

Mountain pine beetle
Dendroctonus ponderosae

Distribution
Saskatchewan, Alberta, British Columbia.

Present in most lodgepole pine forests of British Columbia, adjacent, central and northern Alberta, and in isolated locations in southwestern Saskatchewan. The geographic range has been expanding northward and eastward for the past decade.

Micro-habitat(s)
Trunk, Bark

Biology
The mountain pine beetle has a life cycle that normally lasts one year. In late summer, the adults emerge from the trees in which they feed and develop and fly off in search of new hosts, into which the females bore waiting for males to come to them. The females bore vertical galleries just under the bark, in which they lay their eggs. The larvae that emerge from the eggs spend the winter feeding under the bark. Adult emergence takes place between July and September.

A key stage in the life cycle occurs when the beetle transmits a blue stain fungus to the tree. Attacking beetles carry the spores of the fungus, which gain entry to the tree and eventually overcome its defense system and its ability to withstand beetle attack.

The mountain pine beetle and associated blue stain fungi (*Ascomycetes*) act together to kill trees. Adults transport spores of the blue stain fungi to new trees within a specialized sac (mycangium) on the maxillary cardine. These fungi are believed to stop water transport in the stem and thus kill infected trees.

Although the mountain pine beetle has many natural enemies including insect predators, parasitoids, and woodpeckers, these do not have sufficient impact on incipient and outbreak populations to exert effective control.

Damage
Infested trees can be detected through crown and external symptoms. The first signs are boring dust and resin on the bark associated with the attacking adults, but the mountain pine beetle can only be positively identified (and the success of an attack can only be positively determined) by looking under the bark.

At low (endemic) populations the mountain pine beetle survives in weakened or stressed trees. As populations increase or more trees become stressed because of drought or other causes, the population may quickly increase and spread. Healthy trees are then attacked and huge areas of mature pine stands may be threatened or killed. Warm summers and mild winters play a role in both insect survival and the continuation and intensification of an outbreak. Adverse weather conditions (winter low of -40°C or high winds during dispersal period) can reduce the beetle populations and slow the spread, but insect populations may recover (not the individual insects) and resume their attack on otherwise healthy forests.

Aerial detection of successfully attacked trees is possible as early as late spring (more typically mid-summer) in the year following attack. Detection of small groups of red-topped trees should be followed with ground inspection to verify cause.

The current outbreak in BC is starting to wane. MPB populations are likely to continue to spread eastward through jack pine and are unlikely to be stopped by an occasional cold winter. Over the last decade the insect's range in northern Alberta has expanded annually, despite several cold winters.

Symptoms
Accumulations of pitch or sawdust are conspicuous around entrance holes bored into the bark of trees by adult beetles from mid-July to early September. Sawdust is quickly blown or washed away, but abundant pitch tubes may remain for more than a year after attack. Pitch tubes may be much less evident on trees under severe drought stress prior to attack.

During the fall and winter after attack, woodpeckers feed on bark- and wood-boring insects on infested trees. Trunks of trees foraged on by woodpeckers are easily visible as much bark is stripped off and bark fragments accumulate in piles on the ground at the base of trees. Removal of bark from infested trees reveals adult egg galleries, larval feeding galleries, and one or more life stages (eggs, larvae, pupae, adults), depending on the time since attack. Egg galleries are 10–41 cm (average, 28 cm) long, oriented vertically on the stem, and have a short curved or diagonal section at the bottom.

Grayish blue staining of sapwood, caused by colonization of ray parenchyma cells by blue stain fungi transmitted by adult beetles, provides a conspicuous symptom shortly after successful attack. Various fungal fruiting structures (such as synnemata and perithecia) and mycelia of blue stain fungi and other fungi are often evident in beetle galleries and pupal chambers.

Tree foliage begins to dry out as soon as the conduction of water up the tree is interrupted. As a result, the colour of the foliage on infested trees gradually changes from bright to dull green. This early symptom in the lower crown will often become visible 2-3 months after attack. However, more distinct colour changes occur during the onset of the growing season the spring following attack when tree foliage turns brick red. The needles of infested trees first turn a faint yellow and then a reddish brown by late summer, which allows easy detection; however, by the time trees prominently display these symptoms, they are typically vacated by the mountain pine beetle, which has moved on to attack other trees. With time, retained foliage colour becomes more dull, and most of the foliage drops in 2-3 years; this will vary from species to species and with weather conditions. These rapid and distinct colour changes are used to schedule aerial mapping of recently attacked trees.

Diet and feeding behavior
Phloeophagous: Feeds on phloem.

Brown spruce longhorn beetle

Tetropium fuscum (Fabricius)

Distribution
Nova Scotia

Micro-habitat(s)
Bark

Biology & Damage
The adult has a flattened body, 1 to 1.5 cm long. The head and neck area are dark brown to black. The elytra (wing covers) can be tan, brown or reddish brown and have 2 to 3 longitudinal stripes. The antennae are red-brown and about half of the body length. The legs are dark brown. The egg measures one mm long, is oblong and white with a tinge of green. The larvae is yellow-white, about 14 to 28 mm long, and slightly flattened. The larva's head is reddish and about half of the body. The head is reddish brown and about 3 mm wide. The pupa is white and measures 10 to 17 mm long and 3.8 mm wide.

In the spring, female beetles lay eggs in the bark of standing or recently felled trees. Eggs are usually laid singly, but sometimes in clusters of up to ten eggs. Larvae hatch 10 to 14 days later, and bore into the phloem to feed, producing a network of irregular tunnels packed with sawdust-like frass (excrement).

Most *T. fuscum* overwinter as prepupal larvae either under the bark or in characteristic L-shaped pupal cells about 2-4 cm deep in the sapwood. Pupation occurs in spring and adults emerge about 14 days later, chewing a round or oval exit hole in the bark about 4-6 mm in diameter. The adults live approximately two weeks and can be found from June to August. Both males and females are strong flyers.

Over most of the range of spruce in Canada, the BSLB would likely have one generation per year.

In its native range BSLB is recognized mainly as a secondary forest insect, attacking trees that have already been subjected to other types of insect attack or environmental stresses. During a population outbreak, beetles can attack living, healthy trees. Outbreak levels have the potential to persist for a decade and continually cause damage over extensive tracts of vulnerable conifer forest. In Europe, *T. fuscum* often attacks stands of Norway spruce over 50 years of age. Tunnels in the wood as a result of larval feeding reduce timber quality.

Symptoms

- streams of resin scattered along the trunk
- holes in the bark about 4 mm across
- networks of feeding tunnels just under the bark, up to 6 mm across;
- tunnels in the wood about 4 cm deep and 6 mm wide. These tunnels appear L-shaped when the wood is cut longitudinally.
- Coarse sawdust may be found in and around tunnels or plugging the exit hole.

Other information
This insect is native to Europe, where it can be found from Scandinavia to Turkey. It is also known from Japan and western Siberia. The find in Nova Scotia is believed to be the first discovery in North America.

In March, 1999, the brown spruce longhorn beetle (BSLB), *Tetropium fuscum* was found in dying red spruce trees in Point Pleasant Park, Halifax, Nova Scotia. The following summer, the Canadian Forest Service (CFS) reared over 40 *T. fuscum* adults from red spruce bolts collected in the park. Subsequent investigations by the CFS concluded that *T. fuscum* was also attacking apparently healthy trees. Specimens collected in the park in 1990, originally identified as a related native species (*Tetropium cinnamopterum*) have also now been confirmed as *Tetropium fuscum*. Some fungi such as *O. tetropii* or *Pesotum fragrans*, have been isolated from brown spruce longhorn beetles or from boles infested by this insect. These fungi are not considered as being pathogenic.

Diet and feeding behaviour
Phloeophagous: Feeds on phloem.
Borer: Bores into and feeds on the woody and non-woody portions of plants.

Spruce budworm
Choristoneura fumiferana (Clemens)

Distribution
Canada

Micro-habitat(s)
Needle, Bud, Male flower, Cone

Damage, symptoms and biology
Spruce budworm damage appears in May. Evidence of a spruce budworm infestation includes the destruction of buds, abnormal spreading of new twigs, defoliation of current-year shoots and, if an affected branch is disturbed, the presence of large numbers of larvae suspended from strands of silk.

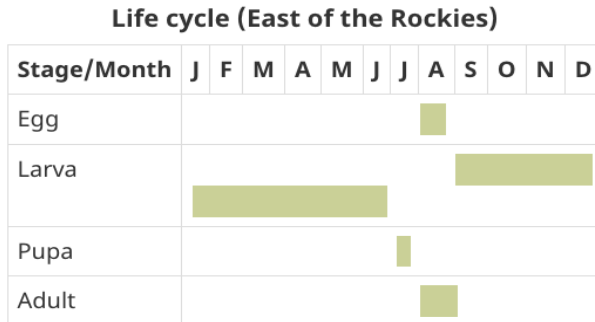
Defoliation begins at the top of the tree and quickly progresses to the periphery of the crown from the top downwards. Current-year needles are partially or completely consumed and, if large numbers of larvae are present, previous-year needles may also be affected. Spruce budworm larvae also feed on staminate (male) flowers and cones. During epidemics, the larvae may destroy all of the cones.

Severely affected stands turn a rust colour due to the presence of dried out needles held by strands of silk spun by the larvae. In the fall, most dead needles are dispersed by the wind and defoliated stands take on a greyish appearance.

A single year of defoliation generally has little impact on the tree. However, it does cause weakening of the tree, making it more susceptible to attacks by other insects. Defoliation over a few consecutive years causes tree growth loss. However, if defoliation of current- and previous-year shoots continues uninterrupted over several years, some trees will die, while others will continue to gradually decline for several years, even after the end of the infestation. This is the case with fir, the species most vulnerable to spruce budworm attacks, which dies after four consecutive years of severe defoliation.

In July and August, the female deposits her eggs in clusters of 10 to 30 under the needles of shoots, preferring those exposed to sunlight. The newly hatched larvae move towards the interior of the crown in search of a suitable overwintering site and construct a silken shelter, called a hibernaculum.

Life cycle (East of the Rockies)



Other information
A native species, the spruce budworm is considered the most serious pest of fir and spruce forests in North America. Its range coincides with that of fir, white spruce, and more and more with the range of the black spruce.

Radial growth analyses of trees have shown that cyclical invasions likely occurred between the 18th and 20th centuries. Spruce budworm populations are believed to have fluctuated during this period at intervals of 30 to 40 years. Since the beginning of the 20th century, three invasions have occurred in eastern North America.

The spruce budworm is generally found in large fir stands. Much research has been conducted on this insect by the Canadian Forest Service and it is being monitored by the provincial forest departments. Most control methods mentioned in the recent literature involve the use of biological insecticides, primarily *Bacillus thuringiensis var. kurstaki* (B.t.k.).

Through a combination of annual surveys, prediction models, targeted control strategies and proper forestry practices, it is now possible to reduce economic losses caused by spruce budworm outbreaks.

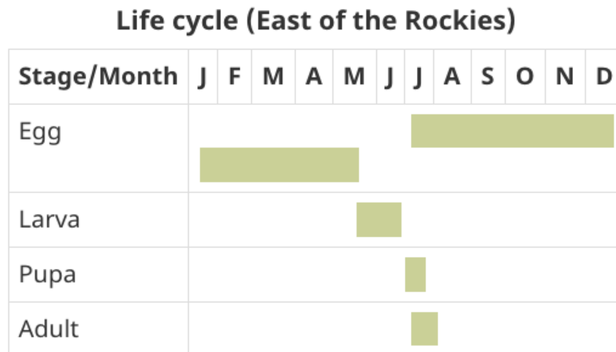
On isolated or ornamental trees, vigorously shaking the tree or spraying with a powerful water jet will cause the larvae to drop to the ground. On small trees, the larvae can be removed by hand.

Diet and feeding behaviour
Heteroconophagous: Feeds occasionally on seeds and cones, but usually lives and feeds on stems and needles.
Phyllophagous: Feeds on the leaves of plants.
Webworm: Spins a silk shelter in which to hide or feed.
Pollinivorous: Feeds on pollen.

Forest tent caterpillar

Malacosoma disstria Hubner

Life cycle (East of the Rockies)



Distribution
Canada

Micro-habitat(s)
Leaf

Damage, symptoms and biology
Defoliation is caused by the caterpillar, which begin to feed on the new leaves as soon as they appear in May. Given this insect’s voracious appetite and gregarious behaviour throughout most of its development, its presence can be quickly detected. Older larvae devour entire leaves and, when the tree is completely defoliated, migrate in search of other sources of food. Larvae can also be observed in colonies on tree trunks sheltered from the sun’s rays.

During massive invasions, trees can be completely defoliated over large areas. Even when severely defoliated, trees withstand infestations relatively well. Infestations generally last no more than three consecutive years. However, on trembling aspen, radial growth loss and twig dieback occur. Denuded trees will produce another crop of leaves during the season.

In the fall, the presence of egg bands, which resemble spongy, brownish masses, can be easily detected on small branches and twigs. In late June, the female deposits between 150 and 350 eggs in masses that encircle the twigs. The embryo develops over the course of the season and overwintering takes place as a fully developed embryo within the eggshell.

Other information
A species native to North America, the forest tent caterpillar is the most widespread defoliator of deciduous trees. Its range extends from coast to coast.

The insect has been known for many years and the first outbreak was recorded in 1791. Since then, the forest tent caterpillar has been reported at regular intervals in Canada.

Infestations are generally short and parasitoids are very important in the natural control of populations. The most important parasitoid is the large flesh fly, Sarcophaga aldrichi Parker, which acts quickly after the start of an infestation, and can destroy up to 80% of the pupal population.

In recreational parks or on ornamental trees, it is recommended that egg bands be removed in the fall. At that time of year, they are more visible because the leaves have dropped. In the spring, colonies of young larvae at rest can be removed by hand. On small trees, a water jet can be used to dislodge larvae from the foliage.

Diet and feeding behaviour
Phyllophagous : Feeds on the leaves of plants.
Free-living defoliator: Feeds on and moves about freely on foliage.

Emerald ash borer
Agrilus planipennis

Distribution
Quebec, Ontario

Micro-habitat(s)
Leaf, Branch, Trunk

Damage, symptoms and biology
Tree decline, including:

- yellowing of the foliage
- thinning crown
- evidence of adult beetle feeding on leaves
- long shoots growing from the trunk or roots
- vertical cracks in the trunk
- deformed bark (3-4 mm)
- small D-shaped emergence holes
- S-shaped larval tunnels under the bark filled with fine sawdust
- presence of woodpeckers in winter and woodpecker holes

The EAB has killed millions of ash trees in Southwestern Ontario, Michigan and surrounding states, and poses a major economic and environmental threat to urban and forested areas in both countries. The EAB attacks and kills all species of ash (except Mountain ash which is not a true ash).

The emerald ash borer has only one generation per year in the south of its distribution area in Michigan. Adult emergence starts with the month of June and ends with the end of July. A few days after mating, female lay eggs, one at the time, in bark crevices. One female lays between 60 and 90 eggs during its lifespan. Larvae dig S shaped galleries in the phloem in order to feed themselves. They hibernate in the bark and pupate in April or May. The lifecycle of the emerald ash borer, north of its distribution area, is not known for the moment, but it could last two years.

Other information
Native to eastern Asia, this pest was first discovered in Canada and the U.S. in 2002.

While the EAB can fly up to several kilometres, another significant factor contributing to its spread is the movement of firewood, nursery stock, trees, logs, lumber, wood with bark attached and wood or bark chips.

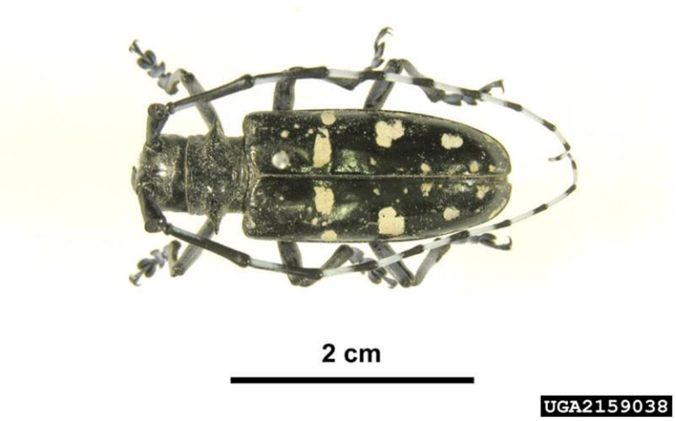
Regulated materials can be freely moved within a regulated area, but cannot be moved outside of a regulated area without prior written permission from the CFIA. Anyone violating this requirement may be subject to a fine and/or be liable for prosecution.

Regulated materials for EAB include nursery stock, trees, logs, wood, rough lumber including pallets and other wood packaging materials, bark, wood chips or bark chips from ash (Fraxinus species), and firewood of all tree species.

Diet and feeding behaviour
Phyllophagous : Feeds on the leaves of plants.
Xylophagous : Feeds on woody tissues (wood).

Asian longhorned beetle

Anoplophora glabripennis



Distribution

Ontario, United States

Micro-habitat(s)

Twig, Bark

Damage, symptoms and biology

In China, this species may have a one or two year life cycle, depending on the geographical region. The egg, larva, or pupa can overwinter. Young adults emerge from infested trees in May and may fly several hundred meters to search for a host. However, they tend to attack the same tree from which they emerged. Adults are active from early-summer to mid-fall. They feed on the bark of twigs periodically throughout the mating and egg-laying period. On sunny days the adult beetles are most active from mid-morning to early-afternoon. They usually rest in the canopy on cloudy days.

In preparation for egg-laying, females chew oval grooves in the bark in which they lay one egg about 5-7 mm in length. On average, each female will live 40 days and during that period will lay about 25-40 eggs. The wounds may occur anywhere on the tree, including branches, trunk, and exposed roots. Eggs hatch in one to two weeks. Young larvae begin feeding in the phloem tissue and as they mature they migrate into the wood, creating tunnels as they feed. These galleries cause tree dieback and death. Larvae become pupae, then adults, in the tunnels in summer. The new adults exit the tree through large round holes about 10-15 mm in diameter created by the newly emerging adults. Dripping sap is often seen to be flowing from the egg-laying wounds.

Piles of coarse sawdust around the base of the tree and in branch axils can be seen as well. The adults are large bluish-black beetles (2.5 to 3.5 cm in length) with white spots and very long antennae. The larvae and pupae are normally inside the tree within the larval tunnels. Full grown larvae can reach 50 mm in length.

Other information

In China, *Anoplophora glabripennis* is known as the "starry sky beetle" and is considered a major pest of hardwood trees in many parts of the country. Based on the Chinese distribution and the current infestations in the United States and Canada, it has been shown that the beetle can survive well in the hardwood forests of southern Canada.

The first report of this beetle being established outside of its native range was from the cities of Brooklyn and Amityville, New York in 1996. Many trees were found to be heavily attacked, particularly maples. Quarantine and eradication procedures were quickly implemented to prevent further spread and to eliminate the population. In July-August, 1998, three separate infestations were discovered around Chicago, Illinois. In October 2002 an infestation was discovered in Jersey City, New Jersey. In September 2003 an infestation was discovered in an industrial park located on the boundary line between the Cities of Vaughan and Toronto in the province of Ontario. All of these infestations are under strict quarantine control and are undergoing eradication.

Diet and feeding behaviour

Phloeophagous : Feeds on phloem.
Borer: Bores into and feeds on the woody and non-woody portions of plants.

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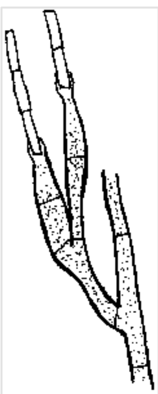
Biotic Pathogens

Bacteria are single-celled organisms that lack a true cell nucleus and have a single chromosome instead. There are only a few pathogenic bacteria that attack trees.

The majority of **forest pathogens are fungi,** which generally belong to one of the following divisions: *Basidiomycotina*, *Ascomycotina* or *Deuteromycotina*.

Deuteromycotina reproduce asexually by producing conidia on conidiophores (**Figure 1**) or within special structures, such as pycnidia. *Ascomycotina* reproduce sexually by producing 4, 8, 16 or 32 ascospores inside sacs, or asci (**Figure 2**), within structures called ascomata. These ascomata may be cup-shaped (apothecia), bottle-shaped (perithecia), or balloon-shaped (cleistothecia).

Basidiomycotina reproduce sexually by forming basidia, which produce four basidiospores (**Figure 3**) on a structure called ascoma. The basidia develop in gills, pores, teeth or other structures. Rusts (Uredinales) are *Basidiomycotina* that function as obligate parasites and have a complex life cycle that generally requires an alternate host.



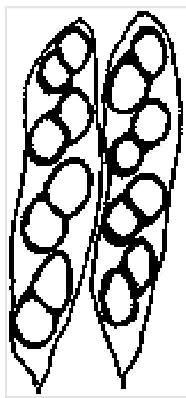
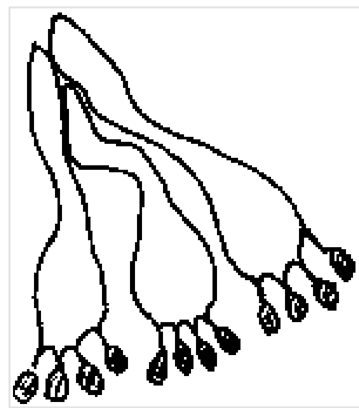


Figure 1 *Conidiophores and conidia*

Figure 2 *Asci and ascospores*

Figure 3 *Basidia and basidiospores*



Western gall rust

Endocronartium harknessii (J.P. Moore) Y. Hiratsuka

Micro-habitat(s)
Twig, Branch

Distribution
Canada

Damage, symptoms and biology
The fungus causes a gall that encircles the stem or bole of infected trees. White blisters develop at the site of the gall, just beneath the bark. In spring, the blisters burst and orange spores are released which end up infecting other pines.
Rupturing of the blisters results in desiccation of the underlying living bark, killing the bark area around the gall. Following the death of the water-conducting tissues, some needles will die in the lower part of the branch, near the distal portion of the gall.

Damage is not significant on mature trees where most infections occur on branches. Branch galls do not result in serious growth losses. However, infections on young trees more often result in main stem galls that can cause stem malformations and predispose the tree to breakage in high winds or under heavy snow loads (Figs e, f).

A large number of galls reduces the aesthetic appearance and value of ornamentals and Christmas trees.

Other information
Unlike the other important stem rusts, *E. harknessii* does not require an alternate host to complete its life cycle. Infection occurs directly from pine-to-pine. This allows rapid intensification of the disease when conditions optimal for infection occur. However, such conditions only occur every several years, resulting in "wave years" of infection and gall formation.
Pruning the infected branches prior to spore production is a good means of control. Rodents feed on the galls in winter, and this may result in a high level of mortality some years.

Needle cast

Isthmiella faullii

Micro-habitat(s)
Needle

Distribution
Eastern Canada

Damage, symptoms and biology
This disease is the most common and most destructive needle cast in fir. It severely defoliates seedlings and young trees, reduces their growth, and may sometimes kill them. In larger trees, however, the damage does not cause any serious problems. The current year's needles are infected first, but they do not show any damage. The following spring, brown spots appear and spread, eventually covering the entire surface of the needles by mid-summer. The first fruiting bodies form on the upper surface of the needles and discharge spores in late summer or early fall. It is unclear just what role these spores play, but they may give rise to the second type of spores. Ascospores form in mid-summer on the needles infected two years earlier. Hysterothecia, the fruiting bodies bearing these spores, create a black line on the underside of the needles. This line is actually the ascus, which will release ascospores able to infect new shoots the following spring.

Other information
No measures are implemented to control this disease in the forest. With high-value trees, however, pruning of affected branches represents a good means of suppression. The disease causes considerable damage in Christmas tree plantations. Fungicide spraying may also be effective, but it must be done at the right time, that is, when the spores are released.

Armillaria root rot

Armillaria mellea

Micro-habitat(s)
Base of tree

Distribution
Eastern Canada

Damage, symptoms and biology
This is the most destructive and widespread disease involving pathogens that attack the roots and base of trees. In forest stands the disease will often kill trees either singly or in patches known as disease centers. These disease centers will continue to grow in size as the disease spreads outward over time.

Trees with armillaria root disease might or might not show external symptoms. The first symptoms of the disease are a decline in tree vigour, foliage yellowing followed by gradual browning, and a considerable flow of resin in conifers. Needles on dying pine trees first turn yellow-green and then red before falling off. Spruce needles often become a dull green (but not red) before they fall off. The infection begins when the fungus, living in the ground, sends out filaments that invade healthy roots. It then moves to the root collar, and spreads to the tree trunk. The spread of infection induces sapwood decay in the affected parts, and eventually kills the tree. Trees with root decay die as a result of sap flow being cut off or following wind throw. The infected areas have cream-coloured plates along with black mycelial cords resembling shoe strings. The rotting wood beneath the bark has a water-soaked appearance and is pale brown. Over time, the wood yellows, then whitens and becomes soft, spongy and stringy. In the fall, golden yellow fruiting bodies can be seen near infected trees or at their base. The fruiting bodies have darkish scales on the cap and fairly close yellowish white gills. The long, fibrous stem is encircled by a thin membranous ring. The fruiting bodies produce spores that are dispersed by the wind and end up creating new pockets of infection.

Other information
Armillaria root disease is caused by several closely related species of Armillaria. *Armillaria ostoyae* is the most prevalent and destructive of the Armillaria spp..
The causal fungus of Armillaria root rot can remain alive for many years in rotting wood on the ground. Some root disease centers have been estimated to be more than 400 years in age. Although the fungus usually lives on dead organic matter, it can attack healthy trees and cause major damage. The fruiting body is edible but opinion is divided regarding its flavour. It is best to consume only young specimens. Be sure to carefully identify them first. Trees whose foliage appears healthy but have rotten roots can be hazardous in campgrounds, or around buildings because they are susceptible to wind-throw.

Needle rust of pine

Coleosporium asterum (Diet.) Syd.

Distribution

Common throughout the range of host trees in Canada.

Damage, symptoms and biology

The pine-aster rust causes minor needle cast and discoloration of needles of pine and, in cases of severe infection, some reduction in terminal growth, but only rarely does it kill trees. Generally, only relatively small trees, less than 8 to 10 feet in height, are affected, and only heavily infected older needles are cast prematurely, resulting in lowered food production, consequent growth reduction, and reduced value for Christmas trees. However, death of seedlings could result from a combination of rust attack and insect attack fatal to the new shoots.

Coleosporium asterum is a macrocylic rust, producing five spore stages. In the early spring the pycnial stage appears as orange droplets on lesions on pine needles that were infected the previous fall. A white, columnar blister, the aecial stage, then forms on the needles in late spring or early summer, ruptures and releases orange-coloured aeciospores that are dispersed by the wind and infect the alternate hosts, aster, *Aster sp.*, and goldenrod, Solidago sp. Throughout the summer, on the underside of the leaves of the alternate host, the uredial stage develops and produces orange, cushion-like masses, which produce uredialspores that re-infect and spread the disease to other aster and goldenrod plants. Several generations of this stage may be produced during the summer months. In late summer, the telial stage develops on the underside of the alternate host leaves, germinates and produces the basidial stage, which releases basidiospores that are dispersed by the wind and re-infect the needles of the primary pine host, where the fungus then overwinters.

The current year's foliage that is infected late in the fall usually dies and falls from the tree the following summer. In some cases the infected needles will persist on the tree for 3 to 5 years. Infections that result in whole tree mortality are rare because the current year's needles are not affected until late in the fall, after the growing season is completed. Consecutive years of infection, accompanied by an additional stress, such as drought, could result in loss of vigour, growth loss, and whole tree mortality. Less vigorous trees are more susceptible to attack by other insects and diseases, such as bark beetles, Ips sp., and Armillaria root rot, Armillaria ostoyae (Romagn.) Herink.

The result of several consecutive years of defoliation can reduce the merchantability of trees in the Christmas tree and ornamental tree industry. In these cases, an application of a fungicide registered for control of this pine needle rust is recommended. The removal of any alternate host plants, aster, *Aster sp.,* and goldenrod, *Solidago sp*., from within 300 m of pine plantings should also provide some level of control.

Forest Pests and Climate Change

Many of Canada's most notorious forest pests and diseases have become household names in recent years:

- The mountain pine beetle killed off a large portion of British Columbia's Lodgepole Pine trees from the late 1990s through the 2010s and has also spread east, threatening forests in Alberta;
- The emerald ash borer has aggressively attacked eastern Canada's Green Ash trees, killing 99% of Toronto's 850,000+ Ash trees, and is now spreading west to the prairies; and
- Dutch elm disease is slowly but surely stripping cities and towns across eastern and central Canada of their majestic American Elms.

Under normal conditions, forest pests and tree diseases can be natural agents of disturbance that promote forest health and diversity. Unfortunately, our warming climate is tipping the ecological balance and turning them into a worsening threat.

Terry Teegee knows the forests of the west coast intimately, and has seen the astonishing results of insect damage first hand. He is Regional Chief of the British Columbia Assembly of First Nations, Tribal Chief of the Carrier Sekani Tribal Council, and a registered professional forester. Teegee and his community have witnessed sporadic pine beetle outbreaks going back many generations: "our elders talked about it: we'd hear stories about the forest being blood red." Recently however, pine beetle infestations have become massive in scale and in consequences.

The numbers are astounding. During the early 1990s, the beetle destroyed an average of about 45,400 hectares of forest per year; between 2004-2014 the beetle was a hundred times more destructive, killing over 6.4 million hectares per year. Teegee watched this devastation unfold. "We've seen a vast area being infested faster and faster," he says. "The reason for that is climate change."

> "We've seen a vast area being infested faster and faster. The reason for that is climate change."

Teegee says that climate change is leading to warmer winters and summers, and that both of these seasonal changes are contributing to the beetle's massive impact. In the past, he says, "we'd get an early freeze of the land and of the trees in October, and that kept the mountain pine beetle in check. That hasn't occurred often enough since the 80s." Teegee also observes that "with climate change we've seen a lot longer summers, meaning that there are two flights of mountain pine beetle. And that's unprecedented, but has happened more and more in the past twenty years."

The latest pine beetle infestations in BC have largely run their course, primarily because they've killed off most of their preferred tree species. But that doesn't mean the threat is over. Teegee says that "2008 was basically where mountain pine beetle exhausted its use of the pine tree because there were none left, and now it's carrying on into the boreal forest." The beetles have begun to attack jack pine, and forestry researchers have identified climate change as a major risk factor in the likelihood of this destructive species spreading to the vast pine forests of eastern Canada.

Teegee's experience of warming winters and summers leading to a sudden explosion of insect damage is a pattern that has also been seen with other pests across the country. In Toronto, for example, hotter summers allowed ash borer populations to undergo two reproductive cycles rather than just one, doubling their normal rate of infestation. Research has also shown that deep winter cold spells are needed to limit outbreaks of many pests, including ash borers and tent caterpillars. The warming climate thus weakens natural controls on insect pest populations at the same time as it accelerates their rates of growth and reproduction. This combination allows pests to spread much farther and faster than before.

> Deep winter cold spells are needed to limit outbreaks of many pests, including ash borers and tent caterpillars.

Pests attacking new species and making their way into new ecosystems are especially concerning consequences of climate change. Insects can now be found in unexpected places, such as near the tops of mountains or far north, near the tree line. These shifts in habitat and species can happen rapidly and can have devastating consequences when infestations reach forests that haven't evolved to resist these invasive threats.

Trees, of course, have natural defenses that allow them to repel and recover from many kinds of pests and diseases. Unfortunately the same changes in climate that promote the aggressive spread of insects also impact trees' capacities to defend against them. During warmer and drier conditions associated with periods of drought, trees are less resilient to the effect of insects and disease. And when faced with multiple sources of stress – such as an onslaught of insects during a drought – trees are much more likely to die.

Mitigation and Adaptation

Urban and wild forest management strategies can play an important role in reducing the impact of forest pests in the face of climate change.

The city of Winnipeg and the province of Manitoba, for instance, have implemented strategies to reduce the spread of Dutch elm disease, including practices around firewood storage, tree pruning, early detection, and the rapid removal of infected trees. Alberta and Saskatchewan have implemented a variety of strategies targeting the mountain pine beetle, in the hopes of slowing its spread, though they understand it may be difficult to stop it altogether.

Climate projections such as those presented in the Climate Atlas are essential to inform management strategies in both urban and wild settings. Projections show shifts in temperature, which could have implications about where pests might be found in the future, as well as what conditions trees will face as climate change alters the seasonal distribution of warmth, cold, and precipitation.

A key message arising from forestry research is that climate change will likely bring on sudden and unpredictable disturbances. Forest managers will have to cultivate diverse and resilient tree populations and management practices, because climate change means having to be ready for the unexpected.

Ultimately, the most direct way to preserve our forests in the face of these threats is to take prompt and effective action to prevent climate change from accelerating. The less warming that comes to pass, the less stress will be placed on the natural world, and the less our practices will have to adapt to more serious risks.

Teegee says "I think we're in dire straits with the reality of climate change," but notes that "the good thing about human beings is that we're resilient. We'll make a change." For Teegee, responding to climate change means recognizing that "we've lost that real connection with the land" and that fundamentally "we've really got to think about what's important in our lives" in order to live in balance with nature.

Shape-shifting forests: a tale of climate, wildfires and surprising outcomes

The story of North American forests is one of resilience, adaptation, renewal and hope. **January 2024**

If you hike or stroll through one of Canada's northern forests, you might experience a world of towering trees, cool shade filled with the scent of pines and spruces — home to many different plants and animals of all shapes and sizes. But Ellen Whitman, a wildfire research scientist at the Canadian Forest Service, sees things through a different lens. What she notices is a landscape quietly and gradually transforming.

A very different place

Ellen sheds some light on this phenomenon. "Globally, we're noticing a change in forest biomes as they shift away from mature forests toward shrub and herb-dominated ecosystems," she notes. "Head up to the Northwest Territories and you'll find parts of forests that have been utterly transformed. The towering jack pines have surrendered their reign to grasses and stunted aspens, armed with light seeds that can be carried on the wind," she says. The small, forested area that caught her eye back then is "a very different place now."

She first became interested in Wood Buffalo National Park and the southern Northwest Territories in 2014, after a major wildfire season. She worked with two other NRCan scientists, Marc-André Parisien and Dan Thompson, along with wildfire expert Mike Flannigan of Thompson Rivers University. The goal? To compare several paired forested areas with similar climate, pre-fire vegetation and soil conditions. One of each pair had experienced two fires in a short time, also known as short interval reburns. The other had a longer period of regrowth between fires. The differences were significant. The scientists published their findings in the international science journal *Nature*, noting that, in places with short interval reburns, open stands of aspens dominated in place of dense conifer forests, and the understorey vegetation beneath the trees consisted of sparse shrubs and grasses.

More recently, Ellen and a team of researchers studied wildfire and climate trends in northwestern boreal forests. Looking mainly at Alberta, using historical data from 1970 to 2019 their research findings were notable: the annual number of large wildfires and the number of extreme short interval reburns both increased as the climate grew warmer and drier. This research supports the growing body of evidence that increasing fire activity affects not just the local environment, but the overall ability of the forest to regenerate.

This transformation is most evident in western and northern parts of Canada and in the southwestern United States. In some reburned areas, you can still spot trees, but they're less dominant than in neighboring forests, creating a more open, almost savanna-like appearance. Savannas, which are common in Africa and Australia, have a drier climate characterized by rolling grasslands scattered with shrubs, trees and occasional patches of forest.

Key players: wildfires and climate

So, what exactly is happening? Ellen breaks it down: "Climate change and increasingly severe wildfires are key players in this transformation. While they might not be the sole driver, they're certainly capable of leading to this shift."

Climate stresses come in the form of droughts, floods and warmer than usual weather patterns. When it's drier than usual, wildfires tend to happen more often and become more severe.

What's more, areas recently burned by fires lack nearby sources of seeds for trees to regrow. Sometimes it's because the burned patch is so vast that the seeds would have a long way to travel. In other cases, it's because the seed bank, which refers to the dormant seeds that normally exist in the soil, was destroyed in the fire. And even if a tree seedling manages to take root, it might struggle with unusually hot and dry weather. Simply put, they may not survive in today's climate, which is different than it was when forests first took root decades and centuries ago.

Long term shifts

“There are ongoing long-term shifts away from old-growth tree species like spruce, toward shorter-lived ones like pine or aspen,” Ellen points out.

However, none of this is new, exactly. The balance of tree species in North American boreal forests have shifted many times since the last major ice age 11,700 years ago, as temperatures and wildfire patterns change. Wildfires are a natural phenomenon and can help forests thrive. “Fires can spark overdue regeneration, particularly where they’ve been artificially suppressed,” she points out. “Forests aren’t inherently superior to other ecosystems, and sometimes a bit of rebalancing is needed where they have invaded, such as in some former grasslands.”

Resilience: a race to keep up?

Forests and wildlife can be resilient. Trees have long been adapted to wildfires and changing conditions, while animals can find safer havens. Mature trees have great inertia, which means even if the climate changes fast, they will most likely persist. But Ellen notices a crucial shift. The speed of change is picking up and ecosystems have less time to recover between wildfires. She explains: “there’s some evidence they’re starting to lose the ‘safe operating space’ they need to be resilient to disturbances.”

The story gets more complex when the wider ecological impact is considered. Wildfires create a ripple effect. “In North America, the loss of large, old-growth trees could have consequences for creatures uniquely developed to thrive in mature forests,” notes Ellen. These include specialist species like martens and fishers, members of the weasel family that make their dens inside tree hollows, for example. Beyond that, wildfires impact human social and economic values by reducing carbon storage, altering water dynamics and even affecting how much sunlight the planet can absorb.

Hope, renewal, adaptation

The story of forests is not just a tale of loss, but one of renewal and adaptation. “We can expect most of our burned area to recover fine,” says Ellen. The reality is forests evolve. They may not always resemble the forests we’re used to seeing or respond how we expected. But different combinations of native and non-native plants are sure to fill the voids.

Ellen’s research serves as a reminder that our own actions have far-reaching impacts on the ecosystems we share. There are ways to adapt and mitigate these changes. Land managers can use strategies like fuel treatments and prescribed burning to lessen the severity and spread of wildfires. On a personal level, we can contribute by reducing energy use and cutting down on greenhouse gas emissions. The key is to find a balance that lets nature thrive, while providing the essential ecosystem services we rely on. There is still much work to do be done as Ellen and other wildfire scientists continue their quest to understand the drivers and consequences of changes unfolding in our forests.

Government of Canada Gouvernement du Canada

Drought

Drought is expected to become more frequent and severe in parts of Canada.

Drought is defined as a shortage of precipitation over an extended period, usually a season or more, resulting in insufficient water availability that adversely impacts vegetation, animals and people.

Areas of western Canada are already experiencing frequent and severe droughts. Scientists expect new areas across the country to be affected and drought to become even more frequent and severe. The consequences could have far-reaching impacts on Canada's forests.

Why knowing about drought is important

Drought threatens Canada's forests by limiting the available water that trees need to survive. When water is limited, trees become weakened. Weakened trees cannot grow at a normal rate, may not be able to regenerate, or could die. It is also difficult for trees to defend themselves against insects and diseases as they become stressed. Similarly, during wildland fires, weakened trees are at higher risk. For the Canadian forest industry, these issues directly affect the available wood supply.

Canadian Forest Service researchers have developed a measure of drought called the Climate Moisture Index (CMI). CMI is calculated as the difference between the annual amount of precipitation and the expected amount of water that evaporates each year and can be used to indicate the amount of moisture available in a given year.

Tracking drought helps forest managers anticipate and manage for a changing climate. For example, the SeedWhere program can be used to predict where similar climates will be located under a range of future climate scenarios and timeframes. Forest managers can use this tool to select the planting stock (e.g., species and provenance) that is best adapted to predicted drought conditions.

What has changed

Several regions of Canada experienced substantial droughts between 1951 and 2010, but with significant variability between decades. However, during the first decade of the 21st century (2001–2010), exceptional droughts were observed across the country – for example, the 2001–2002 drought in the Prairies (Figures 1 and 2), caused abnormally high aspen mortality (see Tree mortality).

Similar trends have been reported in forests around the world. With droughts expected to become more frequent and severe in most of Canada's forests, there are growing concerns about the impact of drought on forest distribution, tree health and regeneration success.

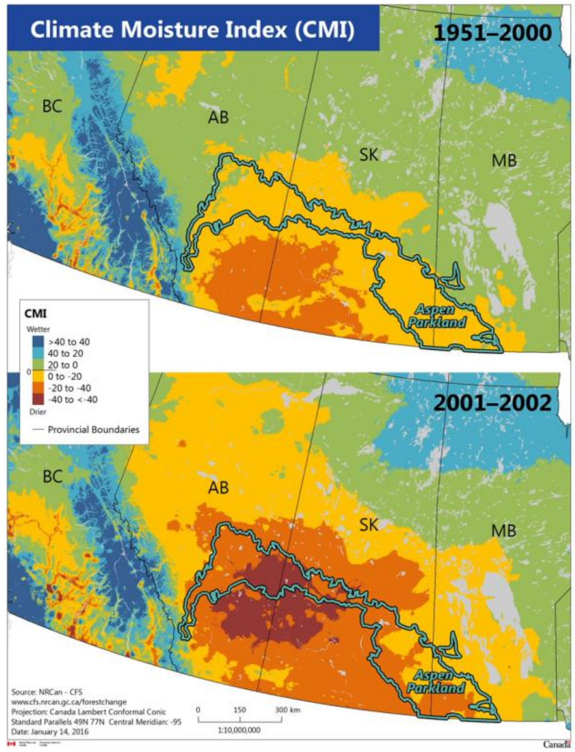


Figure 1 *– Mean Climate Moisture Index (CMI) for 1951–2000 and the 2001–2002 drought in the aspen parkland*

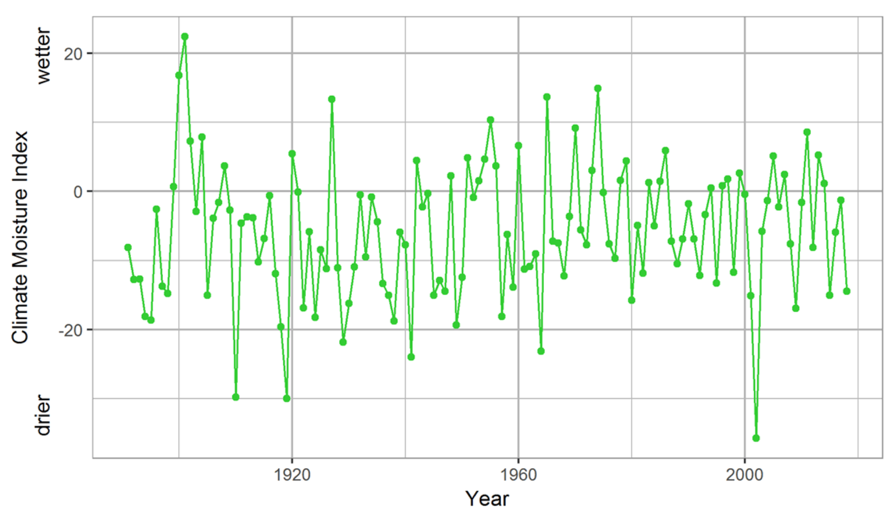


Figure 2 *– Long-term changes in the Climate Moisture Index (CMI) in the aspen parkland*

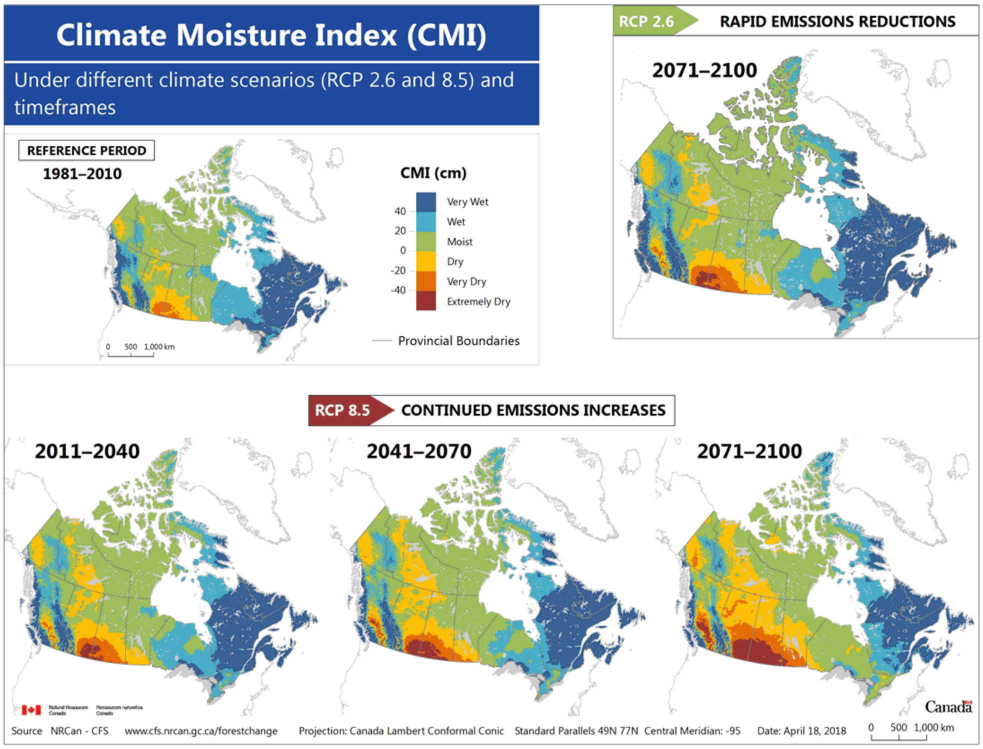


***Figure 3** – Reference period (1981–2010) and projected mean annual Climate Moisture Index (CMI) for the short- (2011–2040), medium- (2041–2070), and long-term (2071–2100) under the Representative Concentration Pathway (RCP)*

The outlook

Increases in drought could have far-reaching impacts on Canada's forests, both directly, through impacts on tree growth and survival, and indirectly, through drought-related increases in the frequency of disturbances such as fire and insect outbreaks.

Drought is expected to become more frequent in several areas that are already relatively dry, such as the southern interior of British Columbia and the Prairie provinces (Figure 3).

Some areas that have not previously experienced frequent drought are also expected to become drier in the future. The current prairie conditions are expected to spread northwards into areas of the southern boreal forest. Such a shift would lead to significant changes in forest ecosystems.

Moist regions, such as the Pacific and Atlantic coastal areas, are expected to be less affected, with limited changes in annual climate moisture index (CMI) values over the next 100 years. However, these moist areas could become more prone to the impacts of seasonal droughts even if the annual CMI indices remain positive.

2025 NCF-Envirothon Alberta

Current Issue Part A Study Resources

Key Topic #3: Inherent Rights of Indigenous Peoples to Land Stewardship

11. Identify differences between Indigenous worldviews and Western worldviews regarding land stewardship.
12. Identify and summarize the core themes within the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).
13. Explain why some countries did not sign on to the original adoption of UNDRIP in 2007 and why some of those countries joined UNDRIP later.
14. Describe how land-based learning and Traditional Knowledge systems can contribute to improved land use, forest management, and mitigation strategies.
15. Describe how Indigenous stewardship and traditional ecological knowledge could help meet global conservation goals.

Study Resources

Resource Title	Source	Located on
Medicine Wheel for the Planet: A Journey Toward Personal and Ecological Healing	*Dr. Jennifer Grenz, 2024*	Pages 55-56
Integrative Science and Two-Eyed Seeing: Enriching the Discussion Framework for Healthy Communities	*Bartlett et al., 2014*	Pages 57-60
United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) for Indigenous Adolescents	*United Nations Children's Fund, 2013*	Pages 61-69
A Celebration of Traditional North American Knowledge: Indigenous Ingenuity (Chapter 11 Traditional Ecological Knowledge and Our Sustainable Future)	*Deidre Havrelock & Edward Kay, 2023*	Pages 70-76
VIDEO: What Is Indigenous Land Management? *(4 minutes)*	*SCOPE TV, 2020*	Page 77
Indigenous Knowledges and Climate Change: Indigenous ways of knowing are shaping climate solutions	*Climate Atlas of Canada, 2019*	Page 78
Native Science: Natural Laws of Interdependence	*Gregory Cajete, 2000*	Pages 79-82
Indigenous conservation	*Nature Conservancy Canada, 2024*	Pages 83-84

Study Resources begin on the next page!

Medicine Wheel for the Planet: A Journey Toward Personal and Ecological Healing

Excerpt From Chapter 2 - *The Missing Puzzle Piece: The Indigenous Worldview*

"Western science has been the cornerstone of my own work; it has served all of us well, and will continue to do so. What I have come to realize is that it is not providing us with the whole picture. Or rather, it may not be providing us with what we need for "big picture" problem solving. Ecology is an incredibly complicated field of study that, like many areas of science, has a myriad of focuses, all locked in dogmatic encamped positions. The stakes are too high for us to continue placing our eggs all in one basket. The presence of Indigenous Peoples on Turtle Island (North America) for thousands of years, surviving through changes in climate and speciation, and through the attempted termination of our Peoples by colonial governments, is a testament to our qualifications to lead this important work. Adaptation is who we are as a people. We are the adaptation experts. So why not turn to us at this time of ecological crisis?

Many are starting to.

Those who previously dismissed Indigenous Knowledges are now actively seeking them. Many settler scientists and policy-makers are staring at the puzzle of planetary health and realizing that their lack of progress could be attributed to missing pieces vital to understanding the whole picture. I wish I could find myself freely and fully embracing these new-found relationships. At first, I did. This is what I had been longing for – scientists valuing the knowledges of the Peoples of the land. What I didn't anticipate, perhaps foolishly so, was that just as I experienced with my own land-based knowledges as a practitioner, settler researchers only want to take what we have to offer without understanding exactly what it is they are taking and who they may be leaving behind. Our Indigenous Knowledges are being sought with the detachment of a consumer coveting the latest fad. Our Indigenous Knowledges are not fads. And there is absolutely nothing detached about them as they are inherently a part of us. We are our knowledges. We are the land.

It is our worldview that makes us different, and this truth often goes unacknowledged. Or perhaps the problem is a complete lack of recognition that we see the world differently at all. This awareness goes far deeper than simply learning some Indigenous knowledge. The trend to incorporate our traditional knowledges into ecology often limits our contributions by treating us as historians and colonizes our knowledges through power imbalances and/or attempts to simply add them on to colonial ways of knowing. It is not okay, and it's plain to see, it is not effective. Traditional ecological knowledge is knowledge shared by Indigenous knowledge keepers. It is sacred. Information acquired from our deep relationship with the places we are from. Intergenerational awareness, passed through lineages about plants, animals, places, and how we care for them. Knowledges acquired in ways beyond that of the physical. Knowledges continuing to be practised and gained, building upon our ancestral understanding. Knowledges generated and their use guided by community values and needs.

There is great benefit to learning and applying our traditional- ecological knowledge in a settler's world. However, the full benefit will not be realized without a broader understanding of our relational worldview. To use only fragmented pieces of our knowledge is to admire a tree without admiring its roots. My love of the standing people (trees) is not only in admiration of their immense beauty, which I can see, but in their foundation, which I cannot. Their beginning as a seed, their extensive roots, the community they are part of beneath the soil that nurtures and stewards them so that they can then make their majestic appearance on the landscape, their deep connection with Mother Earth, their continued connection and contributions to their communities as they grow. Understanding and acknowledging this is to know the power of the standing people.

Chief Dan George offered his wisdom when he spoke about the integration of Indigenous children into the public school system. I think it speaks to the integration of Indigenous knowledge into any colonial structure: "Can we talk of integration until there is integration of hearts and minds? Unless you have this, you have only a physical presence, and the walls between us are as high as the mountain range."

To know our worldview is to know our hearts and minds. To know only our traditional ecological knowledge is to have only a superficial relationship, leaving our knowledges vulnerable to misuse and misunderstanding. You must know and appreciate our roots to understand our real power, our worldview. The headwaters from which our knowledge flows. Only then can you see the world as we do. And by doing this, as Jane Goodall said in her book *Reason for Hope: A Spiritual Journey*, you will be able to "make the old new again."

Is there any better remedy for an old problem than seeing it from a fresh perspective? This is the puzzle piece missing to heal our planet. While the world begins to turn to Indigenous Peoples for solutions to a colonial-caused climate crisis, fragmented bits of our knowledges are being used to fill in perceived gaps of a pre-existing puzzle picture. This "inclusion" is wrong. There is nothing about the overall picture that is just about right when the image itself is fundamentally incompatible with our knowledges. The missing puzzle piece is, in fact, the missing lens of a relational, Indigenous worldview. A lens that we need to transform how we see our Earth Mother and all relations and relationships upon it. A lens that stops the chasing of tails and illuminates our collective path forward. A lens that catalyzes new paths of inquiry and alternate understandings.

Imagine yourself putting on glasses. Your first look through the lenses shows you the world as a web of connections that span both space and time. You no longer see things or people or animals as individuals. Instead, it's palpably evident how each of these things and beings is connected to all the others and the environment. You look down at yourself and see your own connections. Your feet to the Earth. Your breath to the trees. Your heart to your grandparents and great-grandparents. You become overwhelmed by the intricacy and abundance of these connections. You are surprised by the relationships you have that you never knew you did. What else do you see? Perhaps you can see for the first time that *you are not outside the natural environment but very much a part of it*. You are in relation with the beings upon our Earth Mother. This is the relational, Indigenous worldview."

Our tools: patterns … seeing "big pictures" and using "organics"

In contemporary Canada, the words "healing" and "reconciliation" are words that frequently travel together in discussions configured by Aboriginal perspectives and contexts. Elder Murdena offers a key insight with respect to healing; Willie Ermine offers a key insight with respect to reconciliation. Integrative Science has adopted and adapted both. For Murdena's insight, we realize that participants in the co-learning journey need to be able to place the actions, values, and knowledges of their own culture out in front of themselves like an object, to take ownership over them, and to be able to say "that's me". Furthermore, as guided by Two-Eyed Seeing, we need these "objects" for both the Indigenous and Western worldviews. In this way, participants can learn both "that's me" and "that's you" to foster working together. Thus, we have developed simple responses (in text and visual form) to four "big picture" philosophical questions. These depictions enable us to put these philosophical considerations for our knowledge systems out in front of ourselves like an object (tool). In the Spirit of the East, we believe such can help encourage "our place of beginnings" towards the thought frameworks that Ermine's (2007) insight indicates are required to reconcile the solitudes of Indigenous and Western cultures. That is, we suggest herein that the first phase of entering ethical space for the purpose of reconciling our scientific knowledges and ways of knowing – the ethical space conceived within Ermine's insight – includes learning to appropriately, correctly, and respectfully acknowledge the "that's me" and the "that's you" of our worldviews, as they configure our sciences. Furthermore, in the overall Integrative Science co-learning journey we talk about "growing" rather than "going" forward and knowledge "gardening" more than knowledge translation or transfer (Bartlett 2011). In the words of journey participant Marilyn Iwama: "We are learning to weave back and forth between our knowledges, our worldviews and our stories. We are learning to navigate that weaving by recognizing patterns that help us do that. Call those patterns knowledge orientations. Call them maps – maps for the garden. We have learned the importance of making our knowledges, our stories, visual."

In regards to this desire to "make our knowledges, our stories, visual", we have developed four "big picture" understandings (which are patterns in their own right) that can be put, as "objects" of ourselves, in front of us, congruent with Murdena's explanation of the healing tense. These are explained below. In sharing them herein, we reiterate that our approach is intended to help orient within "our place of beginnings" and we also reiterate our concurrence with Watson and Huntington (2008, p. 276) that the "intellectual traditions we assemble, 'Western' and 'Indigenous,' are not entirely separable into our individual selves, who are instead a 'multiplicity of multiplicities.'"

<u>1. Our World</u>: This relates to *<u>ontologies</u>*, as we share a desire for our knowledges to have an overarching understanding of "how our world is", albeit with differences as to what we deem these to be. The "big pattern" question here is: What do we believe the natural world to be?

- A possible response from within Indigenous science is: beings ... interconnective and animate … spirit + energy + matter …with constant change (flux) within balance and wholeness.
- A possible response from within Western science is: objects ... comprised of parts and wholes characterized by systems and emergences … energy + matter … with evolution.
- A visual that complements these words is provided in Fig. 7.

2. Our Key Concepts and Actions: This relates to *epistemologies*, as we share a desire for our knowledges to observe key values albeit with differences as to what we deem these to be. The "big pattern" question here is: What do we value as "ways of coming to know" the natural world, i.e. what are our key concepts and actions?

- A possible response from within Indigenous science is: respect, relationship, reverence, reciprocity, ritual (ceremony), repetition, responsibility (*after* Archibald, J., 2001, Editorial: sharing Aboriginal knowledge and Aboriginal ways of knowing. Canadian Journal of Native Education, 25(1), 1-5).
- A possible response from within Western science is: hypothesis (making and testing), data collection, data analysis, model, and theory construction.
- A visual that complements these words is provided in Fig. 8.

3. Our Languages and Methodologies: We can focus on core concepts for the *languages and methodologies* that structure our knowledges, as we share a tendency to want such albeit with differences as to what we deem these to be. The "big pattern" question here is: What can remind us of the complexity within our ways of knowing?

- A possible response from within Indigenous science is: ***weaving*** of patterns within nature's patterns via creative relationships and reciprocities among ***love, land, and life (vigour)*** that are constantly reinforced and nourished by ***Aboriginal languages.***
- A possible response from within Western science is: ***un-weaving*** of nature's patterns (especially via ***analytic logic and the use of instruments***) to cognitively reconstruct them, especially using ***mathematical language (rigour)*** and computer models.
- A visual that complements these words is provided in Fig. 9.

4. Our Overall Knowledge Objectives: We can focus on *objectives*, as we share a desire for our knowledges to have overall purpose albeit with differences as to what we deem these to be. The "big pattern" question here is: What overall goals do we have for our ways of knowing?

- A possible response from within the Indigenous sciences is: collective, living knowledge to enable nourishment of one's journey within expanding sense of "place, emergence and participation" for collective consciousness and interconnectiveness … towards resonance of understanding within environment … towards long-term sustainability for the people and natural environment (tested and found to work by the vigourous challenges of survival over millennia).
- A possible response from within the Western sciences is: dynamic, testable, published knowledge independent of personal experience that can enable prediction and control (and "progress") … towards construction of understanding of environment … towards eventual understanding of how the cosmos works (tested and found to work by the rigourous challenges of experimental design).
- A visual that complements these words is provided in Fig. 10.

Fig. 8. Two Eyed Seeing – Big Pic #2, Epistemologies, computer graphic by Integrative Science

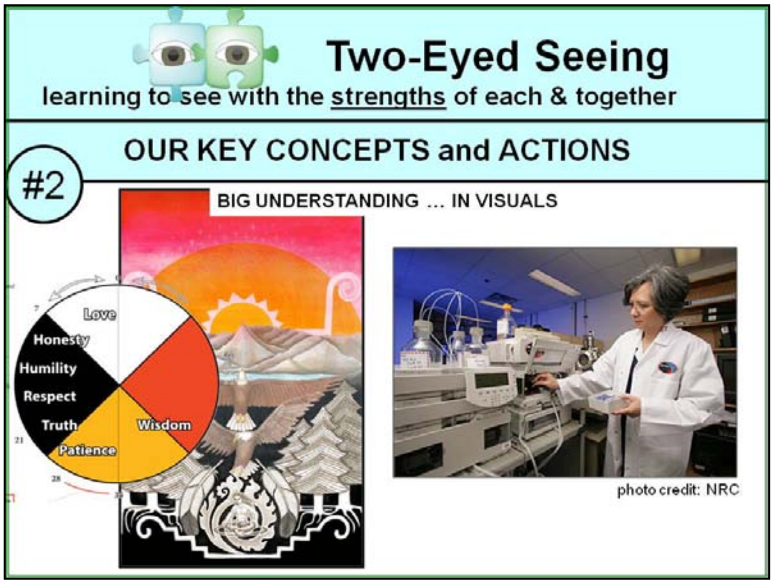


Fig. 9. Two-Eyed Seeing – Big Pic #3, Methodologies, computer graphic by Integrative Science

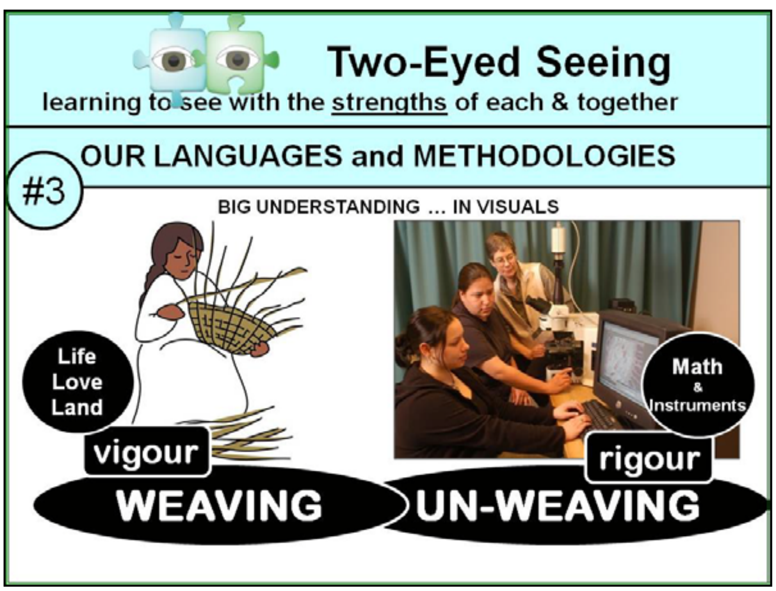
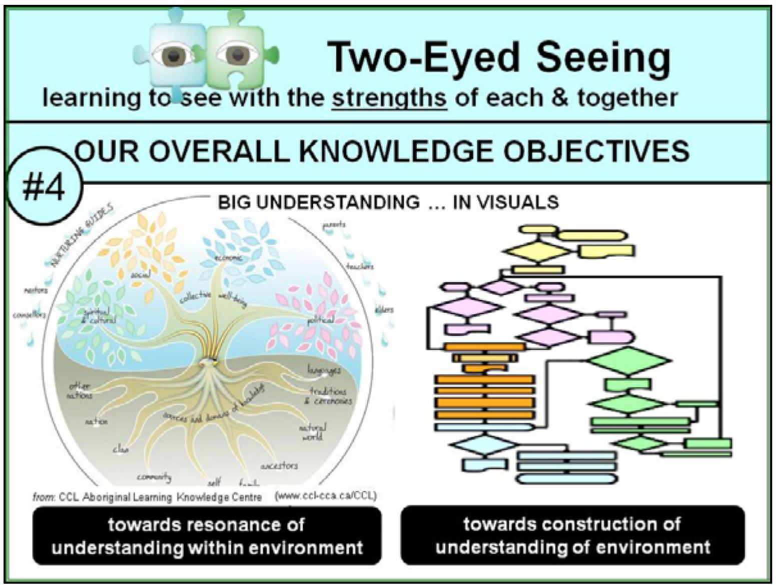
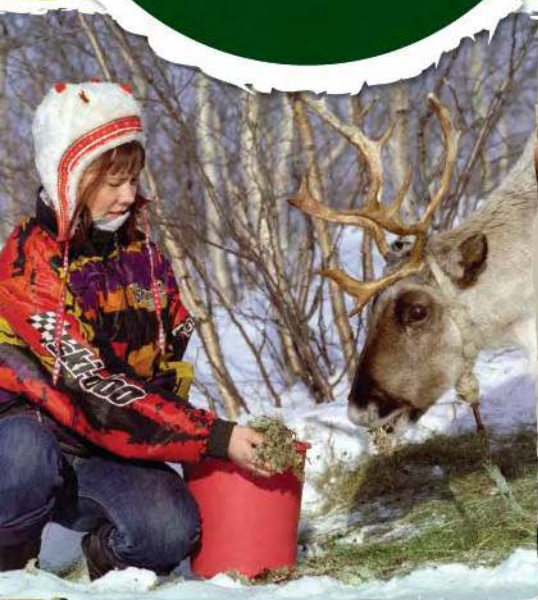


Fig. 10. Two-Eyed Seeing – Big Pic #4, Knowledge Objectives, computer graphic by Integrative Science, including part of the "First Nations Holistic Lifelong Learning Model" from the Canadian Council on Learning, Aboriginal Learning Knowledge Centre (available at: http://www.ccl-cca/CCL).



Know Your Rights!

United Nations Declaration on the Rights of Indigenous Peoples
for indigenous adolescents






Global Indigenous YOUTH caucus

Secretariat of the Permanent Forum on Indigenous Issues

unicef

About UNDRIP

UNDRIP is a declaration containing an agreement among governments on how indigenous peoples should be treated. A group called the Working Group on Indigenous Populations began drafting it in 1985, and it took over 20 years until the Declaration was adopted – or formally accepted – by the United Nations General Assembly, on 13 September 2007. It took so long because it was difficult for some governments to agree on some parts of its content.

At the time of the vote, Australia, Canada, New Zealand and the United States of America voted against the Declaration and 11 countries abstained (decided not to vote). Since then, Australia, Canada, New Zealand and the United States have decided to support the Declaration. It is due to indigenous peoples' advocacy for their rights in their countries that this change has come about.

UNDRIP sets out how governments should respect the human rights of indigenous peoples. It is also an important guide for the proper implementation (or fulfilment) of other human rights agreements or conventions affecting indigenous peoples, such as ILO Convention 169, the Convention on the Rights of the Child and the Convention on the Elimination of All Forms of Discrimination against Women. You can learn more about these documents at the end of this publication in the 'Learn More' section.

UNDRIP consists of **46 articles** that describe specific rights and actions that governments must take to protect these rights. All the articles are very important, linked to each other and form a frame for governments to make sure that the rights of indigenous peoples are protected.

The next section of this publication is a summary of the 46 articles of the Declaration.

United Nations Declaration on the Rights of Indigenous Peoples – in brief

PART 1: IMPORTANT THEMES IN THE DECLARATION

ARTICLES 1–6

The main themes are: (i) the right to self-determination; (ii) the right to be recognized as distinct peoples; (iii) the right to free, prior and informed consent; and (iv) the right to be free of discrimination. These themes are important to keep in mind as you read the Declaration.

The right to self-determination

The right of indigenous peoples to self-determination is fundamental to UNDRIP. While there are different interpretations, self-determination generally means that indigenous peoples have the right to decide what is best for them and their communities. For example, they can make their own decisions on issues that concern them and carry them out in the way that will be meaningful to indigenous peoples, while being respectful of the human rights of their community members (including children) and other peoples as well.

Indigenous peoples have the right to be independent and free. They have the right to be citizens of the country they live in and at the same time to be members of their indigenous communities. As citizens, they have the right to choose to build relationships with other peoples and to take active roles in the country in which they are living.

The right to cultural identity

Indigenous peoples are equal to all other peoples, but they also have the right to be different, for example in the way they dress, the food they eat and in the language they speak.

The right to free, prior and informed consent

Free, prior and informed consent means that indigenous peoples have the right to be consulted and make decisions on any matter that may affect their rights freely, without pressure, having all the information and before anything happens.

Protection from discrimination

The right to be free from discrimination means that governments must ensure that indigenous peoples and individuals are treated the same way as other people, regardless of sex, disability or religion.

PART 2: LIFE, LIBERTY, CULTURE AND SECURITY

ARTICLES 7–10

Article 7: Right to life, liberty and security

Every indigenous person is born with the right to life, to live freely (liberty) and to be safe and secure. Indigenous peoples as a group have the right to live freely, be safe and secure, and not exposed to violence. For example, the children of an indigenous group may not be taken away from their family by force.

Article 8: Assimilation or destruction of culture

Indigenous peoples and individuals have the right not to be assimilated – meaning, they have the right not to be forced to take up someone else's culture and way of life, and for their culture not to be destroyed.

Article 9: Belonging to an indigenous community or nation

Indigenous peoples and individuals have the right to belong to indigenous communities or nations. They may not be discriminated against because of their belonging to (being a member of) an indigenous community or nation.

Article 10: Forceful removal and relocation

Indigenous peoples may not be removed or relocated by force from their lands. If they are relocated, then only with their free, prior and informed consent, meaning that they have the right to make decisions on relocation freely, without pressure, having all the information and before anything happens. They also have the right to compensation for their relocation, and the option to return to their land, if possible.

PART 3: CULTURE, RELIGION AND LANGUAGE

ARTICLES 11–13

Article 11: Right to culture

Indigenous peoples have the right to practice and revive their culture and traditions.

Governments will work with indigenous peoples to ensure indigenous property rights to their cultures, knowledge, spiritual and religious traditions are respected, and to address cases where these have been used without free, prior and informed consent.

Article 12: Right to spiritual and religious traditions and customs

Indigenous peoples have the right to practice their spiritual and religious traditions. Governments will, with indigenous peoples, ensure that indigenous peoples are free to practice, protect and revive and keep alive their cultures, spiritual, religious and knowledge traditions.

Article 13: Right to know and use language, histories and oral traditions

Indigenous peoples have the right to recover, use and pass on to future generations their histories and languages, oral traditions, writing systems and literature and to use their own names for communities, places and people.

Indigenous peoples also have the right to be heard and understood in their own languages in different settings as for example in court, through an interpreter.

PART 4: EDUCATION, MEDIA AND EMPLOYMENT

Article 14: Establishment of educational systems and access to culturally sensitive education

Indigenous peoples have the right to set up and manage their own schools and education systems. Indigenous individuals, particularly children, have the same right as everyone else to go to school and cannot be left out because they are indigenous. This means that governments must ensure that indigenous peoples – particularly children – living in, or outside of, their communities get the same benefit from the education system as others in ways that respect indigenous cultures, languages and rights.

Article 15: Accurate reflection of indigenous cultures in education

Indigenous peoples have the right to their cultures and traditions being correctly reflected in education and public information. Governments will work with indigenous peoples to educate non-indigenous peoples in ways that respect indigenous peoples' rights and promote a harmonious society.

Article 16: Media

Indigenous peoples have the right to create their own media (i.e., radio, TV and newspapers) in their own language and to access non-indigenous media. Government-owned media has a duty to reflect indigenous cultural diversity. Governments will also encourage privately owned media to reflect indigenous cultural diversity.

Article 17: Employment

Indigenous individuals and peoples have the right to be treated fairly and not be discriminated against in all matters relating to work and employment. Indigenous children should be especially protected from work that harms them, and that is bad for their health and education. Governments will work together with indigenous peoples to protect children from this kind of mistreatment.

PART 5: PARTICIPATION AND DEVELOPMENT

Article 18: Participation in decision-making

Indigenous peoples have the right to take part in decision-making in all matters affecting them. This includes the rights of indigenous peoples to select who represents them and to have indigenous decision-making processes respected.

Article 19: Free, prior and informed consent for laws and policies

Governments must seek indigenous peoples' views and opinions and work together with them through their chosen representatives in order to gain their free, prior and informed consent before laws are passed or policies or programs are put in place that will affect indigenous peoples.

Article 20: Subsistence and development

Indigenous peoples have the right to their own political, economic and social systems, and to follow their own traditional ways of growing food and other activities that help them in their daily living. They have the right to seek justice where this right is taken away.

Article 21: Economic and social well-being

Indigenous peoples have the right to improve their economic and social well-being, and governments will take action to help indigenous peoples do so, with particular attention to the rights of indigenous elders, women, youth, children and persons with disabilities.

Article 22: Indigenous elders, women, youth, children and persons with disabilities

Governments, with proper consultation with indigenous peoples, will ensure indigenous elders, women, youth, children and persons with disabilities have their rights respected. Governments will ensure that indigenous women and children are free from all forms of violence and discrimination.

Article 23: Priorities and strategies for development

Indigenous peoples have the right to set their own priorities and directions for development of their communities. Governments will support indigenous peoples to run their own organizations and services, and in deciding for themselves issues affecting their health, housing and other matters.

Article 24: Right to health

Indigenous peoples have the right to use traditional medicines and health practices that they find suitable. They have the right to access health care and social services (i.e., get prenatal care, go to the doctor or social worker or get help with food and housing) without discrimination. Indigenous individuals have the same right to health as everyone else, and governments will take the necessary steps to realize this right.

PART 6: LAND AND RESOURCES

Article 25: Spiritual relationship with traditional land and resources

Indigenous peoples have the right to their special and important spiritual relationship with their lands, waters and resources and to pass these rights to future generations.

Article 26: Right to own, use, develop and control traditional land and resources

Indigenous peoples have the right to own and develop their land and resources. Governments will legally recognize and protect these lands and resources, and will take action to respect indigenous peoples' laws and traditions in non-indigenous legal systems.

Article 27: Indigenous laws and traditions on land and resources

Governments will respect and recognize indigenous peoples' laws and traditions about land and resources and take action to have these respected in non-indigenous legal systems. Indigenous peoples have the right to get help from governments to protect their lands.

Article 28: Rights when lands and resources are wrongly taken away

Indigenous peoples have the right to get back or to be compensated when their lands, territories or resources have been wrongly taken away, occupied, used or damaged without their free, prior and informed consent.

Article 29: Conservation and protection of the environment, lands and resources

Indigenous peoples have the right to their environment being protected. Governments will respect and protect the right of indigenous peoples to develop and protect their lands, water bodies and other natural resources. No dangerous materials should be placed on indigenous peoples' lands without their free, prior and informed consent. Governments will protect the health of indigenous peoples who are affected by dangerous materials placed on their land.

Article 30: Military activities

Military activities will not take place on indigenous lands without indigenous peoples' free, prior and informed consent, unless it is necessary for the well-being of all of society and it takes place through consultations with indigenous peoples' representatives.

Article 31: Cultural and intellectual property

Indigenous peoples have the right to their cultural and intellectual property, and governments will recognize and protect this right. Examples of cultural and intellectual property are stories, songs, dance, designs, art, ceremonies, sacred sites and remains of ancestors. Intellectual property includes things like indigenous peoples' knowledge of their laws, spiritual, social, health, education, economic, and environmental beliefs, systems and practices.

Article 32: Land and resource development

Indigenous peoples have the right to decide how they wish to develop their lands and resources. Governments must respect and protect these rights. Indigenous peoples' free, prior and informed consent must be obtained when any decisions are made that may affect the rights to their lands, resources or waters.

PART 7: SELF-GOVERNMENT AND INDIGENOUS LAWS

ARTICLES 33–37

Article 33: Identity, membership and citizenship

Indigenous peoples have the right to decide what their identity or membership is. They also have the right to decide who their members are according to their own customs and traditions. Indigenous peoples have a right to be citizens of the country in which they live.

Article 34: Distinctive institutional structures and customs

Indigenous peoples have the right to their own structures, traditions and laws in ways that ensure that indigenous peoples enjoy the highest standards of human rights.

Article 35: Individual responsibilities

Indigenous peoples have the right to decide what responsibilities individuals in their community have towards the community as a whole.

Article 36: Right to maintain and develop contacts, relations and cooperation

Indigenous peoples living in different countries have the right to be in contact and carry out activities with each other. Governments, in consultation with indigenous peoples, will support indigenous peoples in exercising this right.

Article 37: Recognition, observance and enforcement of treaties and agreements

Governments will respect all the agreements they have made with indigenous peoples. The Declaration in no way reduces the rights of indigenous peoples in other agreements previously made by indigenous peoples with governments.

PART 8: IMPLEMENTATION

ARTICLES 38–42

These articles explain how governments and the United Nations should work together – in consultation with indigenous peoples – to make sure the rights of all indigenous peoples are protected. Together with indigenous peoples, governments should create laws, shape policies and provide funds to implement the Declaration.

Indigenous peoples have the right to have access to support from the international community in carrying out activities that will lead to this reality. Where their rights are violated, indigenous peoples have the right to compensation.

Indigenous peoples also have a right to access fair conflict resolution with governments or other parties when their individual and collective rights are not being honoured. These conflict resolution processes should respect indigenous rights, customs, and legal systems and promote the highest standards of human rights.

Governments and the United Nations, including the United Nations Permanent Forum on Indigenous Issues, should work with indigenous peoples to make sure the rights of all indigenous peoples as provided by the Declaration are realized and protected.

PART 9: UNDERSTANDING THE DECLARATION

ARTICLES 43–46

These articles explain how to understand the Declaration. Governments can do more but not less than what is written in the Declaration. The Declaration also applies to both males and females.

The Declaration contains both rights and responsibilities of indigenous peoples. Care must be taken to ensure that the rights are not used to deliberately disturb the unity, peace and security of a country.

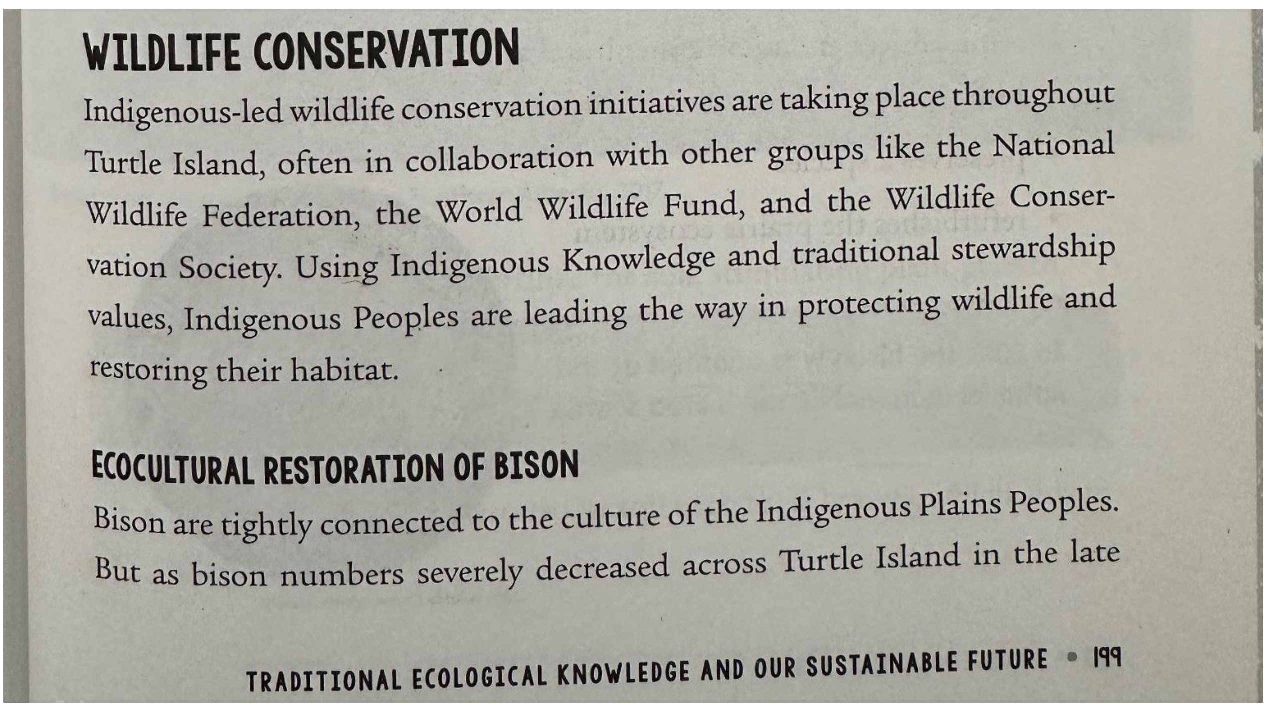
A Celebration of Traditional North American Knowledge: Indigenous Ingenuity

Chapter 11 ***Traditional Ecological Knowledge and our Sustainable Future***

"Western science is often referred to as an objective form of knowledge, meaning it investigates a problem without personal feelings influencing the outcome. Traditional Ecological Knowledge is more profound than this since those who use this scientific approach are conscious of their living and breathing within the same ecosystem that is being investigated and used. In other words, Traditional Ecological Knowledge carries a deep emotional connection to what is being studied, developed, or consumed – land, animal, or water. This interconnected relationship produces a great sense of responsibility within Indigenous Peoples, obligating them to choose technologies and practices that are beneficial to the well-being of all their relations.

Choosing a relationship-based approach to STEM is a sophisticated worldview, one that Indigenous Peoples have favoured and followed for thousands of years. This scientific philosophy involves not only investigation and experimentation, but empathy, patience, respect, and even love – love for Mother Earth. Today, scientists and researchers are looking to Indigenous Elders, hunters, gatherers, and Knowledge Keepers for ways to achieve ecological sustainability, strengthen food systems, improve environmental protections, and counteract climate change. Likewise, Indigenous scientists and Indigenous researchers are educating us all on the benefits of Traditional Ecological Knowledge. We can choose a path that continually consumes Mother Earth, or we can choose a path that seeks understanding, restoration, and balance. There is much to learn from traditional societies who have lived within an ecosystem gathering ecological knowledge for thousands of years.

Like people, ecosystems are resilient; with support, they can recover from years of exploitation."



WILDLIFE CONSERVATION

Indigenous-led wildlife conservation initiatives are taking place throughout Turtle Island, often in collaboration with other groups like the National Wildlife Federation, the World Wildlife Fund, and the Wildlife Conservation Society. Using Indigenous Knowledge and traditional stewardship values, Indigenous Peoples are leading the way in protecting wildlife and restoring their habitat.

ECOCULTURAL RESTORATION OF BISON

Bison are tightly connected to the culture of the Indigenous Plains Peoples. But as bison numbers severely decreased across Turtle Island in the late

TRADITIONAL ECOLOGICAL KNOWLEDGE AND OUR SUSTAINABLE FUTURE • 199

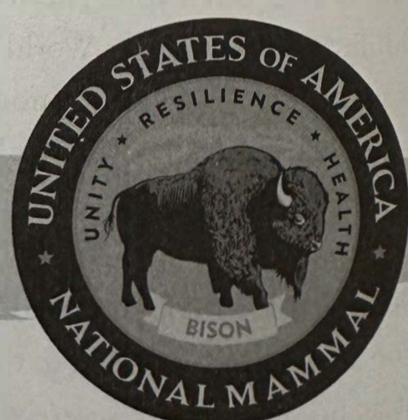
1800s while Indigenous Peoples were forced onto reservations, cattle quickly repopulated the Great Plains. The loss of bison resulted in Indigenous food insecurity, ecosystem deterioration, and a loss of Great Plains culture. Today, numerous Indigenous nations across Canada and the United States are revitalizing their territories by bringing bison home.

According to the InterTribal Buffalo Council, tribes in the United States manage more than twenty thousand bison across nineteen states. For instance, the Sugpiaq on Alaska's Kodiak Island have been raising bison since 2017 to combat food insecurity. The Blackfoot Confederacy launched the Iinnii Initiative—"iinnii" refers to buffalo in the Blackfoot language—to create a home for buffalo while conserving traditional lands and protecting their culture. The confederacy is made up of the Blackfeet Nation in Montana and the Kainai, Piikani, and Siksika Nations in Canada.

Bison restoration does the following:

- enables Indigenous food sovereignty
- increases economic development
- reintroduces an important cultural and spiritual component to indigeneity
- preserves a species
- refurbishes the prairie ecosystem

In 2016, the bison was adopted as the national mammal of the United States.



2016 Wildlife Conservation Society

- The Qikiqtani Inuit Association, along with the Canadian government, has established the Tuvaijuittuq Marine Protected Area off the northwest coast of Ellesmere Island, Nunavut, to protect Arctic habitat for ice-dependent species such as walrus, seals, and polar bears. Meaning "the place where the ice never melts" in Inuktut, Tuvaijuittuq is now closed to new human activity.
- The Confederated Salish and Kootenai Tribe now manages the National Bison Range, originally established by the US federal government in 1908 on land taken without consent from the Flathead Indian Reservation in Montana. The herd at the National Bison Range descends from a free-ranging herd started by tribal members in the 1800s, when bison were near extinction. On December 27, 2020, the congressional bill restoring the range to tribal management was signed into law. Today, they have their bison back!

LANDSCAPE STEWARDSHIP

Indigenous Peoples of Turtle Island didn't just live off the land; they managed and manipulated the land and its ecosystems for thousands of years. Because of their deep expertise in land management, many Indigenous nations are now working to reclaim and steward traditional territories in order to restore ecosystems that have been depleted of natural resources or damaged by natural disasters caused by climate change.

YUROK SUSTAINABLE FORESTRY AND CLIMATE CHANGE

The traditional territory of the Yurok Tribe of Northern California once spanned two hundred thousand hectares along the Klamath River, from the Cascade Mountains in what is now southern Oregon down to the river's mouth on the Pacific coast. Over the decades European colonizers took much of their land for commercial logging and gold mining, and the Yurok people were left with just 22,700 hectares surrounded by a damaged ecosystem.

In 2019, however, the Yurok Tribe was awarded the Equator Prize by the United Nations Development Programme for its nature-based solution to achieving sustainable development while tackling climate change. The tribe has earned income and reclaimed more than twenty thousand hectares of ancestral lands through carbon sequestration.

What is carbon sequestration?

Yurok land is filled with native trees. These trees absorb carbon dioxide, a *greenhouse gas* that causes climate change, sequestering it from the atmosphere. In 2011, the tribe became the first Indigenous group to partner with the California Air Resources Board to receive credits for that carbon sequestration. For every metric tonne of carbon dioxide the Yurok trees remove from the atmosphere, the tribe receives one credit. The credits are then sold to regulated industries, and the money is used to finance community programs and buy back more ancestral land.

Through the Yurok Tribe Environmental Program, the people are using their own Traditional Ecological Knowledge to manage the forest for both the community's benefit and the environment's.

SEMINOLE EVERGLADES RESTORATION INITIATIVE

The Seminole Tribe has lived in the Florida area for thousands of years. They understand their local ecology on a deep level and are bound to the land on an even deeper level. When the health of the Everglades began to decline due to urban development and drainage projects—reducing the

Everglades to nearly half its original size—the Seminole sought to revive the wetlands by controlling the quantity and quality of water flowing off their land into the Everglades.

The Seminole Everglades Restoration Initiative includes the following:

- reviving more natural water patterns
- improving water quality
- increasing water-storage capacity
- enhancing *hydroperiods*, the length of time an area remains wet

Today, the Seminole Tribe is part of the South Florida Ecosystem Restoration Task Force, a partnership of federal, state, tribal, and local governments involved in restoring and protecting the Everglades.

INTERTRIBAL SINKYONE WILDERNESS COUNCIL

In 1986 a group of seven Indigenous nations with long-standing, intergenerational cultural connections to the lands and waters of Northern California formed the InterTribal Sinkyone Wilderness Council. This group eventually grew to include ten tribes, including the Cahto, Pomo, and Yuki, all seeking to stop the logging of old-growth rain forest, protect salmon and other native species, promote healing, and revitalize their cultural relationships with land and water. They now steward over 4,530 acres using traditional practices:

- rotational burning of undergrowth within forests to combat the state's increasingly extreme and destructive wildfires
- selective thinning and harvesting of seaweed, basket-making materials, and plant medicines

LAND GUARDIANS

Indigenous land guardians oversee the extraction of natural resources and help manage and restore ecosystems on ancestral territories. They are trained specialists guided by Indigenous law, generations of Traditional Knowledge, modern science, and a deep sense of responsibility. In British Columbia's Mackenzie River valley, guardians monitor pipeline repairs. In eastern Manitoba, guardians test water quality around hydroelectric dams. In Labrador, guardians monitor some of Canada's largest mines.

Off the coast of Alaska, the Unangax̂ communities of St. Paul Island and St. George Island are working to create a marine sanctuary around the Pribilof Islands, also called the PRIME (Pribilof Islands Marine Ecosystem) Initiative. The proposed initiative would unite the Unangax̂ tribal government with the US federal and Alaskan governments to address conservation concerns, such as the dwindling animal population, while working to ensure the sustainability of local fisheries. The PRIME Initiative seeks balance between cultural, environmental, and economic interests.

In 2021, Grupo Ecológico Sierra Gorda of Querétaro, land guardians in Mexico, received the Equator Prize for protecting the Sierra Gorda Biosphere Reserve and promoting the sustainable development of its 638 communities.

Having a group of land guardians oversee and manage an ecosystem results in a healthier landscape, cultural revitalization, intergenerational sharing of knowledge and traditions, understanding and respect for Indigenous rights, as well as pride in ancestral homelands. Guardians work to ensure traditional lands will continue to sustain life.

Help Wanted! Responsibilities of a Land Guardian

- Building relationships with corporations who want to use land resources
- Restoring animal and plant species to the land
- Testing water quality
- Collecting data
- Monitoring development projects
- Maintaining cultural sites
- Protecting marine environments
- Liaising between the community and corporation through each phase of a project

CORPORATIONS EMPLOYING INDIGENOUS KNOWLEDGE: DE BEERS AT THE GAHCHO KUÉ MINE

Six Indigenous groups have come together with the diamond company De Beers Canada in an environmental stewardship agreement called Ni Hadi Xa. The name means "people watching the land together" in Denesuline. De Beers is combining scientific and Traditional Ecological Knowledge in the environmental monitoring around its diamond mine thanks to this partnership with the Deninu Kue First Nation, Lutsel K'e Dene First Nation, North Slave Métis Alliance, Northwest Territory Métis Nation, Tlicho Government, and Yellowknives Dene First Nation.

What is Indigenous Land Management?

SCOPE TV – VIDEO

(4 minutes)

What Is Indigenous Land Management? | SCOPE TV

Lee heads to the Ngarang-Wa Indigenous land on the Gold Coast to find out how Australia's first people looked after and cultivated the land, and how their techniques are used to protect the land in the present day.

https://www.youtube.com/watch?v=PiQCI329TBY

Indigenous ways of knowing are shaping climate solutions

Indigenous knowledge carries ancient and intergenerational wisdom that is flexible, fluid, and adaptive as it evolves through relationships with the land and other beings. This knowledge evolves from and is responsive to the natural world, which makes it ideal for developing and advancing meaningful climate solutions.

Walter Andreef, Métis knowledge keeper and scientist, spends a lot of his time in the bush. “I feel that when I'm in the forest – the boreal forest where it's deep and dark, with all kinds of animals, and bountiful with life – I feel very much at home,” Andreef explains. “It's kind of a place where you feel connected to the land, just as you are in yourself.”

Indigenous knowledge is not uniform across the diversity of Indigenous peoples in Canada, and cannot be separated from the people who hold it. It is embodied.

At the same time, there are some common principles across these knowledge systems which some suggest are important in the context of addressing climate change. For example, the concepts of relationality and stewardship carry teachings that all living things are interconnected and therefore must be respected and cared for.

“Traditional knowledge for us is certainly about how we can survive the odds in harsh environments, the wisdom of all of that has sustained us for millennia…” describes Watt-Cloutier. “What we're trying to teach is that traditional knowledge is not just for Indigenous people, it's for everybody… All you have to do, really, is start to respect and understand traditional knowledge of Indigenous peoples and you will see there will be a groundswell of new creative and innovative ways and means in which to address these challenges that we face today in the world.”

In the most general sense, Indigenous knowledge systems can offer a more holistic approach, that may compliment the disciplinary nature of western sciences.

Blackfoot Knowledge Keeper and scholar Leroy Little Bear says that we must move beyond the either/or mentality of western thought: “We're not talking about either Western science or native science. What we're talking about is a marriage of the two, because that'll bring about enrichment. That's what we refer to as a holistic approach.”

Native Science: Natural Laws of Interdependence

By Gregory Cajete, 2000

Foreword

By Leroy Little Bear, J.D.
Former director, Harvard University Native American Program, and professor emeritus, University of Lethbridge, Alberta, Canada

Science has been and can be defined many different ways depending on who is doing the defining. But one thing that is certain is that "science" is culturally relative. In other words, what is considered science is dependent on the culture/worldview/paradigm of the definer. Immanuel Kant, who divided knowledge into appearances, reality, and theory, suggests the appearances of the world are deeply conditioned by the human sensory and intellectual apparatus. Other beings no doubt experience the same world in radically different ways. Scientific facts—the appearances themselves—are as much a product of the observer's human nature as they are of an underlying reality. We see the world through particularly human goggles (Herbert 1985).

Albert Einstein said that the business of science is "reality." I agree, but the reality brought about by modern science is largely based on Western paradigms. Western paradigmatic views of science are largely about measurement using Western mathematics. But nature is not mathematical. Mathematics is superimposed on nature like a grid, and then examined from that framework. It is like the land survey system: a grid framework of townships, sections, and acres superimposed on the land. These units, in turn, are used as the basis for dealing with the land, but they are not part of the nature of the land. Einstein was so enthralled with the mathematization of nature that he once observed, "How can it be that mathematics, being a product of human thought which is independent of experience, is so admirably appropriate to the objects of reality?" (Lindley 1993) But Jeremy Hayward, among others, feels that in spite of the usefulness of modern scientific discoveries, there is a lot left out of Western science. According to Hayward, the modern world relies on a narrow, distorted view of science to attempt to relate what reality is all about. "It is just that the modern description leaves out so much—it leaves out the sacredness, the livingness, the of the world. And it does get troublesome when some scientists tell us, often with a voice of authority, that the part they leave out is really not there" (Hayward 1997).

If science is a search for reality and if science is a search for knowledge at the leading edges of the humanly knowable, then there are "sciences" other than the Western science of measurement. One of these other sciences is Native American science. Native American science is incomprehensible to most Westerners because it operates from a different paradigm. Measurement is part of Native American science but does not play the foundational role that it plays in Western science. Measurement is only one of many factors to be considered.

In order to appreciate and "come to know" in the Native American science way, one has to understand the culture/worldview/paradigm of Native American people. For Thomas Kuhn, a paradigm is a whole way of working, thinking, communicating, and perceiving with the mind. A paradigm includes tacit infrastructures, which are mostly unconscious, pervading the work and thought of a community (Bohm and Peat 1987). What is the Native American paradigm about?

The Native American paradigm is comprised of and includes ideas of constant motion and flux, existence consisting of energy waves, interrelationships, all things being animate, space/place, renewal, and all things being imbued with spirit. Gary Witherspoon, studying Navajo language and art observes, "The assumptions that underlie this dualistic aspect of all being and existence is that the world is in motion, that things are constantly undergoing processes of transformation, deformation, and restoration, and that the essence of life and being is movement" (Witherspoon 1977). The constant flux notion results in a "spider web" network of relationships. In other words, everything is interrelated. If everything is interrelated, then all of creation is related. If human beings are animate and have spirit, than "all my relations" must also be animate and must also have spirit. What Native Americans refer to as "spirit" and energy waves are the same thing. All of creation is a spirit. Everything in creation consists of a unique combination of energy waves. In other words, what appears as material objects is simply the manifestation of a unique combination of energy waves. Conversely, all energy wave combinations do not necessarily manifest themselves in terms of material objects.

Renewal is an important aspect of the Native American paradigm. From the constant flux, Native Americans have detected certain regular patterns, be they seasons, migration of animals, or cosmic movements. This gives rise to the view that creation is a continuous process but certain regularities that are foundational to our continuing existence must be maintained and renewed. If these foundational patterns are not maintained and renewed, we will go the way of the dinosaurs. We will be consumed by the constant flux. Hence, the many renewal ceremonies in Native American societies.

The land is a very important referent in the Native American mind. Events, patterns, cycles, and happenings occur at certain places. From a human point of view, patterns, cycles, and happenings are readily observed on and from the land. Animal migrations, cycles of plant life, seasons, and cosmic movements are detected from particular spatial locations; hence, medicine wheels and other sacred observatory sites. Each tribal territory has its sacred sites, and its particular environmental and ecological combinations resulting in particular relational networks. All of this happens on the Earth; hence, the sacredness of the Earth in the Native American mind. The Earth is so sacred that it is referred to as "Mother," the source of life.

I define science as pursuit of knowledge. The Native American mind is in constant search for meaning and reality in the constant flux, not only of the Earth, but also of the cosmos. One can readily apply Einstein's definition of science as a search for reality to Native Americans. For Einstein and Western science, creation and existence were made in a certain way by God and will always remain the same; everything and anything in creation and existence just needs to be discovered by humans. Nothing is certain unless it can be referred to as a regular pattern after long-term observation. But, for the Native American, even regularities are subject to change. Native Americans never claim regularities as laws, or as finalities. The only constant is change.

Storytelling is a very important aspect of Native America. It is not just the words and the listening but the actual living of the story. The author does a beautiful holistic treatment of Native American science by giving it "livingness" and spirit. The Native American paradigm comes to life as the author weaves through ecology, relational networks of plants, animals, the land, and the cosmos. It is a renewal ceremony of Native American knowledge, a storytelling of the discoveries of regular patterns manifesting themselves in the flux. In other words, Native American science is a search for reality, and that is "science." This story about Native American science admirably fills the gaps that Hayward identified in Western science: sacredness, livingness, and the soul of the world. It is a science that is many centuries old and continues to be the basis of Native American reality.

Let me conclude with a personal note. I have always had a great interest in science, both Native American and Western. I truly see science as pursuit of knowledge on the edges of the humanly knowable. When asked by the author to participate in his book by writing a foreword, I felt that I would be twice blessed: firstly, when I read his earlier work, *Look to the Mountain*, a path-blazing work in Indian education, and secondly, when I read this work. There was no hesitation on my part because I saw in this work a manifestation of Native American science as a search for reality.

Indigenous conservation

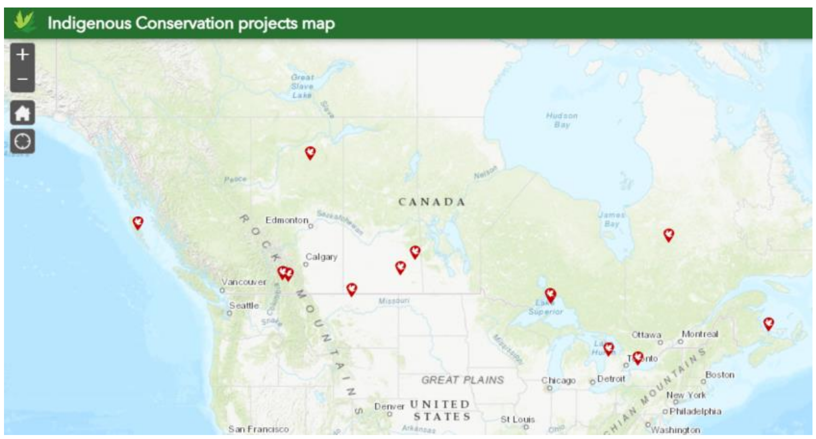
The Nature Conservancy of Canada, 2024

The dynamics of conservation in Canada are changing. Today, Indigenous Peoples are increasingly being heard and recognized as conservation decision-makers and stewards of the land.

The Nature Conservancy of Canada (NCC) acknowledges that Indigenous Peoples have protected and cared for the natural areas, plants and wildlife that have sustained them for millennia.

NCC has much to learn from Indigenous Peoples across Canada that will help us to become better land managers and conservationists. NCC, as a leading conservation organization, also has a unique opportunity to contribute the skills we have acquired to assist Indigenous communities and Nations to achieve their conservation and stewardship goals.

Indigenous Conservation map



NCC's vision and values for championing conservation together

We envision building meaningful relationships that are grounded in mutual respect and the desire to achieve significant and lasting conservation outcomes. NCC will use our capacity, expertise and influence to act as an ally in support of Indigenous-led conservation projects and as a partner in joint initiatives. NCC will expand our understanding of our lands and waters and improve our stewardship by learning from Indigenous Knowledge and history.

From vision to action

NCC has identified five initial areas of focus to advance our Indigenous conservation partnerships:

1. We will further develop and formally integrate Indigenous advisory capacity at both the national and regional levels.

2. We will work with Indigenous advisors and institutions to develop staff training that provides a foundation focused on Indigenous histories and stories to help foster better partnerships.
3. We are committed to developing site-specific approaches to managing and preserving Indigenous cultural heritage resources while simultaneously respecting access to these resources by members of Indigenous communities.
4. We will use our knowledge and experience to support Indigenous communities interested in exploring the land trust model to advance reconciliation through land conservation.
5. We are committed to sharing our technical skills and expertise where needed to support Indigenous conservation initiatives to facilitate the establishment of Indigenous Protected and Conserved Areas (IPCAs) across Canada.

To learn more, download NCC's Indigenous Conservation Framework here. Read NCC's 2023 renewal of that commitment >

To learn more about NCC's progress through the Framework, please read the Progress Reports below:

- Year One Progress Report
- Year Two Progress Report
- Year Three Progress Report

Stories from the land

We believe by working together, we can achieve great things in restoring and conserving the natural environment that we collectively value.

2025 NCF-Envirothon Alberta
Current Issue Part A Study Resources

Key Topic #4: Vulnerability Assessments and Adaptation Strategies

16. Describe a forest vulnerability assessment, including its purpose and steps.
17. Assess forest conditions and apply climate change adaptation strategies to support sustainable forest management.
18. Analyze the benefits and drawbacks of various climate change adaptation strategies for forests, including assisted species migration, selective breeding, and /or afforestation.
19. Define adaptive capacity in relation to vulnerable flora and fauna of forest communities.
20. Distinguish how various ecozones face differing levels of vulnerability and explain which ecological factors drive this vulnerability.

Study Resources

Resource Title	Source	Located on
Climate Change Vulnerability Assessments	*USDA Forest Service, 2023*	Pages 86-87
Adaptation	*Government of Canada, 2024*	Pages 88-89
Sensitivities and Adaptation of Ecosystems and Sectors	*Government of Canada, 2015*	Pages 90-91
Frontiers in Ecology and the Environment - Persist in place or shift in space? Evaluating the adaptive capacity of species to climate change	*Thurman et al. – Frontiers in Ecology and the Environment, 2020*	Pages 92-99
Birds	*Government of Canada, 2024*	Page 100
Assisted Migration	*Government of Canada, 2024*	Pages 101-102
Understanding Climate Change Impacts in Temperate Forests	*Ronald Mahoney - Extension Foundation and Cooperative Extension, 2019*	Pages 103-104
Forest ecosystems of temperate climatic regions: from ancient use to climate change *(excerpt)*	*Frank S. Gilliam – New Phytologist, 2016*	Pages 105-114

<u>Study Resources begin on the next page!</u> ➡

Office of Sustainability and Climate | November 2023

Climate Change Vulnerability Assessments

Assessing vulnerability to address climate change impacts

Climate change vulnerability assessments (CCVAs) are a key component of how we integrate climate change considerations into management and planning at the USDA Forest Service. CCVAs evaluate the potential impacts of climate change on national forests and associated resources. This evaluation provides an understanding of why a resource is vulnerable and leads to potential adaptation actions to reduce vulnerability. CCVAs deliver conclusions at a scope and scale that is relevant to decision-making, and the process of crafting a CCVA brings together diverse types of science and information and vital partnerships.

What is vulnerability?

Vulnerability to climate change is the degree to which systems are susceptible to, and unable to cope with, the adverse effects of climate change. Although many different conceptualizations of vulnerability exist, in natural resource management, it is often helpful to think of vulnerability as a function of three important components: exposure, sensitivity, and adaptive capacity (Fig. 1).

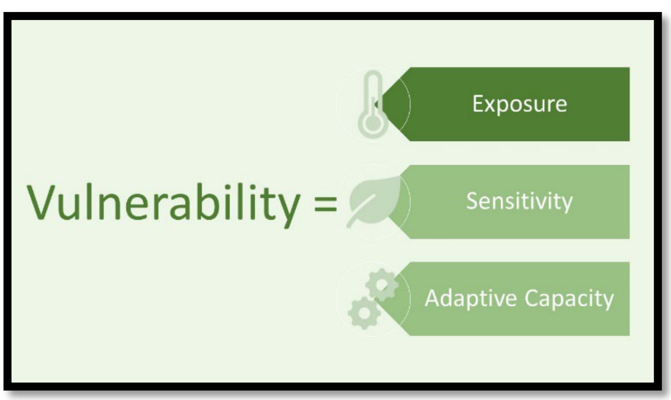


Figure 1. Three components of vulnerability.

Exposure

Exposure is the extent to which climate and climate-related changes may affect a resource or place. Depending on the resource of interest, exposure can include direct effects (increased temperatures, reduced snowfall, more extreme events, sea level rise), and indirect effects (changes in hydrology, vegetation changes, altered disturbance regimes).

Sensitivity

Sensitivity is a measure of how responsive a system or species is to climate change exposure. Sensitivity of species or ecosystems may depend on innate biological and physiological characteristics or specific physical or ecological factors. Different resources can have different sensitivities to the same level of exposure.

Adaptive capacity

Adaptive capacity is the ability of a system or species to cope with change. Adaptive capacity can include the ability of species to physically move to more favorable environments, to adapt to a changing environment, or to evolve to better survive new conditions. Although the natural resource management community generally focuses on the biological or ecological aspects of adaptive capacity, it is also useful to consider how management actions and other human dimensions influence how adaptive capacity is realized.

Assessing vulnerability

Scope and scale

The scope of a CCVA is aligned with one or more resources of interest in management and planning. These targets could include species, habitats, or ecosystems, but could also be focused on watersheds, infrastructure, recreation, cultural resources, or ecosystem services. The geographic scale of a CCVA is relevant to management of the resource of interest and could focus anywhere from the scale of a watershed to a forest, multiple forests, or a region. CCVAs work best when they are aligned with the scale of a decision-making process, e.g., Forest Plan Revision.

Partnerships and Collaboration

Science-manager partnerships and collaboration ensure that CCVAs incorporate local knowledge and address management needs with the right scope and scale. Collaborations can include decision-makers, planners, and local managers alongside scientists within and outside of the Forest Service. Better outcomes can be achieved when the vulnerability assessment process engages with community members and Tribes who may be affected by climate change impacts to resources. In addition, input from a team of experts with a range of backgrounds and perspectives relevant to the assessment's scope is critical. These partners can include Indigenous knowledge-holders, local managers, and natural and social scientists, among others, to inform expert elicitation of a resource's climate change vulnerability.

Science and information

CCVAs evaluate the vulnerability of important resources through multiple lines of evidence. Climate information that includes historical trends and projected future changes forms the backbone of a CCVA. Vulnerability assessments then provide an evaluation of the potential effects of climate change on different resource areas. This evaluation can be accomplished in many ways, including synthesis of peer-reviewed and grey literature, elicitation from experts with a range of backgrounds and perspectives, assessment of existing ecological response models, or creation of new models that project future ecological condition or describe historical ecological dynamics due to climate change. Vulnerability can be presented as narrative descriptions, rankings, categorizations, or the identification of vulnerable locations. To accommodate uncertainty, when possible, the best practice is to provide projections of future climate and future condition of resources as a range of plausible futures.

CCVAs in the Forest Service

The Forest Service Office of Sustainability and Climate (OSC) developed The Vulnerabilty Assessment Dashboard, an interactive tool that illustrates where CCVAs have been completed across all Forest Service Regions. The Dashboard provides a breakdown of assessments completed by fiscal year, identifies which resources have been assessed, and provides links to CCVAs and other documents. These assessments vary in their scope and scale but have each been integral to recent management and planning.

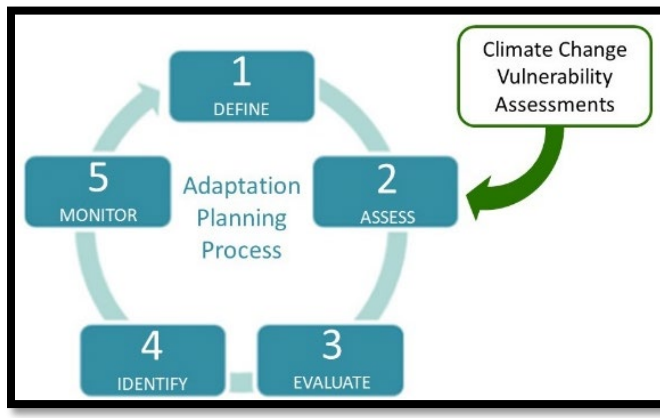


Figure 2. Climate change vulnerability assessments are an integral component of adaptation planning processes.

CCVAs are used in adaptation planning processes at the Forest Service, such as the multi-step Adaptation Workbook, which integrates assessments into management and planning (Fig. 2). Some vulnerability assessments also include descriptions of potential adaptation actions that can be taken to address climate vulnerabilities. These adaptation actions are often developed and selected through collaborative processes and reflect practitioners' input on appropriate management techniques.

For more information on CCVAs, see the guidebooks: Responding to Climate Change in National Forests and Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers.

Government of Canada   Gouvernement du Canada

Adaptation

How exactly is the climate forecast to change, and what could that mean for Canada's forests and forest management?

Canada is working to answer these questions in order to help the forest sector and society in general adapt to changing climate conditions. Today, forest managers must consider a range of possible future climates—those involving, for example, altered growing seasons, more insect infestations, more wildland fires and greater permafrost melting.

An important first step is to identify social, economic and environmental vulnerabilities to changing forest conditions. The next important step is to plan ways to reduce the impact of those vulnerabilities.

For example, projected increases in drought, fire, windstorms, and insect and disease outbreaks are expected to result in greater tree mortality. Fewer trees will reduce Canada's timber supply, which in turn will affect the economic competitiveness of Canada's forest industry. This would leave forestry-dependent communities vulnerable to job losses, closure of forestry processing facilities and an overall economic slump.

New thinking to deal with new conditions

Forest managers have traditionally assumed that the climate conditions of previous decades would be the conditions of future decades. Now, with more knowledge about climate and its patterns of change, forest managers are shifting their thinking.

Adaptation will mean taking action to minimize the negative effects of change. Yet at the same time some changes (such as longer growing seasons or moister weather patterns) may in fact offer new opportunities for the forest sector. Adaptation will therefore also mean taking advantage of the positive impacts brought about by climate change.

The challenge of uncertainty

Many uncertainties exist about how, and to what extent, climate change will affect Canada's forests. This makes planning adaptation efforts a challenging exercise.

Dealing effectively with uncertainty requires having:

- the use of new tools and techniques for decision-making, such as scenario-planning exercises
- a good knowledge of the forest
- an understanding of risks
- the flexibility to adjust to changes

Risk management is a proven technique for identifying potential problems and then developing ways to:

- reduce or avoid them
- respond to them to reduce negative outcomes, where they are unavoidable

In forestry, this means setting management objectives that recognize that the forests of the future will be different from those of today. By identifying the risks associated with these new conditions, forest planners and managers can then focus on finding ways to reduce or optimize the impact of those risks.

Support for adaptation from all parties

The Canadian Council of Forest Ministers (CCFM) has identified climate change adaptation as a priority for the forest sector. Many parties are working to support this priority:

- Forest scientists and forest practitioners across the country are assessing adaptation needs and adaptation options.
- The federal, provincial and territorial governments are collaborating in creating a range of products to help forest managers begin taking adaptation action.

- Provincial and territorial governments are developing approaches to addressing climate change, supporting climate research and raising awareness of the need for adaptation.
- Forest companies are beginning to address issues related to climate change in their management plans.

Practical tools aid adaptation strategies

Tools to analyze forest vulnerabilities

Forest scientists are developing a range of tools for assessing and managing climate-related risks and adaptation options. For example:

- Canadian Forest Service (CFS) researchers have developed a new software tool, BioSIM, which can predict stages in insect development during the growing season. BioSIM has been used to predict how climate change might affect the risk of mountain pine beetle infestations in western Canada.
- CFS scientists have updated Canada's plant hardiness zones using recent climate data. The new map produced shows changes in the hardiness zones consistent with climate change.
- In partnership with provinces, the CFS is developing frameworks, guidebooks and tools to help forest management practitioners:
    - better understand their readiness to adapt
    - identify sources of vulnerability to sustainable forest management

Tools to help forests and the forest sector adapt

Work is underway on several fronts to find ways to help forest stands adapt to new climatic conditions and disturbance regimes. For example:

- Researchers are looking at ways to reduce forests' vulnerability to fire and insect damage.
- Industry is exploring new markets for beetle-killed wood.
- Some forest companies have started using high-flotation tires to navigate wet areas, allowing them to extend their operating season.

Tools to inform forest management decision-making

Scientists are incorporating the data they have on changes in climate conditions into research and planning tools. This gives forest managers better information with which to make decisions. For example:

- Seedwhere is a geographic information system (GIS) tool that can guide planting and seeding decisions for forest regeneration. It can also help forest managers decide where to collect seeds and how far those seeds can be moved.

Looking to the long term

Forest managers need to include climate change considerations in long-term planning if Canada is to maintain a competitive position in world markets. This means enhancing our ability to assess climate effects and identifying ways to adapt forests to ensure a healthy ecosystem and sustained supply of fibre.

Involving everyone in adaptation efforts—government, industry, academia, the public—will be the most effective approach. Good communication and information exchange will help Canadians address shared problems and pool resources to solve them.

Sensitivities and Adaptation of Ecosystems and Sectors

3.1 TERRESTRIAL ECOSYSTEMS

3.1.1 Sensitivities

Most natural systems have moderate to high exposure to the impacts of climate change, when considered over a time period of approximately 50 years. Because natural systems have evolved in response to climate since deglaciation, a sudden shift in climate conditions will challenge their ability to adapt. Boundary shifts at the ecoregion and ultimately the ecozone level may be expected. Climate change will lead to shifts in seasonally dependent biological rhythms and cycles, loss of habitat, extirpation or extinction of native plant and animal species, and the arrival of more invasive species. Other anthropogenic factors, principally those related to land use, will compound these impacts of climate change.

FIGURE 12: *Acadian Forest assemblage near Strathgartney, PE.*

Changes in ecosystems and dominant species will occur due to changes in climate, either through conversion (replacement of the dominant species by a subdominant species) or migration (long-distance movement of species that can rapidly adapt to new soil or topographic factors; Nielson et al., 2005). In southern Atlantic Canada, the future fate of the already highly stressed ecosystems of the remnant Acadian Forest (Figure 12) remains uncertain (Mosseler et al., 2003a, b; Moola and Vasseur, 2004). The limit of the northern boreal forest may expand at the expense of tundra areas (Heal, 2001), although topographic and soil factors will limit the migration of treeline ecosystems (Holtmeier and Broll, 2005; Nielson et al., 2005). Available evidence suggests little or no recent observed change in the northern treeline position in Canada (Masek, 2001).

In concert with the regional warming in spring and summer, there has been a 5 to 6 day advance since approximately 1959 in the onset of phenological spring in eastern North America, as indicated by earlier leaf appearance or flower blooming and earlier bird nesting times (Schwartz and Reiter, 2000). In Atlantic Canada, earlier phenology of spring bloom was observed in interior regions, such as the Annapolis Valley (NS), but no significant differences were seen along the coast (Vasseur et al., 2001). Frequent episodes of winter thaw and late spring frost have led to widespread tree crown dieback in yellow birch throughout eastern Canada (Cox and Arp, 2001; Bourque et al., 2005; Campbell et al., 2005). Over the next few decades, shifting phenology of biological events may be either positive (e.g. enhanced productivity for trees) or negative (e.g. in the case of winter thaw, leading to trunk cracking for red spruce; see Mosseler et al., 2000). Birds are subject to problems associated with climate change, especially in relation to changes in the phenological spring. Early onset of warm days during the nesting season has been shown to negatively affect the breeding success of nesting seabirds due to heat stress and mosquito parasitism (Gaston et al., 2002). The timing of bird migration is also affected by increases in spring temperature, although long-distance migratory birds appear to alter the timing of migration in response to changes in weather and phenology (Marra et al., 2006). The broad spectrum of bird life in a region represents many different habits and habitats. Because they are widely observed and studied, they are useful indicators of environmental change (Boucher and Diamond, 2001).

Long-distance migration requires energy, and migrating birds must balance obtaining food with travelling in less-than-ideal weather. Use of a particular stopover varies with local weather and climate, and shows large interannual variation. The linkages to environmental factors suggest that migrating birds are sensitive to climate variability, which has implications for conservation efforts. A detailed study of the impacts of climate change on migratory songbird species in Atlantic Canada is in progress (Taylor, 2006).

Wildlife population dynamics are closely linked to climate. The seasonal migration of white-tailed deer in New Brunswick appears to be conditioned by winter climate variability as it affects snow cover (Sabine and Morrison, 2002). Milder winters may see this species occupying areas where they are currently absent in winter. Moose are at their southern limit of distribution in Nova Scotia and, under a warming climate, are expected to disperse northward (Snaith and Beazley, 2004).

A review of NAO-related effects on northern ungulates found declines in caribou populations in northern Quebec and Greenland during periods of warmer winters (Post and Stenseth, 1999), suggesting that woodland caribou populations of Newfoundland and Labrador will be negatively affected by climate warming.

3.1.2 Adaptation

Natural systems have proven to be relatively resilient in the face of previous climate changes. However, these changes occurred over longer periods of time and were not compounded by additional stresses imposed by humans. Left to themselves, ecosystems would evolve in response to changing environmental conditions. The necessity of using natural resources for human purposes, however, means that short-term changes in ecosystems are cause for human concern.

Differences in lifespan and size of individual organisms influence the degree to which each species is exposed, as well as the immediacy of the reaction to changed conditions. Insect species respond more rapidly to climate variation and change, in terms of both survival and migration, than do trees and large mammals.

FIGURE 13: *Piping plover, an endangered species that utilizes coastal areas. Photo courtesy of Sidney Maddock.*

Approaches for adaptive responses to climate change impacts on natural ecosystems include comprehensive, integrated land-use management combined with protecting key habitats and species, promoting sustainable use of plant and animal species, and mechanisms for public education, awareness and action (Gitay et al., 2001; MacIver and Wheaton, 2005). Although comprehensive regional planning for biodiversity protection is yet to be realized for Atlantic Canada, all provinces have some kind of protected areas strategy, as well as wildlife and forestry management policies and legislation, and there are equivalent structures in areas of federal jurisdiction. For species at risk, such as the St. Lawrence aster and the piping plover (Figure 13) along the southern Gulf of St. Lawrence, and Long ’s and Fernald’s braya in northern Newfoundland, it is important that climate change sensitivity and risk analysis are considered in recovery management plans. Maintaining and enhancing the interconnected network of parks and protected areas is one means of enhancing the ability of natural ecosystems to adapt to changing conditions (Mosseler et al., 2003a, b; Beazley et al., 2005). Although protected areas are themselves subject to the effects of climate change (Scott et al., 2002), they can provide a base for monitoring and assessing ecosystem change that is less disturbed by human activity than their surroundings.

FRONTIERS IN ECOLOGY
and the ENVIRONMENT

Persist in place or shift in space? Evaluating the adaptive capacity of species to climate change

Abstract

Assessing the vulnerability of species to climate change serves as the basis for climate-adaptation planning and climate-smart conservation, and typically involves an evaluation of exposure, sensitivity, and adaptive capacity (AC). AC is a species' ability to cope with or adjust to changing climatic conditions, and is the least understood and most inconsistently applied of these three factors. We propose an attribute-based framework for evaluating the AC of species, identifying two general classes of adaptive responses: "persist in place" and "shift in space". Persist-in-place attributes enable species to survive in situ, whereas the shift-in-space response emphasizes attributes that facilitate tracking of suitable bioclimatic conditions. We provide guidance for assessing AC attributes and demonstrate the framework's application for species with disparate life histories. Results illustrate the broad utility of this generalized framework for informing adaptation planning and guiding species conservation in a rapidly changing climate.

In a nutshell:

- Adaptive capacity (AC) – the ability of species to cope with or adjust to climatic changes is a key component of vulnerability, yet is difficult to evaluate and apply in practice.
- We describe an attribute-based framework for evaluating the AC of species or populations, which applies broadly to animals and plants.
- We identified "persist in place" and "shift in space" as two classes of responses that reflect the type and level of AC in a species or population.
- Operationalizing the concept of AC facilitates not only the development of adaptation strategies but also the identification of effective management actions under climate change.

Rapid climate change is a defining issue of our time, and anthropogenic warming of the atmosphere is resulting in an array of impacts on species, ecosystems, and human communities. Contemporary climate-change effects range from shifts in the physical environment, including means and extremes in weather patterns, sea-level rise, ocean acidification, and drought, to disruptions in biological processes, such as species' phenologies, interactions, and distributions. Adaptive capacity (AC) is broadly defined as the ability of a species, ecosystem, or human system to cope with or adjust to changing climatic conditions (IPCC 2014). Early use of this concept largely emphasized socioeconomic systems and human institutions, but acknowledged its applicability to natural systems (Engle 2011). Application of AC to biological systems has primarily occurred in the context of climate change vulnerability assessments (CCVAs). CCVAs are the most widely used framework for assessing climate-related vulnerability and consist of three distinct components: exposure, sensitivity, and AC (Foden *et al*. 2013). Exposure reflects the type and magnitude of climatic changes that a species (or population) has experienced or is projected to experience. Sensitivity refers to the degree to which a species is affected by or susceptible to a climate-related change (IPCC 2014). In contrast, AC refers to the ability of a species to cope with, adjust to, and persist in the face of current and future climate change. This process can be further defined with respect to intrinsic capacities versus extrinsic constraints on AC (Beever *et al*. 2016). We focus here on species' intrinsic AC and acknowledge that many extrinsic factors, climatic or otherwise, can act as barriers or constraints to the innate ability of species to cope with or adjust to changes.

Because climate adaptation generally focuses on reducing climate-related vulnerabilities and risks (Stein *et al*. 2014), strategies to enhance a species' AC can be important for achieving adaptation and conservation outcomes (Prober *et al*. 2019). However, incorporation of AC information into CCVAs, climate-adaptation planning, and conservation decision making is fraught with challenges, which frequently include a failure to address AC either explicitly or implicitly, difficulties in distinguishing AC from sensitivity, and the use of definitions and evaluation criteria that are highly variable and often case-specific (Thompson *et al*. 2015). Ongoing setbacks in operationalizing the concept of AC have hindered its application in practice.

The increasing demand among resource managers for methods of evaluating AC has triggered the development of a growing number of trait-based assessment approaches (eg Young *et al*. 2012; Foden *et al*. 2013; Ofori *et al*. 2017). Most approaches to date have used a restricted subset of broadly defined traits (Foden *et al*. 2013) or traits applicable only to specific taxa (Cabrelli *et al*. 2014; Butt and Gallagher 2018). Even for traits that are routinely specified (eg dispersal capacity), variation in evaluation criteria hinders consistent and comparable application across taxa and systems. In a survey sent to participants of vulnerability-assessment training programs offered by the US Fish and Wildlife Service, over half (58%) of 81 respondents identified the lack of tools and methods as a primary challenge to incorporating AC into vulnerability assessments (unpublished data). When queried about priorities for helping conservation agencies apply AC in their work, 82% of participants responded that the development of improved AC assessment tools would be “useful” or “very useful”. These results indicate the need for a synthesis of AC concepts and better guidance on how to assess AC according to a robust and generalizable framework.

Building on prior work that advanced the conceptual basis for AC (Nicotra *et al*. 2015; Beever *et al*. 2016), here we offer an attribute-based framework for evaluating and communicating AC. This framework embraces an expansive view of AC that encompasses the ability to both cope with and adjust to changes, and is designed to help researchers and conservation practitioners incorporate AC into forward-looking adaptation and management practices.

Persist in place or shift in space: dual pathways for AC responses

Past research on AC has predominantly focused on the ability of species to physically move to track suitable bioclimatic conditions. Climate-driven range shifts are the subject of numerous empirical studies (eg see Rumpf *et al*. 2018) and provide the foundation of many vulnerability assessments based on correlative models of species distributions. However, the ability of species to accommodate climatic changes in situ is not as easily documented and is therefore often underappreciated. To highlight the two general pathways in which organisms may respond to climate change through AC, we classify 36 attributes that enable a species or population to “persist in place” or “shift in space” (or both).

A species’ AC is often a reflection of its niche, characterized by the local ecological conditions that influence where an organism can occur. Changes in climatic or other physical conditions can involve shifts in the environment's mean state, variance (ie frequency of extremes), or both (Jackson *et al*. 2009). In turn, the breadth and trend of these variables describe the historical, current, and potential future climatic conditions to which a species is exposed. Coping with new (previously unexperienced) climatic conditions occurs when a species’ existing tolerances (ie thresholds for survival and reproduction) fall within the range of variability of those conditions (Smit and Wandel 2006). In contrast, adjustments are necessary when bioclimatic changes exceed a species’ existing tolerances.

The “shift-in-space” pathway is a principal avenue for species to track suitable bioclimatic conditions. Such adjustments in location generally occur in response to changes in limiting environmental variables. Documented shifts that track temperature change, for instance, often entail poleward or upslope movements (Parmesan 2006). Range shifts tracking other bioclimatic variables (eg moisture) can lead to contrasting spatial patterns, however, with downslope shifts in elevation being as common as upslope shifts across several taxa (Rapacciuolo *et al*. 2014).

Alternatively, the “persist-in-place” pathway can occur through the availability of broad tolerances or existing flexibility (eg phenotypic plasticity), or through the acquisition of new traits or expanded tolerances. Broad tolerances, including those achieved through behavioral flexibility (Beever *et al*. 2017), can buffer a species or population from changing conditions, at least in the near term (Comte and Olden 2017). A persist-in-place response is illustrated by bird species in California's Sierra Nevada mountains, for which nesting has on average advanced by about a week over the past century (Socolar *et al*. 2017). Although birds are highly mobile organisms, this study found the overall response to temperature increases in this avian community to be an adjustment in time (phenology) rather than a shift in space. In-situ adjustments can also result from an alteration or expansion of a species niche, including broadened tolerance or acclimatization to new conditions through microevolution (Hoffmann and Sgrò 2011; Bay *et al*. 2018). Over the past 50 years, for example, certain Hawaiian corals have exhibited evidence of thermal acclimatization to elevated ocean temperatures via increased survivorship and bleaching tolerance (Coles *et al*. 2018).

Attributes characterizing species' AC

We identified 36 attributes for use in assessing AC (graphically depicted as an AC wheel in Figure 1), with individual attributes grouped into the following seven complexes of related characteristics: distribution, movement, evolutionary potential, ecological role, abiotic niche, life history, and demography. These attributes are based on evidence from the scholarly literature, a review of criteria used in other assessment frameworks, and the authors' collective experience in diverse fields of ecology, conservation biology, climate science, and climate adaptation. The distribution and movement complexes broadly encapsulate the extent and capacity of an organism to move through a landscape (shift in space), whereas attributes relating to the life history and demography complexes reflect the capacity for an organism to accommodate changing climates in situ (persist in place). Attributes belonging to the three remaining complexes – namely the evolutionary potential and ecological role of organisms, along with their abiotic limits – can be used to inform both ends of this spectrum. We also highlight 12 "core" attributes, which collectively span the seven complexes and provide a comprehensive means of assessing AC when information for other attributes is unavailable. More detailed information about the core attributes, including their description, relevance to AC, and methods of evaluation, is presented in WebTable 1.

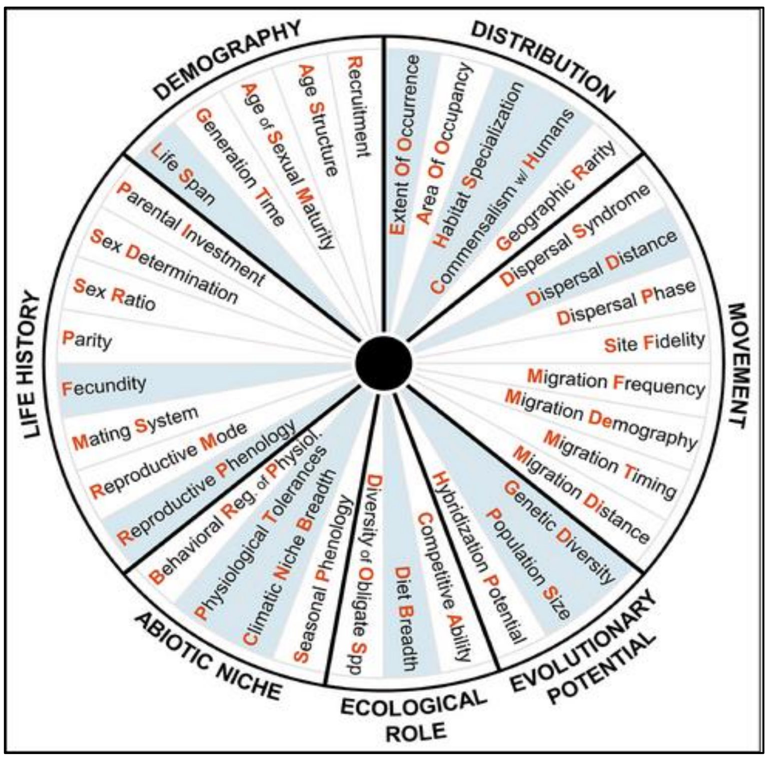


Figure 1

The adaptive capacity (AC) "wheel", depicting 36 individual attributes organized by ecological complexes (or themes). Twelve core attributes, representing attributes of particular importance and for which data are widely available, are highlighted in light blue. Letters used in attribute abbreviations (which appear in Figures 4 and 5) are shown here in red font.

Conservation prioritization relies on the development of standardized and consistent frameworks (Wade *et al*. 2017). Notably, our AC framework expands on prior efforts, and is applicable across taxa and geographies rather than being limited to specific organisms or regions. Recognizing the importance of intraspecific variation for estimating both species persistence and climatic vulnerabilities, our framework includes attributes that may be measured at both population and species levels. This flexibility allows the framework to inform climate-adaptation planning and management decisions across spatial scales.

For each attribute, species can be evaluated on a simple “low–moderate–high” scale, with criteria designed to accommodate either quantitative or qualitative assessments and accept either numerical or categorical values. Data availability will vary widely and may be largely lacking for many understudied species, and therefore for most attributes we provide multiple evaluation criteria for each level of AC to accommodate potential information gaps. In addition, attributes within a given complex can be used as surrogates (or proxies) when information for core attributes is otherwise unavailable. Suggested thresholds are based on well-established vulnerability assessment or extinction risk criteria (eg IUCN 2012; Young *et al*. 2012) or are derived from previous findings about the relationship of the attribute to AC. We summarized the resulting AC as the proportion of attributes within each of the criteria bins (ranging from low to high). We purposely do not propose a composite or overall metric, but instead encourage examining connections among attributes leading to potential cascading impacts or evaluating attributes that, by themselves, are so important that they may overwhelm other considerations (ie “deal makers” or “deal breakers”).

To document the supporting evidence for an AC assessment, we also include a method that is based on the availability (amount), quality, and consistency of input information sources, as well as on expert knowledge. For each attribute, evidence is assessed independently on a “none–low–moderate–high” scale. Details about the entire framework, including attribute definitions, relevance of attributes to AC, relation of attributes to persist-in-place and shift-in-space pathways, scales of assessment, and evaluation and evidence criteria, are provided in WebTable 2.

Testing the applicability of the framework

We demonstrate the broad applicability of the AC framework by testing it on four groups of organisms with disparate life-history characteristics that offer distinct challenges for evaluating AC: (1) migratory species, (2) species with complex life cycles, (3) ectothermic vertebrate species, and (4) sessile species. To illustrate the diversity of AC assessment outcomes across each of these “functional” groups, we provide corresponding case studies.

Migratory species, such as the rufa red knot (*Calidris canutus rufa*) and Dolphin and Union barren-ground caribou (*Rangifer tarandus groenlandicus*), perform cyclical and predictable movements between separate areas, usually triggered by changes in local climate, resource availability, and seasonality, or for mating reasons (Figure 2). Species with complex life cycles, such as the Karner blue butterfly (*Plebejus melissa samuelis*) and alpine bumblebee (*Bombus alpinus*), have life histories that involve an abrupt ontogenetic (developmental) change in an individual's morphology, physiology, and/or behavior, usually associated with a change in habitat use. Species that undergo metamorphosis fall within in this group; examples include most insects, amphibians, and fishes. Ectothermic vertebrate species, such as the European eel (*Anguilla anguilla*) and red-eyed leaf frog (*Agalychnis callidryas*), do not rely on internal physiological sources of heat (ie metabolic processes) to control body temperature, which instead varies with external ambient temperature (Figure 3). To maintain internal body temperatures when conditions change, these organisms must move or behaviorally thermoregulate. Examples include reptiles, amphibians, and most fishes. Sessile species, such as the quiver tree (*Aloidendron dichotomum*) and ivory tree coral (*Oculina varicosa*), are organisms that are unable to move actively or spontaneously (are typically permanently attached) during the adult phase and can only move in response to outside forces, such as water or wind currents; commensal organisms would also qualify as sessile. Examples include aquatic and terrestrial plants, certain marine invertebrates (eg corals, anemones, barnacles, sponges), and freshwater organisms (eg mussels, hydra, certain crustaceans).

Figure 2
Migratory species used in case-study assessments of AC: (a) rufa red knot (Calidris canutus rufa) and (b) Dolphin and Union barren-ground caribou (Rangifer tarandus groenlandicus). Species with complex life cycles used in case-study assessments of AC: (c) Karner blue butterfly (Plebejus melissa samuelis) and (d) alpine bumblebee (Bombus alpinus).
W Golder E Bauer J Utrup A Staverløkk

Figure 3

Ectothermic vertebrate species used in case-study assessments of AC: (a) European eel (Anguilla anguilla) and (b) red-eyed leaf frog (Agalychnis callidryas). Sessile species used in case-study assessments of AC: (c) quiver tree (Aloidendron dichotomum) and (d) ivory tree coral (Oculina varicosa). P Walker J Huber P Humann

To demonstrate application of the framework, we evaluated the AC of two illustrative species from each of the four functional groups of organisms. Visual depictions of the resulting AC assessments are presented in Figures 4 and 5. These examples span a broad range of geographies, taxonomic classifications, conservation statuses, and management contexts. Each of these assessments was independently reviewed by one or more external experts. We showcase a diversity of species with a range of AC, as well as situations in which species may have deal-breaker versus deal-maker attributes, and examples in which practitioners may be faced with limited data availability.

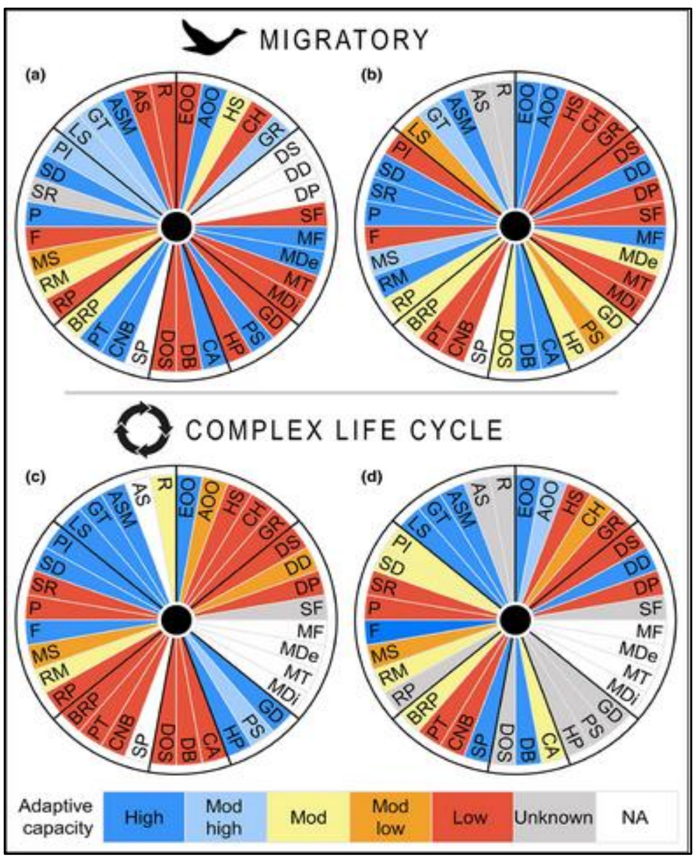


Figure 4

Assessments of AC for four species, illustrating each of two functional groups. Migratory species: (a) rufa red knot and (b) Dolphin and Union barren-ground caribou. Species with complex life cycles: (c) Karner blue butterfly and (d) alpine bumblebee. Colors of wheel "spokes" reflect the relative level of AC: low AC = red, moderate = yellow (with two subcategories: moderately low = orange, moderately high = light blue), high = dark blue. Spokes in gray indicate attributes for which AC is unknown, while spokes in white indicate attributes not applicable (NA) to a particular species. Attributes are defined in WebTable 2; abbreviations of attributes are spelled out in Figure 1.

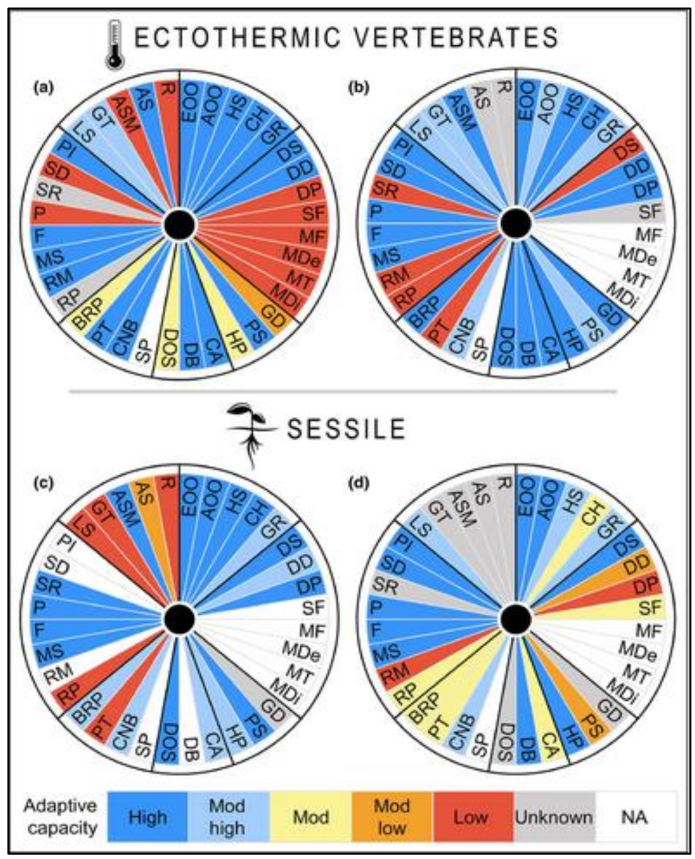


Figure 5

Assessments of AC for four species, illustrating each of two functional groups. Ectothermic vertebrate species: (a) European eel and (b) red-eyed leaf frog. Sessile species: (c) quiver tree and (d) ivory tree coral. Colors of wheel "spokes" match those described in Figure 4. Attributes are defined in WebTable 2; abbreviations of attributes are spelled out in Figure 1.

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Species with a majority of attributes indicating higher levels of AC, such as the red-eyed leaf frog and quiver tree, can be considered to have greater AC overall. Conversely, species with more attributes exhibiting lower levels of AC, like the Dolphin and Union barren-ground caribou, can be regarded as possessing lower AC overall. However, numerous factors can influence the contribution of attributes to the overall AC of a species. Indeed, one or more attributes may exert exceptional influence on overall AC (positively or negatively) and be regarded as deal makers or, perhaps more commonly, deal breakers. The alpine bumblebee, for example, has a flexible diet, disperses well, and has high fecundity – all characteristics of high AC – but its intolerance of prolonged hot spells greatly reduces its overall AC. Because of this single limitation (or deal-breaker attribute), it will be difficult for the bee to sustain populations under either the persist-in-place or shift-in-space response pathway, and the species therefore may be considered to have low overall AC.

Similarly, for organisms that operate at physiological extremes, such as the rufa red knot, high-energy or high-volume food resources are critical. The rufa population's reliance on eggs of the horseshoe crab (*Limulus polyphemus*) for food at a key stopover during its long-distance migration demonstrates a narrow trophic niche (both spatiotemporally and with respect to the target resource) and may indicate niche conservatism, even under the evolutionary pressure of climate change. In contrast, the European eel has a broad diet, consuming both invertebrates and vertebrates, including terrestrial fauna. This wide trophic niche provides greater options for tracking or shifting food resources under climate change, increasing the AC of the species or population (ie a deal maker).

The availability, quality, and consistency of input information (ie evidence) should also be considered when evaluating the resulting assessment of AC. For example, there is little information available about the natural history and ecology of ivory tree coral outside of the Oculina Bank region, a strip of coral reefs off the east coast of Florida. Moreover, values for some AC attributes had to be inferred from empirical studies on a related species, *Oculina arbuscula*. These informational limitations should therefore be considered in the interpretation of this assessment, but can also be used to inform and target future research needs. Conversely, the Karner blue butterfly has been well-studied due to its listing under the US Endangered Species Act and widespread population recovery and monitoring efforts. Given this extensive evidence base, we have relatively high confidence in the resulting AC assessment, which indicates low overall AC for this species.

Using AC to improve conservation outcomes

A detailed understanding of AC, as provided through this new framework, directly supports effective climate-adaptation planning and climate-smart conservation. For example, AC assessments can help establish management and policy priorities by differentiating those species presently capable of autonomously coping with or adjusting to projected changes from those that may require targeted attention or active intervention. Beyond helping to set priorities, the attribute-based framework provides a methodology for developing appropriate and relevant adaptation strategies. Because climate adaptation generally is defined as a means to reduce climate-related vulnerabilities and risks (or capitalize on potential benefits), explicitly linking strategies and actions to projected climate impacts is an overarching principle of climate-smart conservation (Stein *et al*. 2014). One approach for making such an explicit link is to use the components of vulnerability in considering actions capable of reducing exposure, reducing sensitivity, or enhancing AC. Indeed, “building adaptive capacity” figures prominently in a recently proposed typology of adaptation options (Prober *et al*. 2019).

In practice, identifying strategies to enhance the AC of species is challenging. By distinguishing relative AC levels for different attributes and across attribute complexes (Figure 1), our framework helps to match a species’ AC profile with meaningful adaptation strategies and actions. For example, although improving habitat connectivity is a popular and widely invoked adaptation strategy, this may not be so relevant for species with low capacity in the “movement” attribute complex. In instances where the existing locales for such species are projected to become climatically unsuitable, managers may need to consider more intensive interventions, such as managed relocations (Lawler and Olden 2011). Likewise, if a species has low capacity in the “evolutionary potential” attribute complex, relevant responses may involve genetic or population augmentation, or other mechanisms designed to increase genetic diversity to facilitate evolutionary processes. Furthermore, certain AC attributes may be particularly relevant for tailoring interventions to buffer populations from losses during extreme events, such as heat waves, droughts, or floods. For example, Ameca y Juárez *et al*. (2014) identified four traits of herbivorous mammals that increase AC to extreme events, which reflect similar AC attributes in this framework that optimize population size, geographic extent, and competitive and movement abilities. The graphic depiction of relative AC across the full array of attributes (Figures 4 and 5), including identification of deal breakers, offers managers a powerful tool for tailoring strategies to the specific AC profile or climate-change exposure of a given species, and identifying strategies with the greatest potential to reduce vulnerabilities by enhancing AC.

This new AC framework can also assist planners in setting climate-informed conservation goals, and specifically to determine when persistence-oriented goals continue to be appropriate, or when to set goals that accept or even facilitate ecological transformation (ie systems that deviate markedly from prior ecosystem composition, structure, or function). For example, an evaluation of AC may suggest that tree species in a given forest are capable of persisting in the face of climate-related disturbances, such as increased drought and high-severity wildfires. In this case, forest managers might emphasize the use of existing species and locally derived seed sources in restoration efforts. In cases where contemporary and projected disturbances are likely to exceed the AC of existing tree species, it may be worth intentionally transitioning the system to species or genotypes better capable of surviving under future climatic conditions. The detailed understanding of AC that derives from this new framework can help planners prepare for what has been termed “achievable future conditions” (Golladay *et al*. 2016) and craft climate-informed conservation goals. This in turn can inform decisions regarding when, where, and for how long persistence-oriented strategies may be appropriate to employ, and when a shift in focus to change-oriented goals and strategies is necessary (Stein *et al*. 2014).

Caveats for use of the framework

After testing and application, our generalized framework for operationalizing the concept of AC was robust across disparate groups of organisms and systems. However, there are several caveats and limitations not only to the use of the framework but also more generally to the concept of AC itself. These include existing knowledge gaps for certain species, challenges in recognizing the relative contribution of different attributes, issues in summarizing overall AC, and lingering ambiguity in the relationship between AC and species sensitivity.

Lack of information

The framework was designed to accommodate varying levels of input data. Nonetheless, available scientific information that can serve as an input to AC assessments can vary markedly across groups of organisms and geographic regions. This problem is not unique to this AC framework, and many other assessment protocols (eg IUCN Red List of Threatened Species) specifically recognize the issue of data-deficient species (IUCN 2012). As noted previously, we identify 12 “core” attributes that cover the full range of attribute complexes, and represent attributes for which information is often available either directly or through inference even for poorly known species. To provide transparency in the evaluation process regarding availability and quality of information, however, the framework includes a system for evaluating and scoring the strength of evidence for each assessment.

Relative contribution of attributes

Various attributes and attribute complexes will contribute differentially to the AC of different species, and possibly even the same species in different ecological or geographic settings. For example, dispersal-related attributes may be more important to AC in populations at the leading edge versus trailing edge of the range boundary of a species. The framework does not, however, attempt to weight the relative contribution of different attributes; rather, it implicitly assumes an equal contribution from each attribute. In addition, although we highlight the importance of identifying possible deal-breaker or deal-maker attributes, in practice recognizing these may prove challenging. Much also remains to be learned about how AC manifests itself in different taxonomic groups and ecological contexts, whether it is phylogenetically conserved, and if it changes over time.

Conveying overall AC

Although we recognize the desire by some for a single overall metric of AC, either quantitative or categorical, no satisfactory algorithm for calculating such a metric has yet emerged. Indeed, the broader utility of this framework is to provide practitioners with a deeper understanding of and appreciation for the factors underlying a species’ AC (or lack thereof) rather than through production of a simple numeric or categorical rating. The value in assessing AC (and climate vulnerability more broadly) is not just in determining which species have high or low AC or are climate vulnerable, but also in understanding why they do. Insights revealed by understanding the underlying basis for a species’ AC are the key to designing effective adaptation strategies and actions.

Relationship to sensitivity

As noted previously, most vulnerability assessments for ecological resources rely on the three-component CCVA framework of exposure, sensitivity, and AC. There has been long-standing confusion between the concepts of AC and sensitivity; the terms are frequently used interchangeably, and decisions on when to use one or the other term are often made arbitrarily. For example, Gardali *et al*. (2013) explicitly omitted AC in their CCVA "because of the inherent difficulties in scoring adaptive capacity", and therefore relied on several components of sensitivity as indirect measures of AC. Similarly, Williams *et al*. (2008) defined vulnerability as a function of sensitivity (mediated by AC and resiliency) and exposure to climate change. There are also concerns that the three-part vulnerability framework may actually constrain understanding and use of the concept of AC (Fortini and Schubert 2017). Indeed, although numerous attempts have been made to disentangle the definitions of AC and sensitivity (reviewed in WebTable 4), these have not resulted in clear and broadly accepted boundaries.

Our focus here is on AC as a stand-alone concept, and rather than attempt to delineate an artificial boundary between the two concepts, we take an expansive view of AC as the capacity of a species to persist by coping with or adjusting to changing climatic conditions. More narrowly drawn definitions of AC sometimes focus on adjustment aspects, whereas many definitions of sensitivity emphasize coping abilities (or lack thereof) based on existing tolerances and thresholds. Core attributes of AC, as defined here (Figure 1), that are often associated with sensitivity include habitat specialization, physiological tolerances, and diet breadth, while those linked to narrowly drawn definitions of AC include dispersal distance, genetic diversity, population size, and fecundity. The detailed attribute descriptions, methods of evaluation, and suggested thresholds offered in WebTable 2 should prove useful even in vulnerability assessments where a given attribute is treated as an element of sensitivity.

Rising to the adaptation challenge

Climate change is emerging as the conservation and natural-resource–use challenge of our time, yet many managers remain apprehensive about how to address climate considerations in species and ecosystem management. To overcome that challenge, we believe that the science underlying effective climate adaptation must be advanced, and that actionable tools and techniques must be provided to practitioners to realize climate-smart conservation. Understanding the ability of a species to cope with or adjust to changing climatic conditions – its "adaptive capacity" – is key to the design and implementation of effective adaptation strategies, but to date the concept has been difficult to operationalize. Although much remains to be learned about how different species may respond to changing conditions, the attribute-based framework we offer represents a tangible way for conservation and natural-resource practitioners to more consistently apply the concept of AC as they prepare for and adapt to a changing climate.

Government of Canada Gouvernement du Canada

Understanding how birds respond to disturbances in the forest

Scientists are studying birds in Canada's boreal forest. Birds are abundant in the boreal because of its vast size and the variety of habitats that it provides.

Birds are part of the enduring beauty of Canada's forests. They are also a barometer of environmental change. How they respond to disturbances in the forest can suggest how other less visible or harder-to-study species are faring. Canadian Forest Service research aims to inform management decisions that account for bird habitat.

Figure 1..Boreal chickadee

Population trends

The overall long-term population trends of most boreal bird species are either stable or increasing. But populations of some common bird species are in decline around the world, including some found in Canada's boreal forest—for example, the rusty blackbird (*Euphagus carolinus*), Canada warbler (*Wilsonia canadensis*) and Connecticut warbler (*Oporornis agilis*).

Bird populations vary naturally, and the causes of population changes are complex and hard to attribute to any single factor. Population fluctuations may result from both natural causes (weather, fire, insect cycles) and human-related causes (climate change, fire suppression, forest management, forest loss, industrial activities).

The declines seen in some boreal bird species are likely related to various environmental changes and habitat loss and/or degradation that could be occurring on the breeding grounds, the wintering grounds or in migration stopover habitats. Research suggests that winter habitat degradation is one of the most significant factors affecting many migratory birds. Significant amounts of forest cover have been lost in some countries where birds that breed in Canada overwinter.

Impacts of forest harvesting

In Canada's boreal forest, the impact of timber harvesting on bird populations is complicated, differing by species, region, forest type, harvest prescription, length of time after harvest, and so on. Forest harvesting may cause changes in bird species composition, diversity and abundance, and these changes can be positive, neutral or negative, depending on the species and the types of habitat that it uses.

For example, early successional species such as mourning warbler (*Oporornis philadelphia*), chestnut-sided warbler (*Dendroica pensylvanica*) and white-throated sparrow (*Zonotrichia albicollis*) benefit from harvesting, as they prefer a younger forest. But some forest-dependent species, such as brown creeper (*Certhia Americana*), boreal chickadee (*Poecile hudsonica*) and ovenbird (*Seiurus aurocapilla*) are sensitive to the loss of old forest habitat.

Other species, such as woodpeckers, require dead or dying trees for nesting and feeding, while others require the cavities created by woodpeckers in which to nest. Still others, such as raptors and flycatchers, use standing live or dead trees in clear cuts and burned areas, as perches from which to hunt. Protecting forests from fire can reduce the availability of these types of habitat features across the landscape.

Research has shown that harvesting patterns that emulate natural disturbances tend to benefit birds and other wildlife, and promote forest biodiversity in general. As a result, jurisdictions in Canada either require or are moving toward harvesting practices that aim to mimic natural disturbances, and are implementing ecosystem management practices to conserve wildlife habitat. Many provinces have also developed action plans to improve their knowledge of biodiversity in the forest by completing inventories, conducting research and carrying out environmental monitoring. In addition, industry is partnering with environmental non-governmental organizations to develop projects that advance boreal forest science and conservation.

Government of Canada Gouvernement du Canada

Assisted Migration

Forests are climate sensitive, and a range of climate change impacts are already evident across Canada. Trees appear to be responding to warming temperatures by dispersing into more climatically suitable habitats. However, some populations will be unable to keep up with the rapid rate of environmental change.

Numerous adaptation options are being considered as ways to maintain the biodiversity, health and productivity of Canada's forests under continued climate change. One option that is of increasing interest is "assisted migration," the human-assisted movement of plants or animals to more climatically suitable habitats.

In order to ensure that seeds used in reforestation are adapted to their environment, many jurisdictions have developed seed transfer guidelines that recommend where seed from specific geographical areas should be planted. Some jurisdictions in Canada have begun to implement assisted migration of tree species on a small scale by modifying these guidelines. For example, British Columbia has extended seed transfer zones 200 metres higher in elevation for most species, and introduced new policy to allow the planting of western larch outside of its previous range. Alberta has extended seed transfer zones 200 metres higher in elevation and 2 degrees of latitude northward for most species. And Quebec has incorporated the risk of climate change maladaptation into seed transfer functions, planting seed mixtures composed of local and more southern seed sources in some regions. In all cases, it is critically important that the seed used in assisted migration has been documented, tested and stored appropriately, and has come from a wide range of sources and species.

Assisted migration can be contemplated for both conservation goals (e.g., to save a species) and forestry goals (e.g., to maintain health and productivity). Currently, given existing knowledge and established best practices, assisted migration is more feasible for major commercial tree species than for rare species of conservation concern.

<u>Issues to be considered</u>

Assisted migration has the potential to alleviate some of the risks posed by climate change to biodiversity and tree health and productivity, such as species extinction. However, there are possible risks in implementing assisted migration. These might include the impact of the introduced species on the hosting environment, a species becoming invasive, mortality and investment loss if the species or population is not well adapted to the local conditions, and so on. These risks must always be balanced against the risk of not doing it.

Assisted migration describes a wide range of concepts and practices at various scales. But three types of assisted migration, each with a different level of risk and uncertainty, can be distinguished:

- Assisted population migration—The human-assisted movement of populations within a species' established range—*Lower risk*
- Assisted range expansion—The human-assisted movement of species to areas just outside their established range, facilitating or mimicking natural range expansion—*Intermediate risk*
- Assisted long-distance migration—The human-assisted movement of species to areas far outside their established range (beyond areas accessible through natural dispersal)—*Higher risk*

In order to ensure that assisted migration is beneficial and that the risks are minimized, decisions need to be supported by the best possible scientific knowledge. A range of dimensions other than climate, such as photoperiod and soil properties, will need to be considered when deciding what species to move and where to move it to. Where assisted migration is undertaken, migrated populations and the receiving ecosystems should be carefully monitored over time.

Assisted migration is an emerging concept with potential benefits as a climate change adaptation strategy but it poses many questions and offers many unknowns. The idea that humans can help fill the gap between the ability of species to migrate and the rate of change in climate conditions is increasingly being considered and debated as a possible management option.

The Canadian Forest Service is expanding knowledge of assisted migration on several fronts, including research aimed at filling knowledge gaps, development of practical research tools and models, and the conservation of vulnerable species, in addition to collaborating with national and international entities.

Understanding Climate Change Impacts in Temperate Forests

Written by Ronald Mahoney

May 16, 2019, Climate Woodlands – Extension Foundation and Cooperative Extension

Forest ecosystems are complicated and ever changing. Forest landowners and managers must consider a vast array of information to meet either specific stand objectives and/or broader goals of landscape level management. In many situations, land management objectives integrate measurable products, such as timber and forage, and less tangible assets, often collectively described as aesthetics. On other lands, production of timber or other products may be primary, but a broad consideration of ecosystem functions and processes is still required for sustainable success.

To conceive how climate change can and is affecting temperate and boreal forests, it is necessary to first understand how different species in these ecosystems relate to each other (synecology) and how individual species relate to their environment (autecology). Many of the fundamental ecological principles were developed from research and experience in more tropical ecosystems, which have had little climate change or large-scale disturbances. As a result, tropical species have co-evolved to extreme specialization with highly developed adaptations to specific ecological niches and a finely tuned interdependence.

As you move north, more regular and dramatic disturbances occur. For example, the plants and animals of the Inland Northwest have been associated for less than 10,000 years, and in boreal and arctic regions for far less time. Consequently, the synecology of these plant and animal communities is much less developed. Most species are linked more by competition and adaptation to disturbance than by the refined interdependence we see in tropical ecosystems. Many of the pathogen/host interactions in this temperate region would seem to be a result of co-evolution, although many pathogens show the ability to infest diverse hosts. As examples, the white pine weevil (*Pissodes strobi*) infects mostly spruce (*Picea spp.)* and lodgepole pine (*Pinus contorta*), mountain pine beetles (*Dendroctonus ponderosae*) have success in several pine species, and the spruce budworm (*Choristoneura spp.)* can shift from grand fir (*Abies grandis*) to Douglas-fir (*Pseudotsuga menziesii)* to hemlock (*Tsuga spp.)* depending on availability and host condition. There may be more selection pressure for "generalist" pathogens and other opportunistic adaptations of many plants and animals because of more frequent and dramatic disturbances.

Moving from temperate to boreal to arctic forest ecosystems uncovers an increasing ability of organisms to adapt to change. These forests also experience more dramatic disturbances and their effects on species survival are often evident in epidemic pathogen outbreaks with some species being reduced or eliminated. Other species in these changing situations may greatly increase their range, vigor, and percent of the population. Rather than the current focus being on species decline as a result of human activity, perspective on the bigger picture is needed to understand and accommodate changes in species and environments. While human impacts on climate change should be modified, there are many interrelated, but inevitable, changes to understand and plan for to reduce the undesirable effects of climate change.

These generalizations about climate change effects on large-scale ecosystems are only part of a very complex and dynamic interaction of the physical and biological environments. However, they can guide decisions about how specific sites may be affected and how these changes may affect silvicultural objectives and prescriptions.

Species that require very specific ecological conditions to succeed and those that are adaptable to a wide range of conditions and are at the fringes of their tolerance will show the first and most dramatic climate change impacts.

Changes in temperature and water availability can create problems for many of these sensitive species. Periods of unseasonably warm temperatures followed by dramatic freezing periods can leave trees susceptible to frost damage and death (Saxe et al. 2001); two impacts that have already been seen in Alaskan yellow-cedar and in some Inland Northwest larch (*Larix occidentalis*). Many of these changes in climate are not directly manifest in warming, but in when and where precipitation occurs, particularly in having rain instead of snow during winter and in very early or late severe cold. Additionally, changes in water availability can create drought conditions, affecting tree growth during time periods when trees are most in need.

While forests represent a major opportunity for carbon storage to reduce greenhouse gases, their ability to do so is largely dependent on the overall system's response to changes in environmental conditions. The intricate interplay between species range, disturbance regimes, and species' life cycle will all play a role in how well temperate forest ecosystems respond to changing climatic conditions.

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Forest ecosystems of temperate climatic regions: from ancient use to climate change *(excerpt)*

Frank S. Gilliam – New Phytologist – 27 October, 2016

IV. Climate change

Humans have, indeed, long utilized temperate forests for a variety of purposes (Fig. 2). Currently, temperate forests are managed worldwide for timber production, driven by an ever-increasing demand and resulting from relatively rapid growth among overstory dominant species, but also from the versatility of temperate tree species for numerous uses (e.g. paper, construction materials, furniture). Management practices potentially affect these forests across all spatial scales, from the landscape (Rhemtulla *et al*., 2009), to the overstory (Beaudet *et al*., 2004), and, often most sensitive, the herb layer (Moola & Vasseur, 2009; von Oheimb & Härdtle, 2009; Gilliam, 2014; Hedwall & Brunet, 2016). Furthermore, management practices historically often have been carried out using methods that are unsustainable in terms of maintaining forest ecosystem structure and function, including plantation forestry, especially conversion from slower-growing hardwood forests to faster-growing conifer plantations (Seidl *et al*., 2011), and forest fragmentation (Smith-Ramírez, 2004). Naudts *et al*. (2016) suggested that broadscale conversion of temperate European hardwoods to conifer plantations contributes measurably to what is perhaps the most profound modern human influence on these forests – climate change (Lindner *et al*., 2010; Parks & Bernier, 2010).

Thus, I suggest the following as the 'bookends' of anthropogenic impacts on temperate forests. The first is their historic – even ancient – and chronic use/conversion by ever-increasing human populations; the second is climate change. The spatial and temporal dimensions of these are superimposed (Fig. 5). The legacy effects of the recent and distant past are currently on a trajectory of future dynamics operating under the overriding influence of climate change (Dale *et al*., 2001), and all that is associated with it, including altered phenology of organisms (Parmesan & Yohe, 2003) and extremes of weather-related phenomena (Min *et al*., 2011) (Fig. 6). All responses of temperate forests to current land-use pressures must be viewed forever through the lens of climate change (Fig. 5).

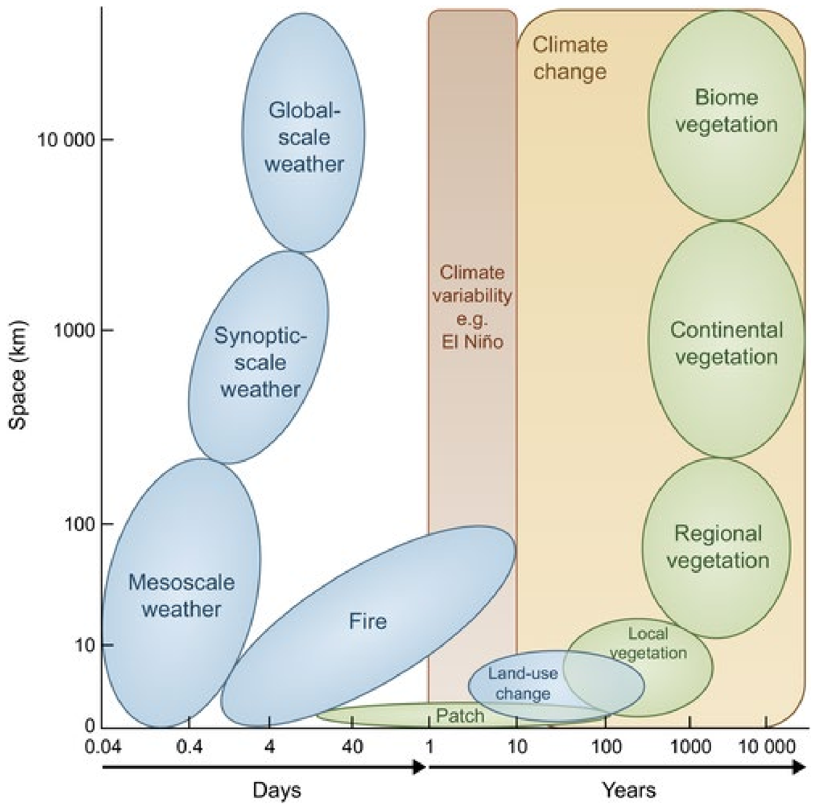

Figure 5 *- Spatial and temporal scales of essential ecosystem drivers (weather, climate variability and climate change, fire and land-use change) and related distribution of vegetation. Figure reprinted from Mackey et al. (2012), with permission from Wiley Press.*

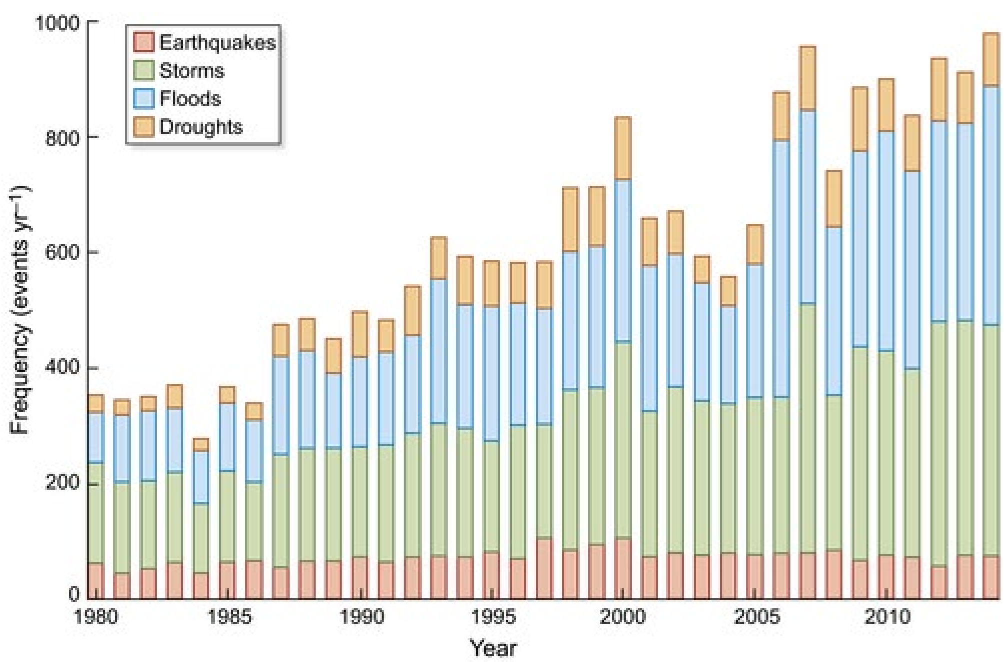

Figure 6 *- Annual frequency of catastrophic natural disturbances globally from 1980 to 2014. Figure originally re-created by Annalisha Johnson (Marshall University, Huntington, WV, USA) from data taken from Münchener Rückversicherungs-Gesellschaft, Geo Risks Research, NatCatSERVICE.*

In this final section, I emphasize challenges for future sustainability of global temperate forests. This is not meant to represent an exhaustive list of all critical issues. Rather, I emphasize those for which sufficient work has been done to provide an understanding of the nature of the problem. These include the effects of atmospheric deposition of excess N, global change-mediated alterations in phenology of temperate forest species and increases in drought/fire.

1. Excess nitrogen

More pronounced in the Northern than the Southern Hemisphere, a major human perturbation of temperate forests worldwide has arisen from emissions of reactive nitrogen (N_r) into the atmosphere leading to chronically elevated deposition of N_r and a cascade of environmental stresses for terrestrial and aquatic ecosystems and human health (Galloway *et al*., 2013). The N comprising 78% of the atmosphere – N_2 – is considered nonreactive N because it enters into essentially no photochemical transformations in the atmosphere and no metabolic pathways in organisms, other than N fixation by a small group of symbiotic and nonsymbiotic prokaryotes. However, numerous forms of N_r exist, including NH_3, NH_4^+, NO, NO_2, NO_3^-, $2N_2O_5$, HNO_3 and several forms of peroxyacetyl nitrates (Horii *et al*., 2005), all capable of undergoing photochemical transformations in the atmosphere and entering terrestrial and aquatic ecosystems.

Although more research on the effects of excess N has focused on herb-dominated than on forested ecosystems (Clark *et al*., 2013; Simkin *et al*., 2016), increasingly work is being devoted to understanding such effects on forest ecosystems, including those of the temperate regions (Sutton *et al*., 2014). Whereas current increases in N deposition are occurring on a global scale (Bobbink *et al*., 2010), N-mediated threats to biodiversity are particularly pronounced for temperate forests, especially given the spatial coincidence of high human population density – and associated N pollution – with temperate forests (Holland & Lamarque, 1997), the disproportionate contribution of the herbaceous layer to temperate forest diversity (Gilliam, 2007), and the sensitivity of the forest herb community to excess N (Gilliam, 2006). More vexing still is that chronically elevated N deposition is occurring contemporaneously and, indeed, interactively with climate change (Maes *et al*., 2014).

Essentially all initial work on effects of excess N deposition on terrestrial ecosystems examined biogeochemical responses. These studies focused on changes in stream chemistry, generally showing increases in NO_3^- (from enhanced nitrification and leaching) and base cations (Ca^{++}, Mg^{++} and K^+) coupled with the movement of NO_3^- (Aber, 1992). Many areas of temperate forests of North America, especially those of the eastern United States, were shown to be sensitive to *N saturation*, a phenomenon which develops as atmospheric and microbial supply of available N exceeds biotic demand. Recent work has emphasized the effects of excess N on biodiversity of temperate forests (Thomas *et al*., 2010; Clark *et al*., 2013; Simkin *et al*., 2016). Despite considerable inter-site variability, a broad consensus is that excess N decreases forest biodiversity in temperate forests of North America.

Gilliam (2006) provided a conceptual model to describe interactive processes that are sensitive to increased N loading in ways that can lead to loss of herb layer diversity, including altering interspecific competition, increasing herbivory and pathogenic fungal infection, inhibiting mycorrhizal associations and enhancing species invasions. Nitrogen-mediated declines in biodiversity are typically seen as loss of species in the herb layer from the increased cover of fewer nitrophilic species at the expense of numerous N-efficient species (Gilliam *et al*., 2016). Fewer studies have focused on responses of tree species to N. Thomas *et al*. (2010) modelled the potential effects of N on temperate forest C sequestration and tree seedling survivorship. Chronically elevated N deposition enhanced C storage, but decreased survivorship in 8 of 11 common temperate tree species. Following N saturation, C sequestration is typically limited by another nutrient (Leuzinger & Hättenschwiler, 2013), often phosphorus (Gress *et al*., 2007).

Research focusing on chronically elevated N deposition leading to N saturation began in Europe much earlier than in North America, primarily because N-related threats appeared earlier and were far more widespread there (Gilliam, 2006). Although a notable amount of European work has been in the boreal region and in herb-dominated ecosystems, most recent work has been carried out in temperate forested regions, with much of that concerned with the response of the typically species-rich herbaceous layer to excess N, largely based on broad regional synthesis studies (De Schrijver *et al*., 2011; Verheyen *et al*., 2012; Dirnböck *et al*., 2014; Ferretti *et al*., 2014).

Borrowing a phrase from my home state of West Virginia, where coal mining is common, many N-effects studies in Europe use the forest herb layer community as 'the canary in a coal mine' (wherein caged canaries were once placed in a coal mine, whose death served as an early indication of impending peril for coal miners from coal gas). The wide spatial extent of sampling employed by these studies adds considerable validity and credibility to their findings. Verheyen *et al*. (2012) compiled data from 1205 permanent/semi-permanent sample plots among 23 carefully selected understory resurvey studies. Utilizing a wide gradient in N deposition across deciduous temperate forests in Europe, they assessed the importance of factors influencing forest herb communities, including rate of N deposition, change in density of large herbivores, and change in forest canopy cover and composition. Their results demonstrated the interactive nature of these factors, concluding that N-mediated increases in nitrophilous species can be obscured by changes in the forest overstory. Similarly, Dirnböck *et al*. (2014) synthesized long-term monitoring data from 1335 permanent samples among 28 forested sites from northern Fennoscandia to southern Italy, noting temporal trends in herb-layer species cover and diversity. They found a pattern of gradual replacement of N-efficient species by nitrophilous species in response to N deposition that was consistent on the European scale. Hedwall & Brunet (2016) attempted to separate effects of global change and altered land-use in both boreal and temperate forests of Sweden by documenting temporal variation in herb layer species over a 20-yr period in both boreal and temperate forests of Sweden, finding that most species changed in overall frequency. Comparing functional traits of both increasing and declining species, they found that current floristic dynamics were caused by combined effects of climate warming, nitrogen deposition and changing land-use (e.g. plantation forestry). Herb species' changes were more pronounced in temperate, rather than boreal, forests.

Less is known regarding the effects of excess N on temperate forests of Asia (Liu *et al*., 2013) and the Southern Hemisphere. In China, this arises because of the chronically highly dissected extent of temperate forests (Liu, 1988) and the spatial distribution of highest amounts of N deposition occurring in tropical/sub-tropical regions (Lu *et al*., 2015). In addition to elevated rates of N emissions to the atmosphere (Liu *et al*., 2013), much of China's problems with excess N is associated with over-use of N fertilizers for summer maize agriculture (Zhang *et al*., 2015). Kim *et al*. (2011) concluded that increases in N availability throughout Korea and Japan was most likely due to deposition of pollutant N from atmospheric sources from both industrial and agricultural regions. Perakis & Hedin (2002) found that, as a result of their location relative to oceans, with prevailing winds coming off those oceans, forests of the temperate regions of the

Southern Hemisphere receive some of the lowest annual rates of N deposition anywhere in the world (Godoy *et al*., 2001).

2. Altered phenology

Given that a prominent feature of all temperate forests is their distinct seasonality, phenology – seasonally recurring events of an organism's life cycle, for example, flowering, emergence of invertebrates, movement of migratory animals, and especially their timing and relationship with the physical environment – plays a key role in the structure and function of temperate forest ecosystems. For plants, phenological changes can be triggered by environmental cues, for example, chilling, spring temperature, growing degree days and daylight (Elmendorf *et al*., 2016). Because of their lack of thermoregulation, ectothermic animals (e.g. insects) can resemble plants with respect to environmental influences on and control of phenology, particularly temperature. Changes in phenology can affect several processes essential to survival, growth and reproduction of all organisms, especially critical when complex interspecific interactions are involved, such as plant–pollinator dynamics.

Many plant species are classified phenologically, based on seasonal patterns of flowering via photoperiod. Long-day plants flower in spring as day length increases, whereas short-day plants flower from late summer into the fall as day length decreases. Actually, it is the length of uninterrupted darkness that controls flowering, such that long-day plants are more accurately short-night plants and *vice versa*. Despite this importance of photoperiod, thermoperiod – daily and seasonal patterns of change in temperature – also affects virtually all phenologically controlled plant processes. Anecdotally, gardeners rue days of atypically warm temperatures in late winter that allow flower and leaf buds to break dormancy, only to be followed by seasonal temperatures < 0°C that kill new, susceptible tissues.

Evidence indicates that climate change has altered growing seasons in the temperate regions worldwide. Based on global meta-analyses of > 1700 wild species, including woody and herbaceous plants, birds, insects, amphibians and fish, Parmesan & Yohe (2003) found widespread changes in phenology and species distributions attributable to climate warming. Despite some species' temporal stability, most exhibited change as predicted by the United Nation's Intergovernmental Panel on Climate Change. They found advancing spring events of 2.3 d/decade, and shifting biogeographical ranges toward the poles of 6.1 km per decade (Parmesan & Yohe, 2003), calling such changes a 'coherent fingerprint' of the overall effect of climate change on natural systems.

Ibáñez *et al*. (2010) observed that climate warming has altered both spring and autumn phenologies of many species, but found considerable interspecific variation and, for a given species, spatial variation in response to climate change. Forecasting future change, they used a long-term (1953–2005) dataset including spring and autumn plant phenological events (flowering/leaf out and leaf coloring/leaf fall, respectively) of tree, shrub and herbaceous species of temperate forests of South Korea and Japan, finding that most species currently exhibit advanced spring phenology and delayed autumn phenology, consistent with expectations, but also that autumn-based changes are more rapid than those associated with spring. The latter observation contrasts with comparable studies in Europe which show that spring events are changing more rapidly than autumn events (Menzel *et al*., 2006).

For temperate forests, three relevant factors affecting the phenology of dominant tree species are photoperiod, degree of winter chilling and temperature (Körner & Basler, 2010). There is, however, interspecific variability in which predominant factor(s) control phenology among temperate forest species, with photoperiod increasing in importance with forest succession; that is, it is more important for long-lived, late-successional species than for short-lived, early-successional species. Although this may mitigate warming-induced change in temperate forest composition, Körner & Basler suggested that opportunistic (e.g. exotic invasive) species may benefit from a warming climate and claim a competitive advantage over photoperiod-sensitive species (Körner & Basler, 2010).

Altered phenology is a driver of change not only for plant species, but also for animal species, creating a complex scenario for plant–animal interactions, particularly pollination. Less a problem for climax canopy hardwood species, which are almost exclusively wind-pollinated, this is irrelevant for temperate conifers, but an especially serious threat for forest herbaceous species. Potts *et al*. (2010) reviewed patterns of global declines in numerous pollinator species, with an understandable focus on insects – especially bees – considering that they are the primary pollinators of both agricultural crops and wild species. Potential drivers of pollinator loss include habitat loss/fragmentation, agrochemicals, pathogens and introductions of novel species. Also included is climate change, and interactions among virtually all drivers. Effects of climate change on insect pollinators are seen on all hierarchical levels of organization, from the individual to population and community levels. Especially troublesome are the temporal and spatial mismatches between plant species and their insect pollinators, arising temporally from changes in phenology of plant and insect species, and spatially from altered distributions (Potts *et al*., 2010).

Climate change-altered phenology has extended into changing life cycles among insects, an example of which is the mountain pine beetle (MPB; *Dendroctonus ponderosae*), native to western North America, and a generalist pest for the genus *Pinus*, often erupting epidemically, and killing wide swathes of trees throughout the region (Fig. 7a). Mitton & Ferrenberg (2012) studied a recent epidemic of MPB that was an order of magnitude larger than ever recorded and extending to higher elevations/latitudes than on record. They demonstrated that, following 20 yr of increasing air temperatures in the Front Range of the Colorado Rocky Mountains, the flight season of MPB began > 1 month earlier than historically known and extended twice that duration. More important was their novel finding that the life cycle of some broods of MPB increased from one to two generations per year (Fig. 7b). They explained that because this species lacks a diapause (suspension in development), its development is controlled solely by temperature. Accordingly, MPB populations currently respond to climate warming via faster development and expanse into previously inhospitable environments (Mitton & Ferrenberg, 2012). This work, however, was challenged by Bentz & Powell (2014), who agreed that MPB is influenced by climate change, but stated that such studies need to consider thermally dependent traits that have evolved to maintain seasonality.

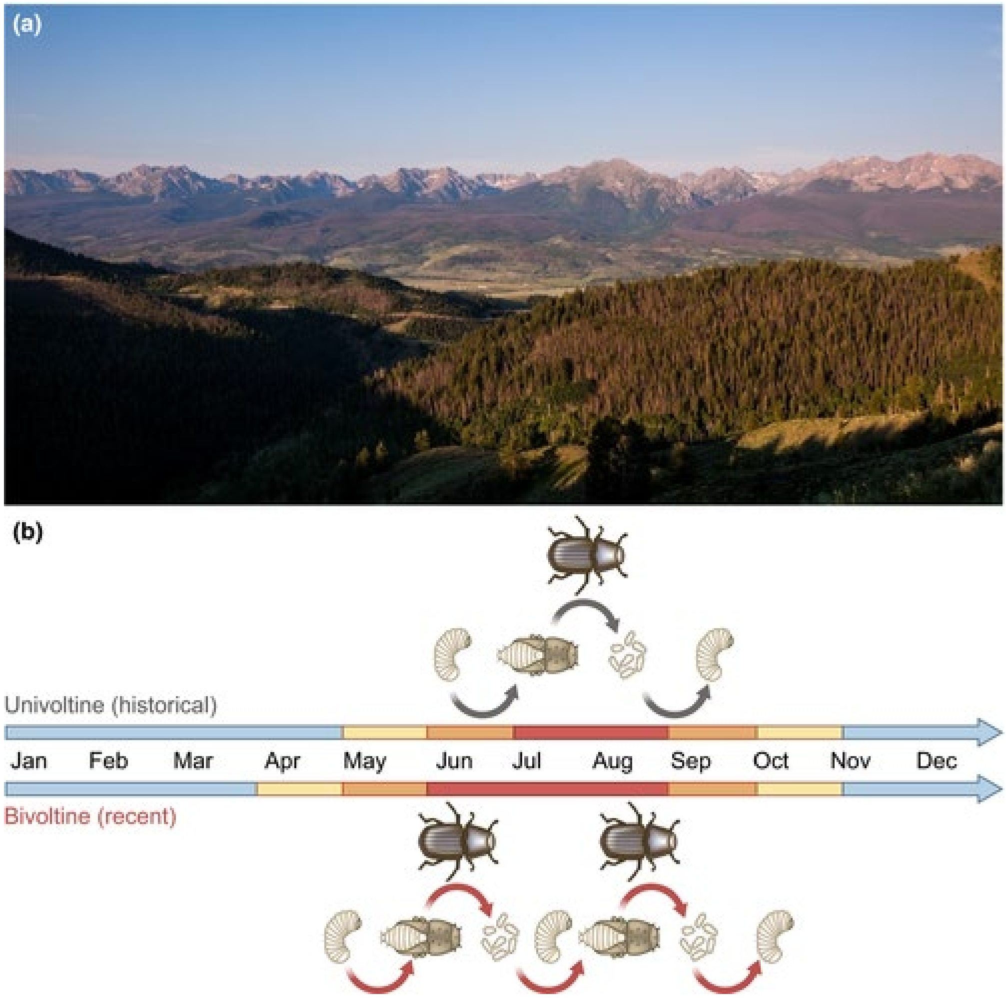

***Figure** 7 - The mountain pine beetle (MPB) of western North America. (a) Wide swathes of beetle-killed trees in the Williams Fork Mountains (foreground) and the Gore Range of northern Colorado. Photo credit: Jeffry B. Mitton, used with permission; (b) Historical univoltine life cycle of MPB (above calendar arrows and linked by grey arrows) and observed bivoltine life cycle (below calendar arrows and linked by red arrows). Colors of calendar arrows indicate monthly temperature regimes: blue: < 0°C, yellow: 0–4.99°C, orange: 5–9.99°C, and red: ≥ 10°C. Figure from Mitton & Ferrenberg (2012), with permission from authors.*

Climate change interactions have been reported for other forest pest insects. DeRose *et al*. (2013) combined empirical data, based on US Forest Service Forest Inventory Analysis data, with three global change models to evaluate and predict the effect of increasing temperature on the distribution of spruce beetle (*Dendroctonus rufipennis*), which attacks spruce forests of North America. They predicted that extent of attack should increase with temperature, but that there should be time lag in response, given the long-lived nature of host spruce trees.

This phenomenon is not confined to North America. Netherer & Schopf (2010) reported similar findings from throughout Europe for defoliating insects, bark beetles and especially the pine processionary moth (*Thaumetopoea pityocampa*), a defoliating insect for numerous conifer species. Its altitudinal and latitudinal distributions are controlled primarily by temperature and are already modified by climate change. Because of the prevailing oceanic climate in the

Southern Hemisphere (i.e. generally lower temperatures during the growing season), climate change is predicted to promote contrasting effects on insect cycles there, as well (Deutsch *et al*., 2008).

Related to climate change-mitigated alterations in phenology are similarly altered changes in biogeographical ranges of species. Again, Parmesan & Yohe (2003) concluded that climate change has caused mean pole-ward range shifts of 6.1 km per decade. Using seven global circulation models (GCMs), Hansen *et al*. (2001) projected future distributions of prominent temperate forest types of North America, including the eastern deciduous forest and western mountain/coastal forests of the United States, focusing on major tree species. These models differ in their type – equilibrium vs transient – and in assumptions of change in temperature and precipitation. Equilibrium models are older and simulate instantaneous increases in CO_2, being run until equilibrium climate conditions are reached; the more recent transient models assume increases in glasshouse gases at 1% yr^{-1} until 2100, allowing climatic adjustment. Although specific predicted outcomes for eastern forest species varied among models (Fig. 8), all concurred in predicting profound shifts in dominant species, especially the virtual elimination the maple–beech–birch forest type (one of the more species-rich forest types of the region) and loblolly–shortleaf pine, and expansion of oak–hickory and oak–pine types (Fig. 8). Potential ranges for several subalpine coniferous species are predicted to contract in the western United States (data not shown). Among their conclusions is that changes in climate and land use in the future will be of a magnitude to cause even greater changes in biodiversity. Although distributions of some species, communities and biomes are likely to expand, others will contract, creating novel communities (Hansen *et al*., 2001).

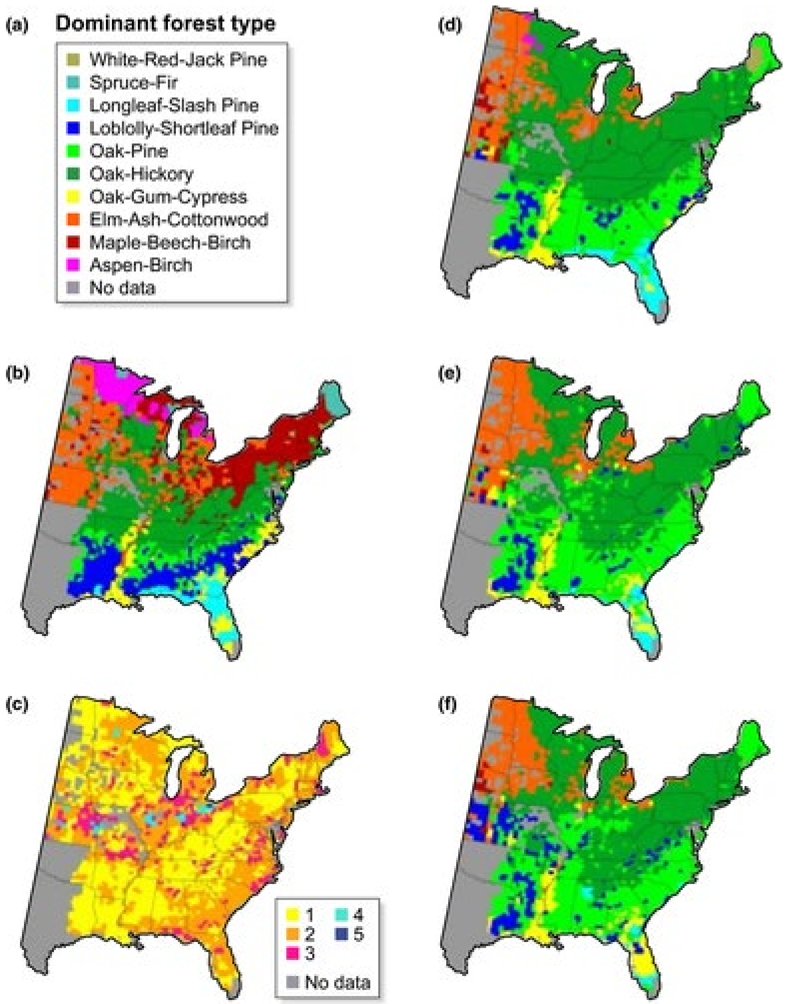

Figure 8 *- Potential distributions of forest community types in the eastern United States as simulated with the DISTRIB model (an empirical model that uses a regression tree analysis approach) under five different global circulation model (GCM) scenarios and representing an approximate doubling of concentrations of CO_2 – see Iverson & Prasad (2001) for description of model and GCM scenarios. (a) Color key for forest types; (b) current forest-type distribution based on 100,000 forest inventory plots; (c) uncertainty map, with the number of unique forest community types simulated across all five future GCM scenarios plotted; (d) potential forest community type distribution under the HADCM2SUL scenario, among the coolest of future warming scenarios; (e) a modal map of future biome distributions (shown are the biomes most often simulated for the future across all five GCMs; refer to panel (c) for the 'uncertainty' associated with the modal map); and (f) forest community type distribution under the CGCM1 scenario, among the warmest of future scenarios. Figure from Hansen et al. (2001), with permission of Oxford University Press.*

3. Drought/fire

In their now-classic paper, Hansen *et al*. (1988) provided forecasts of several outcomes of global climate change using the three-dimensional model of the Goddard Institute for Space Studies. These included increased atmospheric warming globally, with degree of warming dependent on growth of trace gas emissions. Another prediction, one relevant for the present and future of global temperate forests, was a notable increase in the frequency of extremes of weather events and conditions. Indeed, this prediction is well-supported by current data collected by the *Münchener Rückversicherungs-Gesellschaft, Geo Risks Research, NatCatSERVICE*, wherein they examined global annual frequency of catastrophic disturbances 1980–2014 (Fig. 6). All types of catastrophic disturbance, save earthquakes, have increased during this period. These are true extremes, indeed, considering that frequencies of both flooding and drought exhibit large increases over the *c*. 35 yr time period. Relevant to the current discussion is the increased frequency of drought, a disturbance not directly associated with any particular biome, but representing an especially serious threat to temperate forests (Fig. 6).

Forests typically develop in the temperate zone wherever there is sufficient precipitation to maintain soil moisture amounts capable of supporting tree growth and survival. Thus, the occurrence of extensive drought will have directly damaging effects on tree species. In addition to the direct limitations of drought-induced moisture stress, however, is the drought-induced increase in the frequency of fire. Wildfire activity has not only been predicted to increase in the future under a climate warming scenario, but also such increases are hypothesized to bring about biogeographical shifts that reduce the resilience of fire-prone forests worldwide (Harvey *et al*., 2016). Although the relative contribution of fire to forest decline is greatest in the boreal forest, fire still represents a threat to temperate forests, especially conifer forests already weakened by drought (Hansen *et al*., 2013). Harvey *et al*. (2016) tested two hypotheses associated with this observation in fire-prone subalpine (largely conifer) forests in the Rocky Mountains of the United States: (1) availability of viable seeds will decrease in large patches following stand-replacing fire, and (2) seedling establishment and survival will decline measurably following post-fire drought. They found that total tree seedling establishment declined sharply post-fire with greater drought severity and with greater distance to seed source. Many responses exhibited interspecific variation, suggesting fire/drought-induced changes in forest composition. They concluded that, given the predicted increase in frequency of drought and wildfire in the future, post-fire tree seedling establishment of these forests could be reduced substantially. Although some of these reductions might be offset by compensatory increases from lower montane and upper timberline species, important near- to mid-term shifts in the composition and structure of high-elevation forests will occur under continued climate warming and increased wildfire activity.

Not part of their study, yet no less important, is the interaction of drought and fire with increases in extent and severity of forests pests, as discussed in Mitton & Ferrenberg (2012) in North America and Netherer & Schopf (2010) in Europe. That is, the scene depicted in Fig. 7(a) of wide swathes of insect-killed stems is of trees more susceptible to insect death because of drought stress, and simultaneously represents substantial fuel for intense fires. Furthermore, McDowell *et al*. (2008) established a close connection between climate change-enhanced drought and increases in pests for temperate forests of North America.

Full Article and Sources found here: https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.14255

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Current Issue Part A Study Resources

Key Topic #5: Legislation and Regulations

21. Describe how governments determine if forest harvesting levels will be sustainable in the future with climate change.
22. Explain how natural disturbances such as wildfires, windstorms, droughts, and hail storms impact the forest industry's total annual harvest quota.
23. Describe how forest certification can be used as a global tool to manage forests sustainably.
24. Identify key takeaways of the 2015 Paris Agreement and how the commitments made influence forest sustainability.
25. Explain the main goals of the 2022 Kunming-Montreal Protocol and the positive impacts this agreement could have on forest sustainability.

Study Resources

Resource Title	Source	Located on
Managing for diversity: How sustainable forest management conserves and protects Canada's diverse forest values	*Natural Resources Canada, 2024*	Pages 117-120
Forest Management and Disturbances	*Environment and Climate Change Canada, 2024*	Pages 121-124
Sustainability and Timber Harvest (AAC)	*Environment and Climate Change Canada, 2018*	Page 125
Making the case for sustainable forest management certification	*Canadian Council of Forest Ministers, 2020*	Pages 126-127
The Paris Agreement	*United Nations Climate Change, 2024*	Pages 128-129
Implementing Article 5 of the Paris Agreement and achieving climate neutrality through forests: From COFO24 to COP24	*Food and Agriculture Organization of the United Nations, 2018*	Pages 130-131
Kunming-Montreal Global Biodiversity Framework	*UN Environment Program, 2022*	Pages 132-133
Selections from: Climate Change Adaptation Plan	*USDA Forest Service, 2022*	Pages 134-139
European forests: how climate change, land ownership, and forest-related policies influence future wood supply	*International Institute for Applied Systems Analysis, 2024*	Pages 140-141

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Current Issue Part A Study Resources

Selections from: Guide to Chinese Climate Policy 2022, Chapter 23-Forestry	*Sandalow et al. – The Oxford Institute for Energy Studies, 2022*	Pages 142-151
Closing Adaptation Knowledge Gaps in Asia-Pacific	*UN Climate Change News, 2023*	Pages 152-153
Forestry Cooperation	*Association of Southeast Asian Nations, 2024*	Pages 154-157
Executive Summary *from* Latin American and Caribbean Forests in the 2020s: Trends, Challenges, and Opportunities (*excerpt*)	*Ardila et al. – Inter-American Development Bank, 2021*	Pages 158-163

<u>Study Resources begin on the next page!</u> ➡

Managing for diversity: How sustainable forest management conserves and protects Canada's diverse forest values

Canada's forests are much more than just trees. Forests are complex ecosystems that also include soil, air, water and all the living organisms that depend on them for survival. Canada manages its forests for diverse values through the principles of sustainable forest management (SFM), taking not only today's needs, but future needs into consideration.

- The many forest types across the country hold an array of environmental, economic, social and cultural values that are important to diverse groups and individuals.
- SFM aims to protect and conserve the integrity of forest ecosystems and their inherent values.
- SFM is based on sound forest science, resource monitoring and reporting, as well as consultations with stakeholders, the public and Indigenous communities.

The sustainable forest management planning process

Most public land in Canada is regulated by provincial and territorial governments who have the primary authority to create and enforce laws related to natural resource management. Forest harvesting on public lands is enabled through forest management agreements with forest companies, often referred to as tenures or licences. Under these agreements, companies are permitted to operate on public lands for a substantial period (usually 20–25 years) and must adhere to SFM principles. Forest management plans are required for these public lands and must be approved by the province or territory before any harvesting occurs. Forest management plans are very complex and require input from a variety of subject area experts. The planning team for such is led by a registered professional forester who is licenced under provincial legislation (an "ingénieur forestier" in Québec) and subject to high ethical standards and continuing education.

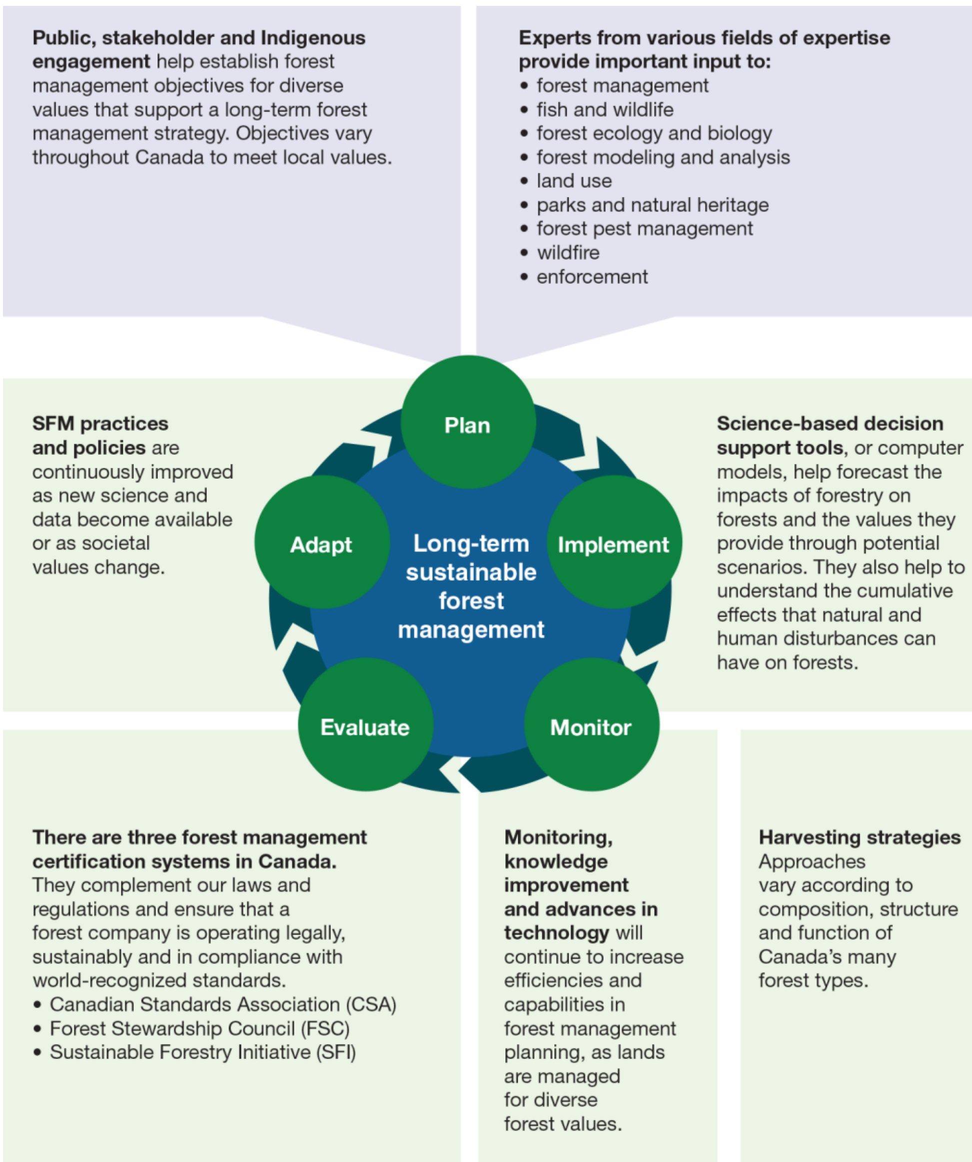
Values and objectives can go above and beyond what is required by legislation. To minimize conflicting values, forest managers can use an Integrated Resource Management (IRM) approach, whereby many values and interests are considered in the management process. Those values could include:

- ensuring sufficient habitat is available for locally important wildlife
- working to reduce the wildfire risk around communities
- addressing the impacts of climate change
- ensuring enough timber is harvested to provide local forestry jobs

Typically, forest management plans are 5–10 years in length. They outline forest management objectives for diverse values that support a long term forest management strategy. A key component of the forest management planning process is public and stakeholder engagement to ensure locally and regionally important values and objectives are identified and captured. Public and stakeholder engagement occurs multiple times throughout the development of the management plan. In addition to formal meetings, local citizen committees are encouraged to have frequent communication with the forest planning team throughout the process. Public consultation is also extremely important in the forest management planning process to consider the diverse societal values and perspectives.

Indigenous participation is another extremely important part in the management planning process and is increasing in many jurisdictions, especially where traditional uses and treaty rights may be impacted. Formal agreements featuring Indigenous-led forest management zones are in place in certain regions of Canada, as are agreements pertaining to the management and conservation of old-growth forests. Forest management planning, in most provinces and territories, has begun to formally incorporate local and Traditional Knowledge. Indigenous communities are progressively acquiring more forest management rights within their traditional territories.

Overview of the adaptive forest management cycle used to sustainably manage Canada's public forests.



Sustainable forest management: A careful balancing of diverse values

One SFM pillar is **economic values**. Forest harvesting and wood product manufacturing are critical sources of jobs for many communities in Canada, particularly rural and Indigenous communities. These jobs depend on a long-term, stable supply of wood. Sustainable harvesting of trees is determined through an annual allowable cut (AAC), which the province or territory establishes to maintain a wood supply in perpetuity.

The **environmental values** pillar of SFM can be represented by numerous values, but usually includes the protection of biodiversity, soils and water, and the reduction of carbon in the atmosphere. Forest managers strive to emulate natural disturbances in the management plan. Forest management practices supporting environmental values can involve:

- maintaining various stages of forest development, including old-growth forests, for providing diverse habitats
- managing the presence of a range of tree species of various ages over time
- leaving forest corridors to improve landscape connectivity
- varying the size and shape of harvested areas to represent natural disturbance patterns
- keeping a variable number of live and old trees, often called “veteran trees,” and cavity trees for birds and other wildlife within harvest areas
- providing buffers around nesting trees and streams to preserve wildlife habitats and water quality

The third SFM pillar is **social or cultural values**. Cultural heritage and spiritual values are significant to many individuals and groups, including Indigenous Peoples. These values, along with the locations of particularly important sites, are identified during the planning process and should be included in scenario modeling activities. Indigenous rights are considered throughout the management planning process and any historically significant locations are identified for preservation.

Sustainable forest management: A driver of change

It is important to recognize that the balance of economic, environmental and cultural values changes over time. For instance, sustainable timber harvest used to be the primary focus of SFM. More recently, environmental values have been growing as the top priority for SFM. Forest management and conservation laws, policies, regulations and management guides are also shifting toward more emphasis on the ecological well-being of the forest.

- There is an **increased commitment to preserving biodiversity**, which includes the adoption and implementation of the Kunming-Montreal Global Biodiversity Framework (GBF) to halt and reverse biodiversity loss by 2030.
    - To support the global goals and targets set out in the framework, Natural Resources Canada (NRCan) is supporting Environment and Climate Change Canada (ECCC) to develop Canada’s 2030 National Biodiversity Strategy.
    - At the provincial level, Nova Scotia has introduced a stand-alone *Biodiversity Act*, which provides for conservation and sustainable use of biodiversity in the province.
- **Alternative silviculture options are used to reduce clearcutting**. For example, Nova Scotia is adopting ecological forestry where public land is divided into three zones that work together to balance a range of interests (conservation, high production forest and mixed forest or matrix).

Canada’s forests are protected through strong laws and regulations at the federal, provincial/territorial and even municipal levels. SFM is a concerted effort among all levels of government, industry, and the public. There are several overarching federal acts that support SFM objectives, including the:

- *Forestry Act*
- *Species at Risk Act*
- *Migratory Birds Convention Act*
- *Fisheries Act*
- *Impact Assessment Act*
- *Canadian Environmental Protection Act*
- *Pest Control Products Act*
- *Fertilizers Act*

- **Old-growth forests are increasingly being protected and conserved**.
  - For example, the Province of British Columbia has introduced a plan to establish new Forest Landscape Planning tables to improve old-growth management, including the incorporation of Traditional Knowledge.
  - The Government of Canada, through ECCC and supported by NRCan, has also committed to the establishment of the Old Growth Nature Fund in collaboration with the Province of British Columbia, non-governmental organizations, and Indigenous and local communities.

The *Species at Risk Act* is a fundamental part of Canada's strategy to preserve biodiversity. It was created to meet Canada's commitment under the United Nations Convention on the Conservation of Biodiversity.

- **Conservation areas are increasing**. As a Party to the United Nations Convention on Biological Diversity and the new GBF, Canada has committed to conserving 30% of Canada's lands and water by 2030.
  - To achieve this goal, the Government of Canada has committed to establishing ten new national parks in the next five years, including the proposed national park reserve in the South Okanagan-Similkameen in British Columbia.
  - The Government of Canada also continues to designate many of its federally managed lands as other effective area-based conservation measures (OECMs), which are specific areas that have conservation and biodiversity objectives in addition to other primary objectives. OECMs, such as Boishébert and Beaubears Island Shipbuilding National Historic Sites in Miramichi, New Brunswick and the Acadia Research Forest (ARF) near Fredericton, New Brunswick contribute to achieving Canada's conservation target by protecting old-growth forest ecosystems and representative natural forest conditions common to the Acadian Forest Region.
- **Forests play a key role in our nature-based climate solutions**.
  - The Government of Canada's 2 Billion Trees Program (2BT) provides funding over 10 years to support provinces and territories, municipalities, Indigenous organizations and governments, and for-profit and not-for-profit organizations in planting an incremental two billion trees across Canada that will support climate change mitigation and adaptation, while increasing biodiversity and human well-being.
  - Canada's National Adaptation Strategy (NAS) sets out a blueprint to reduce the risk of climate-related disasters, improve health outcomes, protect nature and biodiversity, build and maintain resilient infrastructure while supporting a strong economy and workforce.
  - NRCan's Climate Change Adaptation Program (2022–2027) provides funding for projects to help position Canada's regions and sectors to adapt to climate change.

Sustainable forest management is the driver of practices and policies to balance a complex diversity of values in forest ecosystems, communities, and economies. Managing forests for societal values that are increasing in number and often changing is an immense challenge. However, it is a challenge that Canada's forest managers are addressing through ongoing engagement with the public and stakeholders and through adaptive sustainable forest management.

FOREST MANAGEMENT AND DISTURBANCES

CANADIAN ENVIRONMENTAL SUSTAINABILITY INDICATORS

Forest management and disturbances

In 2022, Canada's forests made up an area of approximately 3.7 million square kilometres (about 40% of Canada's land area). These forests account for approximately 9% of the world's forests. Much of it grows in the boreal zone, throughout which over 2.8 million square kilometres of forest are interspersed with lakes, wetlands, and other ecosystems. Canada's rich forest ecosystems offer significant environmental, social and cultural benefits, as well as opportunities for responsible economic development.1 This indicator presents a series of measures covering timber harvest, forest disturbances, and forest regeneration.

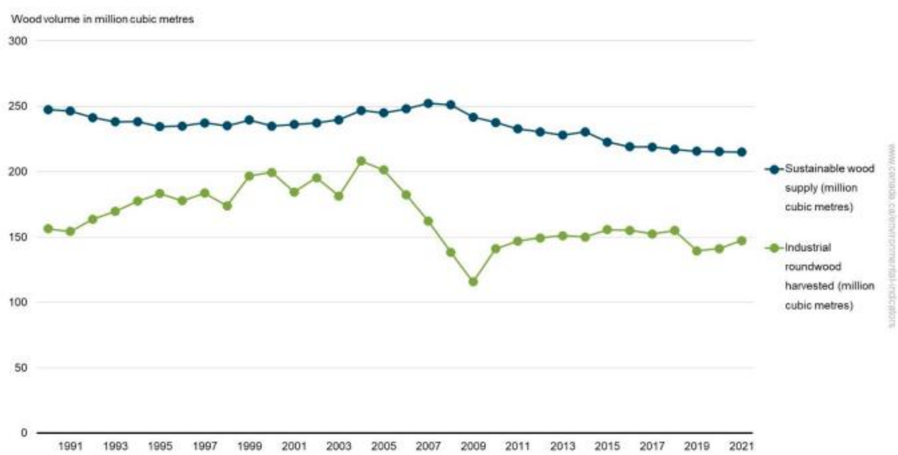
Timber harvest

This section compares the total amount of wood harvested with the sustainable wood supply. To ensure that forests can continue to provide timber, harvests must remain within sustainable limits. The sustainable wood supply is defined as the potential volume of timber which can be harvested sustainably as determined by a complex analysis of ecological, economic, and social considerations. The volume of wood harvested should remain at or below the sustainable wood supply, and it is usually well below these limits. Annual timber harvest compared to the sustainable wood supply

Key results In 2021:

- Canada's sustainable wood supply was approximately 215 million cubic metres
- the amount of industrial roundwood harvested in 2021 was 147 million cubic metres, which represents approximately 68% of the sustainable wood supply

Figure 1. Maximum sustainable wood supply and annual harvest of industrial roundwood, Canada, 1990 to 2021



Data for Figure 1

[1] Natural Resources Canada (2024) The State of Canada's Forests Annual Report. Retrieved on March 25, 2024.

Note: Sustainable wood supply data presented are for industrial roundwood only. Harvested industrial roundwood is intended to be delivered to a mill (for example, logs and bolts, and pulpwood) and also includes poles and pilings.
Source: Canadian Council of Forest Ministers (2024) National Forestry Database.

The annual harvest of industrial roundwood reached a peak of 208 million cubic metres in 2004, declined to a low of 116 million cubic metres in 2009, then increased to reach approximately 147 million cubic metres in 2021. This pattern is mostly the result of economic factors, such as the collapse in the United States housing market in 2008 and subsequent global economic downturn that led to reduced demands for Canadian lumber and pulp and paper products. The 2021 increase in harvest is mostly attributable to net increases in timber volumes harvested in British Columbia and Quebec. Both the estimated wood supply and the volume of wood harvested fluctuate in response to a wide range of ecological, social and economic factors. Changes in wood supply are largely a result of adjustments in provincial forest management objectives, such as, decreases in order to conserve animal habitat or increases to harvest insect-damaged wood. Comparing the amount of timber harvested to the estimated sustainable wood supply is one way to track forest management.

Canada is committed to sustainable forest management, which is defined as "management that maintains and enhances the long-term health of forest ecosystems for the benefit of all living things while providing environmental, economic, social and cultural opportunities for present and future generations." 2 In practice, sustainable forest management means ensuring that forests provide a broad range of goods and services over the long term. Therefore, forest managers plan for harvest levels that ensure the long-term sustainability of environmental, economic and social objectives for the managed forest.

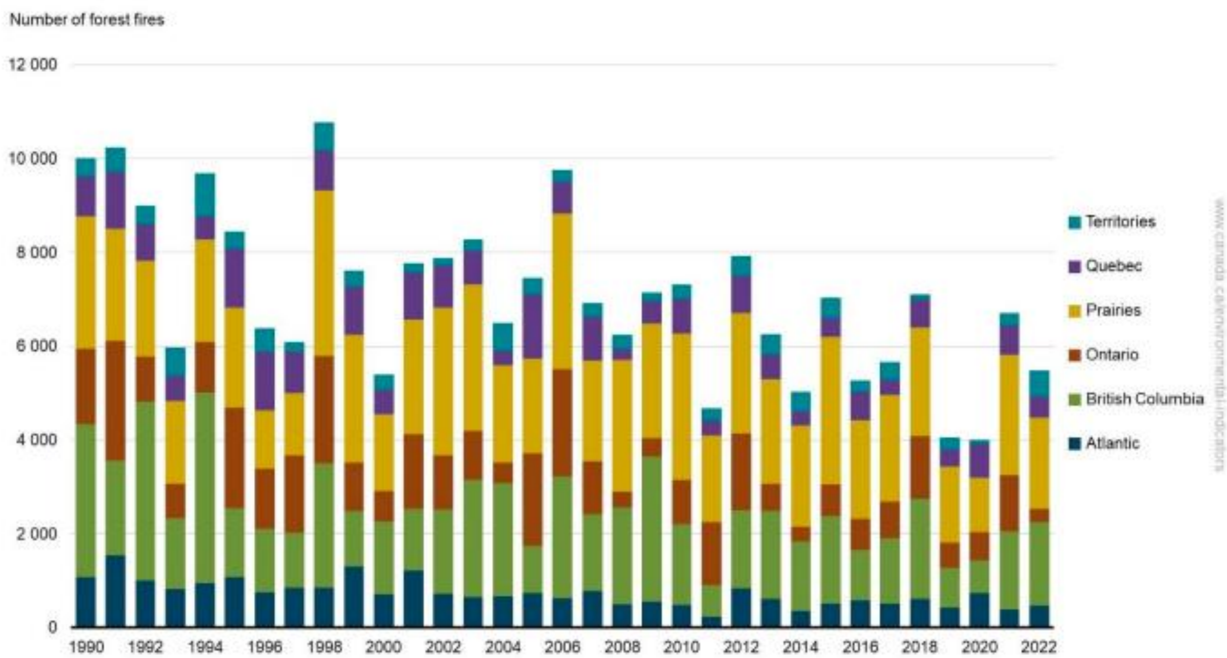
Forest disturbances

Number of forest fires and area burned

Key results

- In 2022, Canada experienced an estimated 5 639 fires that burned approximately 16 543 square kilometres of forest
- While the number of fires and area burned fluctuate year over year, Canada experienced a peak in 1998 for number of fires and in 1995 for area burned with a low in 2020 for both number of fires and area burned

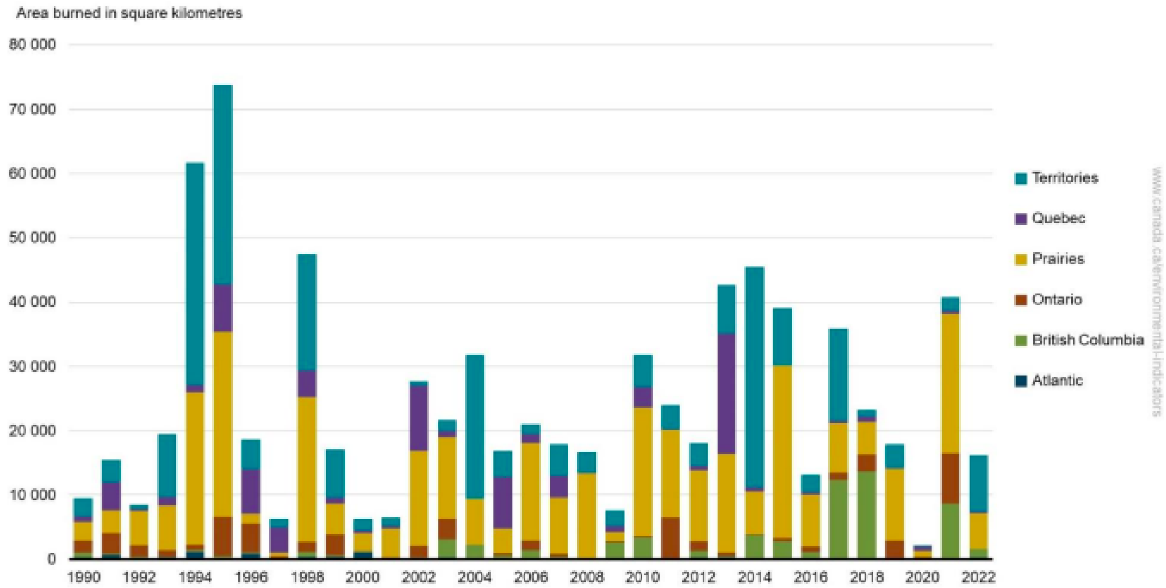
Figure 2. Number of forest fires by region, Canada, 1990 to 2022



Data for Figure 2

Note: Data include fires of known and unknown or indeterminable origin. The Territories region includes Yukon and Northwest Territories. Nunavut was not included as they are not a part of the data sharing agreement with Natural Resources Canada. The Prairies region includes Manitoba, Saskatchewan, and Alberta. The Atlantic region includes New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador. Totals for 2022 do not include all forest fires taking place in national parks as they have not been reallocated to the appropriate provinces and territories.
Source: Canadian Council of Forest Ministers (2024) National Forestry Database.

Figure 3. Area burned by forest fires by region, Canada, 1990 to 2022



Note: Data include fires of known and unknown or indeterminable origin. The Territories region includes Yukon and Northwest Territories. Nunavut was not included as they are not a part of the data sharing agreement with Natural Resources Canada. The Prairies region includes Manitoba, Saskatchewan, and Alberta. The Atlantic region includes New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador. Totals for 2022 do not include all forest fires taking place in national parks as they have not been reallocated to the appropriate provinces and territories.
Source: Canadian Council of Forest Ministers (2024) National Forestry Database.

Forest fires are a natural part of the forest ecosystem and are important for maintaining the health and diversity of the forest. Fire is the primary means of environmental change in the boreal zone and is as crucial to forest renewal as the sun and rain. Forest fires release valuable nutrients stored in the debris on the forest floor. They open the forest canopy to sunlight, which stimulates new growth. 3 However, they can also result in costly economic and environmental losses and public health and safety concerns by directly threatening communities and infrastructure or reducing visibility and air quality through smoke. The expected hotter and drier conditions as a result of climate change may result in more frequent and severe forest fires in Canada.

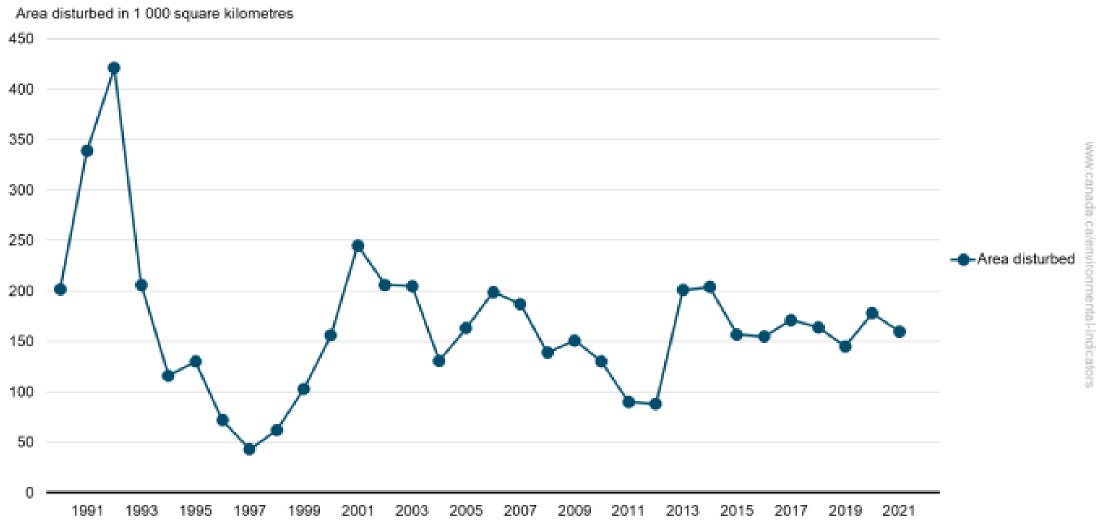
4 The total area burned varies widely from year to year, but averages about 25 000 square kilometres annually. Only 3% of all wildland fires that start each year in Canada grow to more than 2 square kilometres in area. However, these fires account for 97% of the total area burned across the country.5 In 2021, about 3 090, or 46% of forest fires across Canada were caused by human activity. This resulted in approximately 5 500 square kilometres of forest burned, representing nearly 14% of the total area burned nationally.6

Area disturbed by insects

Key results

- In 2021, approximately 160 000 square kilometres of Canadian forests were disturbed (including beetle-killed trees) by insects

Figure 4. Area disturbed by insects, Canada, 1990 to 2021



Data for Figure 4

Note: Includes beetle-killed trees. Trees that suffer moderate to severe defoliation are those on which 30% or more of the current foliage has been removed.
Source: Canadian Council of Forest Ministers (2024) National Forestry Database.

Canada's forests are home to thousands of species of native and introduced insects. Most of the time, these species contribute a vital role to the normal functioning of forest ecosystems as prey for other species or by recycling nutrients back into the forest.7 Only a small number of insect species kill trees and damage forests. This can occur when insect populations experience outbreaks over vast areas. Disturbance, or defoliation, is the removal of all or most of a plant's leaves by natural disturbance agents (for example, insects) or through the actions of humans (for example, the application of herbicides). These impacts can reduce Canada's timber supply and influence the functioning of forest ecosystems, which can in turn affect carbon stocks, increase fire risk and reduce the recreational and non-timber uses of forests.

Sustainability and Timber Harvest

Wood supply estimation Wood supply, the volume of timber that can be harvested sustainably, is estimated for each province and territory. Wood supply levels are estimated for forests that are actively managed for timber, which is a subset of forests and other wooded land. Provincial and territorial wood supplies are summed to estimate Canada's wood supply. Wood supply is the sum of 2 values: 1. The estimated Annual Allowable Cut (known as Allowable Annual Cut in British Columbia, and known as Guarantee of Supply in Quebec) for provincial Crown lands, that is, publicly owned lands under provincial jurisdiction. The estimated Annual Allowable Cut is the volume of industrial roundwood that can be harvested sustainably each year from provincial Crown lands, as estimated by professional foresters. Provincial Crown lands make up 77%5 of Canada's forest, but the percentage varies by province. Most provinces establish Annual Allowable Cuts levels for their Crown lands based on a policy of maintaining a non-declining future wood supply. They also consider a range of additional factors. For example, Annual Allowable Cuts levels may be decreased in order to maintain animal habitat, or they may be increased so that insect damaged wood can be salvaged. The importance of individual factors to the Annual Allowable Cut varies among provinces and even among forest management areas within provinces, due to regional differences in forestry policies. Each province is responsible for the extensive rationale behind an Annual Allowable Cut determination for individual forest management areas. Additional information is available from provincial resource management organizations.6 The volume of wood harvested may be above or below the Annual Allowable Cut in any one year, but it must balance out over the regulation period, which varies from 5 to 10 years depending on the jurisdiction. Annual Allowable Cuts are set based on an assessment of a wide range of ecological, social and economic factors, therefore they are only a proxy for the sustainable level of harvest.

CANADIAN COUNCIL OF FOREST MINISTERS

FACT SHEET

MAKING THE CASE FOR SUSTAINABLE FOREST MANAGEMENT CERTIFICATION

Since third-party sustainable forest management (SFM) certification programs were introduced in Canada in the mid-1990s, certification—which complements Canada's already stringent laws and regulations regarding forest management—has become a widely respected means of demonstrating that Canadian forest companies meet the highest standards of sustainable forest management.

Photograph from "The Forests of Canada" collection, Natural Resources Canada, Canadian Forest Services, 2003.

Today, three third-party certification standards have been widely adopted in Canada. In addition to Canada's own standard, developed by the Canadian Standards Association (CSA), forest companies have also adopted certification programs developed by the Forest Stewardship Council (FSC) and the Sustainable Forestry Initiative (SFI). All three programs are recognized internationally. As of 2014, Canada leads the world in third-party sustainable forest management certification with 161 million certified hectares.

CSA and SFI are endorsed by the international Programme for the Endorsement of Forest Certification schemes (PEFC), the world's largest forest certification umbrella organization. Certification of chain of custody, a mechanism used to track wood from certified sources through all phases of manufacturing to the buyer, is offered by the FSC, SFI, and PEFC (CSA or SFI).

To verify that forest lands are being managed sustainably, all three certification standards used in Canada require that a forest company's planning, procedures and systems meet the standard's requirements, and employ auditing procedures to measure performance of on-the-ground forest operations against predetermined criteria. Companies are also required to publicly disclose audit reports; verify that harvested areas are being reforested; confirm that all applicable laws have been obeyed; and demonstrate that no unauthorized logging has taken place.

In addition, a separate certification process addresses chain-of-custody issues—ensuring that there is rigorous tracking and record keeping from the forest floor through all the steps of wood processing, manufacturing and distribution.

More Than Just Harvesting

All three of the certification programs in use in Canada, besides including requirements for timber harvesting, address the conservation of biological diversity, the maintenance of wildlife habitat and the protection of soil, water and air quality. In addition, the standards address social and economic issues arising from forest management that affect local communities, in particular by seeking to engage local communities in discussion and decision-making regarding these issues.

Aboriginal Engagement

Each of the certification programs requires, in its own way, engagement with Aboriginal peoples to ensure that Aboriginal rights, knowledge and values are respected. They also promote economic and social benefits for Aboriginal communities by engaging Aboriginal companies and

Advantages of Adopting Multiple SFM Standards

Port Hawkesbury Paper LP (PHP LP), a leading producer of super calendered and other fine papers, was one of the first Canadian forest products companies to adopt more than one major SFM standard. According to Andrew Fedora, PHP LP's Leader in Sustainability and Outreach, "SFM standards and programs are essential for any forest products company interested in improving their forestry practices and maintaining public trust." This can be achieved by following a single SFM standard but there are clear benefits to maintaining multiple certifications. PHP-LP is currently dual-certified to the FSC and to the SFI standards.

"All major SFM standards are robust," said Mr. Fedora, "but each (standard) excels slightly in different areas. Some standards put more emphasis on elements such as safety, training and efficiency; while others focus more so on stakeholder engagement and social issues." Incorporating more than one SFM standard helps companies such as PHP LP increase the merit and credibility to their SFM system.

Certification to more than one standard also reinforces the marketability of PHP LP's products. "In terms of both product sales and public trust, some markets favor certain SFM standards over others," states Mr. Fedora. "Maintaining multiple certifications helps strengthen our social license and allows us to service a wider range of customers from around the globe."

workers in harvesting, processing, and other forest-related activities.

Clear Cutting

Each standard addresses clear cutting in its own way. All of the standards are sensitive to the ecological requirements of specific forest types and recognize that the choice of silvicultural systems should be guided by what is ecologically appropriate for the local forest, which in many Canadian forests could be a clear cut system.

How Standards Evolve

All of the standards remain current and relevant through reviews which usually occur every five years. When it's time to make revisions, committees consisting of representative stakeholders are established and the public is invited and encouraged to raise issues and contribute ideas. What is learned through consultation and review becomes the basis for updating the standards. Competition among the various systems has also helped to promote continuous evolution.

Why Forest Companies Seek Certification

Since forest certification systems were introduced in the mid-1990s, Canadian forest companies and industry organizations have embraced them enthusiastically.

This is because an increasing number of forest product buyers around the world demand certification as a means of demonstrating to their customers that wood products come from forests managed to standards recognized by respected non-governmental organizations. In addition, the standards provide practical guidance on improving sustainable forest management practices. This, in turn, improves economic performance and makes Canada's forest products more marketable around the world.

and develop in-house professional expertise to conduct the employee training, internal monitoring, public consultation, and liaison with external auditors that are integral to all certification regimes. Typically, a coordinator and small staff provide core expertise, supplemented over time by the increasing sustainable management skills of employees throughout the company.

Why Buyers Want Certified Forest Products

In recent years, a rapidly growing number of responsible forest products buyers have adopted procurement policies requiring that any paper or wood product be certified as legally obtained and sustainably produced. Corporate social responsibility of this kind is considered essential to the long-term sustainability of the world's forests.

The Relationship between CSA Certification and National Laws in Canada

The foundation for acceptable forest management practices in Canada is set out in a comprehensive body of provincial and federal forestry and related laws and regulations. Consequently, there is no need for Canada's CSA Standard to duplicate that framework. The purpose of the CSA and other standards is to provide a means of measuring forest companies' practices against nationally and internationally recognized criteria for sustainable forest management defined by respected non-governmental organizations. Importantly, the CSA standard complements applicable laws and regulations by acknowledging that they must be obeyed, and that no unauthorized logging can be allowed—in effect, adding weight to the laws of the land.

The Paris Agreement

What is the Paris Agreement?

The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016. Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels."

However, in recent years, world leaders have stressed the need to limit global warming to 1.5°C by the end of this century. That's because the UN's Intergovernmental Panel on Climate Change indicates that crossing the 1.5°C threshold risks unleashing far more severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall. To limit global warming to 1.5°C, greenhouse gas emissions must peak before 2025 at the latest and decline 43% by 2030.

The Paris Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations together to combat climate change and adapt to its effects.

How does the Paris Agreement work?

Implementation of the Paris Agreement requires economic and social transformation, based on the best available science. The Paris Agreement works on a five-year cycle of increasingly ambitious climate action -- or, ratcheting up -- carried out by countries. Since 2020, countries have been submitting their national climate action plans, known as nationally determined contributions (NDCs). Each successive NDC is meant to reflect an increasingly higher degree of ambition compared to the previous version.

Recognizing that accelerated action is required to limit global warming to 1.5°C, the COP27 cover decision requests Parties to revisit and strengthen the 2030 targets in their NDCs to align with the Paris Agreement temperature goal by the end of 2023, taking into account different national circumstances.

Nationally Determined Contributions (NDCs)

In their NDCs, countries communicate actions they will take to reduce their greenhouse gas emissions in order to reach the goals of the Paris Agreement. Countries also communicate in their NDCs actions they will take to build resilience to adapt to the impacts of climate change.

Long-Term Strategies

To better frame the efforts towards the long-term goal, the Paris Agreement invites countries to formulate and submit long-term low greenhouse gas emission development strategies (LT-LEDS).

LT-LEDS provide the long-term horizon to the NDCs. Unlike NDCs, they are not mandatory. Nevertheless, they place the NDCs into the context of countries' long-term planning and development priorities, providing a vision and direction for future development.

How are countries supporting one another?

The Paris Agreement provides a framework for financial, technical and capacity building support to those countries who need it.

Finance

The Paris Agreement reaffirms that developed countries should take the lead in providing financial assistance to countries that are less endowed and more vulnerable, while for the first time also encouraging voluntary contributions by other Parties. Climate finance is needed for mitigation, because large-scale investments are required to significantly reduce emissions. Climate finance is equally important for adaptation, as significant financial resources are needed to adapt to the adverse effects and reduce the impacts of a changing climate.

Technology

The Paris Agreement speaks of the vision of fully realizing technology development and transfer for both improving resilience to climate change and reducing GHG emissions. It establishes a technology framework to provide overarching guidance to the well-functioning Technology Mechanism. The mechanism is accelerating technology development and transfer through its policy and implementation arms.

Capacity-Building

Not all developing countries have sufficient capacities to deal with many of the challenges brought by climate change. As a result, the Paris Agreement places great emphasis on climate-related capacity-building for developing countries and requests all developed countries to enhance support for capacity-building actions in developing countries.

How are we tracking progress?

With the Paris Agreement, countries established an enhanced transparency framework (ETF). Under ETF, starting in 2024, countries will report transparently on actions taken and progress in climate change mitigation, adaptation measures and support provided or received. It also provides for international procedures for the review of the submitted reports.

The information gathered through the ETF will feed into the Global stocktake which will assess the collective progress towards the long-term climate goals.

This will lead to recommendations for countries to set more ambitious plans in the next round.

What have we achieved so far?

Although climate change action needs to be massively increased to achieve the goals of the Paris Agreement, the years since its entry into force have already sparked low-carbon solutions and new markets. More and more countries, regions, cities and companies are establishing carbon neutrality targets. Zero-carbon solutions are becoming competitive across economic sectors representing 25% of emissions. This trend is most noticeable in the power and transport sectors and has created many new business opportunities for early movers.

By 2030, zero-carbon solutions could be competitive in sectors representing over 70% of global emissions.

Food and Agriculture Organization
of the United Nations

Implementing Article 5 of the Paris Agreement and achieving climate neutrality through forests: From COFO24 to COP24

23/07/2018

On 16 July 2018, government representatives, civil society and international organizations gathered for the high-level side event co-hosted by Poland's Presidency for COP24 and FAO entitled "Implementing Article 5 of the Paris Agreement and achieving climate neutrality through forests". It took place during the 6th World Forest Week at FAO Headquarters in Rome, Italy and highlighted the catalytic and driving role of forests in strengthening efforts to implement the Paris Agreement.

Article 5 of the Paris Agreement invites countries to take action to conserve and enhance sinks and reservoirs of greenhouse gases, including forests. The article also encourages actions to implement and support, including through results-based payments, the existing Warsaw Framework for REDD+ adopted in COP 19, and alternative policy approaches such as sustainable management of forests.

At the same time, achieving the Sustainable Development Goals of ending hunger and poverty while making agriculture and food systems sustainable will require food system transformations and strategies that leverage the food system to boost economic growth in countries where industrialization is lagging. "*The Paris Agreement and 2030 Agenda for Sustainable Development recognizes that we need to look at food security and the management of natural resources together. Both global agreements call for a coherent and integrated approach across all agricultural sectors. Forests and forestry have key roles to play in this regard*" said FAO Deputy Director-General of Programmes, Dan Gustafson.

The world continues to make progress in all dimensions of sustainable forest management. Although forests continue to be lost, the rate of loss has been cut by 25% since the period 2000-2005. Promisingly, the proportion of protected forest area and forests under long-term management plans are increasing. Deforestation and forest degradation are still concern in some regions, particularly in the tropics, indicating the need for more action to reduce deforestation and implement sustainable forest and land management practices.
"*Sustainable and effective forest and peatlands management cannot be achieved without the involvement of local communities and civil society who can bring valuable knowledge and a fresh viewpoint to discussions. Innovative forest monitoring tools available today are crucial in efforts to demonstrate the reduction of deforestation,*" said H.E. Siti Nurbaya, Minister of Environment and Forests, Indonesia.

Actions to reduce emission levels arising from deforestation and forest degradation and to enhance forest carbon sinks are one of the most significant and cost-effective ways to reduce global emissions, while also producing important adaptation, biodiversity, livelihood and development benefits. "*Improving the income and living conditions of local communities and indigenous peoples while ensuring the conservation of biodiversity is one of the main outcomes expected from the implementation of programmes and projects related to sustainable forest management,*" said H.E. Rosalie Matondo, Minister of Forest Economy, Republic of Congo.

Ms Beth MacNeil, Assistant Deputy Minister, Natural Resources Canada, Canadian Forest Service shared the example of the Clean Energy for Rural and Remote Communities Program intended to fund initiatives to reduce reliance on diesel fuel in Canada's rural and remote communities, the majority of which are Indigenous. Part of this programming will support the use of the forest biomass in producing heat and power.

Mr Slawomir Mazurek, Undersecretary of State, Ministry of the Environment, Republic of Poland and the host of COP24, highlighted the importance of innovations and developing enabling conditions for the use of wood for housing and energy efficiency in buildings. He stressed that Poland promotes integrating the protection of forests with their multiple uses, through sustainable management practices, as a way to implement Article 5 of the Paris Agreement.

"*Forests are one of the priority topics for COP24 Presidency, including the COP24 President himself, who attaches great importance to this topic. We see and recognise the vital role which forests play in achieving climate neutrality*," he said.

"*We must keep the momentum from the discussions here at COFO24, toward COP24, and beyond, and ensure the message that forests have not only a huge catalytic role but a driving role to bring along other sectors. We must work together across sectors to ensure their potential is fully realised*," was the conclusion of Tiina Vahanen, Forestry Department, FAO, in her closing remarks.

Kunming-Montreal Global Biodiversity Framework

Excerpts

Annex

Kunming-Montreal Global Biodiversity Framework

Section A. Background

1. Biodiversity is fundamental to human well-being, a healthy planet, and economic prosperity for all people, including for living well in balance and in harmony with Mother Earth. We depend on it for food, medicine, energy, clean air and water, security from natural disasters as well as recreation and cultural inspiration, and it supports all systems of life on Earth.

2. The Kunming-Montreal Global Biodiversity Framework seeks to respond to the *Global Assessment Report of Biodiversity and Ecosystem Services* issued by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES),[4] the fifth edition of the *Global Biodiversity Outlook*,[5] and many other scientific documents that provide ample evidence that, despite ongoing efforts, biodiversity is deteriorating worldwide at rates unprecedented in human history. As the IPBES global assessment report states:[6]

> An average of around 25 per cent of species in assessed animal and plant groups are threatened, suggesting that around 1 million species already face extinction, many within decades, unless action is taken to reduce the intensity of drivers of biodiversity loss. Without such action, there will be a further acceleration in the global rate of species extinction, which is already at least tens to hundreds of times higher than it has averaged over the past 10 million years.
>
> The biosphere, upon which humanity as a whole depends, is being altered to an unparalleled degree across all spatial scales. Biodiversity – the diversity within species, between species and of ecosystems – is declining faster than at any time in human history.
>
> Nature can be conserved, restored and used sustainably while other global societal goals are simultaneously met through urgent and concerted efforts fostering transformative change.
>
> The direct drivers of change in nature with the largest global impact have been (starting with those with the most impact) changes in land and sea use, direct exploitation of organisms, climate change, pollution and invasion of alien species. Those five direct drivers result from an array of underlying causes, the indirect drivers of change, which are, in turn, underpinned by social values and behaviours (…)The rate of change in the direct and indirect drivers differs among regions and countries.

3. The Kunming-Montreal Global Biodiversity Framework, building on the Strategic Plan for Biodiversity 2011–2020, its achievements, gaps, and lessons learned, and the experience and achievements of other relevant multilateral environmental agreements, sets out an ambitious plan to implement broad-based action to bring about a transformation in our societies' relationship with biodiversity by 2030, in line with the 2030 Agenda for Sustainable Development and its Sustainable Development Goals, and ensure that, by 2050, the shared vision of living in harmony with nature is fulfilled.

Section B. Purpose

4. The Kunming-Montreal Global Biodiversity Framework aims to catalyze, enable and galvanize urgent and transformative action by Governments, and subnational and local authorities, with the involvement of all of society, to halt and reverse biodiversity loss, to achieve the outcomes it sets out in its Vision, Mission, Goals and Targets, and thereby contribute to the three objectives of the Convention on Biological Diversity and to those of its Protocols. Its purpose is the full implementation of the three objectives of the Convention in a balanced manner.

5. The Framework is action- and results-oriented and aims to guide and promote, at all levels, the revision, development, updating, and implementation of policies, goals, targets, and national biodiversity strategies and actions plans, and to facilitate the monitoring and review of progress at all levels in a more transparent and responsible manner.

6. The Framework promotes coherence, complementarity and cooperation between the Convention on Biological Diversity and its Protocols, other biodiversity related conventions, and other relevant multilateral agreements and international institutions, respecting their mandates, and creates opportunities for cooperation and partnerships among diverse actors to enhance implementation of the Framework.

Section F. 2050 vision and 2030 mission

10. The vision of the Kunming-Montreal Global Biodiversity Framework is a world of living in harmony with nature where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

11. The mission of the Framework for the period up to 2030, towards the 2050 vision is:

> To take urgent action to halt and reverse biodiversity loss to put nature on a path to recovery for the benefit of people and planet by conserving and sustainably using biodiversity and by ensuring the fair and equitable sharing of benefits from the use of genetic resources, while providing the necessary means of implementation.

Section G. Global goals for 2050

12. The Kunming-Montreal Global Biodiversity Framework has four long-term goals for 2050 related to the 2050 Vision for biodiversity.

GOAL A

The integrity, connectivity and resilience of all ecosystems are maintained, enhanced, or restored, substantially increasing the area of natural ecosystems by 2050;

Human induced extinction of known threatened species is halted, and, by 2050, the extinction rate and risk of all species are reduced tenfold and the abundance of native wild species is increased to healthy and resilient levels;

The genetic diversity within populations of wild and domesticated species, is maintained, safeguarding their adaptive potential.

GOAL B

Biodiversity is sustainably used and managed and nature's contributions to people, including ecosystem functions and services, are valued, maintained and enhanced, with those currently in decline being restored, supporting the achievement of sustainable development for the benefit of present and future generations by 2050.

GOAL C

The monetary and non-monetary benefits from the utilization of genetic resources and digital sequence information on genetic resources, and of traditional knowledge associated with genetic resources, as applicable, are shared fairly and equitably, including, as appropriate with indigenous peoples and local communities, and substantially increased by 2050, while ensuring traditional knowledge associated with genetic resources is appropriately protected, thereby contributing to the conservation and sustainable use of biodiversity, in accordance with internationally agreed access and benefit-sharing instruments.

GOAL D

Adequate means of implementation, including financial resources, capacity-building, technical and scientific cooperation, and access to and transfer of technology to fully implement the Kunming-Montreal Global Biodiversity Framework are secured and equitably accessible to all Parties, especially developing country Parties, in particular the least developed countries and small island developing States, as well as countries with economies in transition, progressively closing the biodiversity finance gap of $700 billion per year, and aligning financial flows with the Kunming-Montreal Global Biodiversity Framework and the 2050 Vision for biodiversity.

CLIMATE ADAPTATION PLAN

Executive Summary

Climate change threatens the ability of the USDA Forest Service to fulfill its mission by undermining the health, diversity, and productivity of the Nation's forests and grasslands. A robust climate change response aligns with the agency's core values of conservation, interdependence, safety, diversity, and service. The "USDA Forest Service Climate Adaptation Plan" outlines key climate risks to the agency's operations and critical adaptation actions to reduce these risks and help ensure that the Forest Service continues to meet the needs of present and future generations.

Figure 1 shows the focus areas associated with these adaptation actions. The focus areas reflect more specific activities that the agency can undertake across its programs to implement the overarching actions and reduce the greatest risks to the agency's mission and operations. Tribal engagement, environmental justice, workforce climate literacy, and the USDA Climate Hubs will serve as foundations for adaptation and guide how we implement the corresponding actions to achieve the desired outcomes. The Forest Service will annually evaluate progress on adaptation actions and focus areas using the Climate Action Tracker. Actions will align with other USDA and agency programs and initiatives on climate change, environmental justice, and wildfire risk.

CLIMATE CHANGE IMPACTS AND VULNERABILITIES

The Forest Service identified key risks to the agency's mission in six categories:

1. Shifting fire regimes and resulting effects on ecological integrity, multiple uses, human safety and well-being, and wildland fire management operations.
2. Extreme events and disturbances, including the effects of flooding, drought, insect outbreaks, invasive species, and severe storms.
3. Chronic stressors to watersheds and ecosystems, such as altered productivity and composition, changes in habitat for plants and animals, and implications for the agency's ability to manage these systems over time.
4. Disruption in the delivery of ecosystem products and services, including clean water, carbon uptake and storage, forest and rangeland products, and recreation opportunities.
5. Disproportionate impacts on disadvantaged communities and Tribal Nations, including human health impacts, loss of cultural resources, and threats to economic prosperity and equity.
6. Threats to the agency mission, infrastructure, and operations from disruption to operations, strains on workforce capacity, more complex public engagement, and fewer resources.

ADAPTATION ACTIONS

To reduce these risks, the Forest Service will take six overarching adaptation actions that correspond to the six categories above:

1. Adapt to changing fire regimes.
2. Prepare ecosystems and watersheds for extreme events and intensifying disturbances.
3. Sustain and improve ecosystem and watershed function in the face of chronic stressors.
4. Support the delivery of ecosystem products and services in a changing climate.
5. Deliver environmental justice through adaptation actions.
6. Increase agency capacity to respond to climate change.

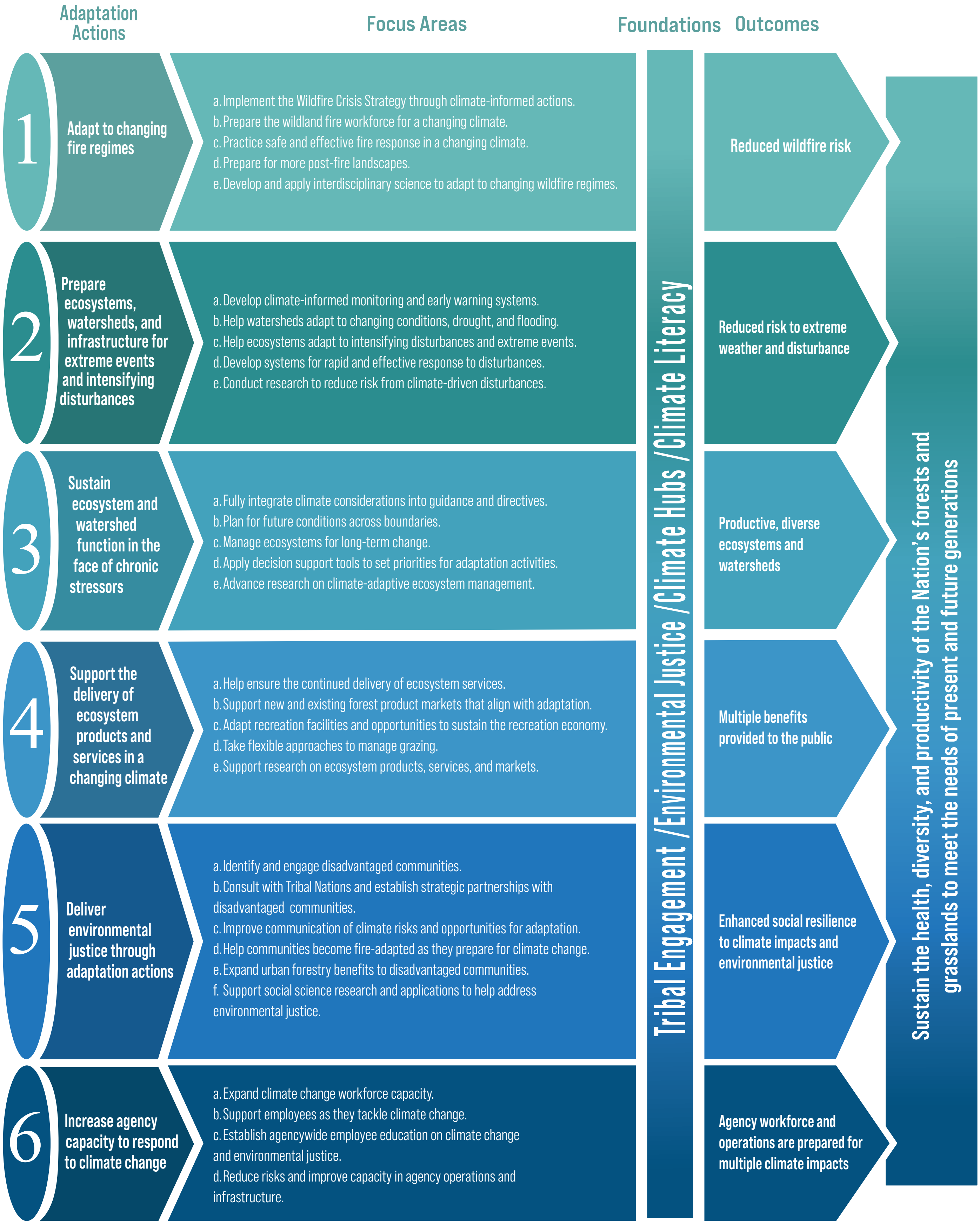


Figure 1. Overview of Agency Adaptation Actions.

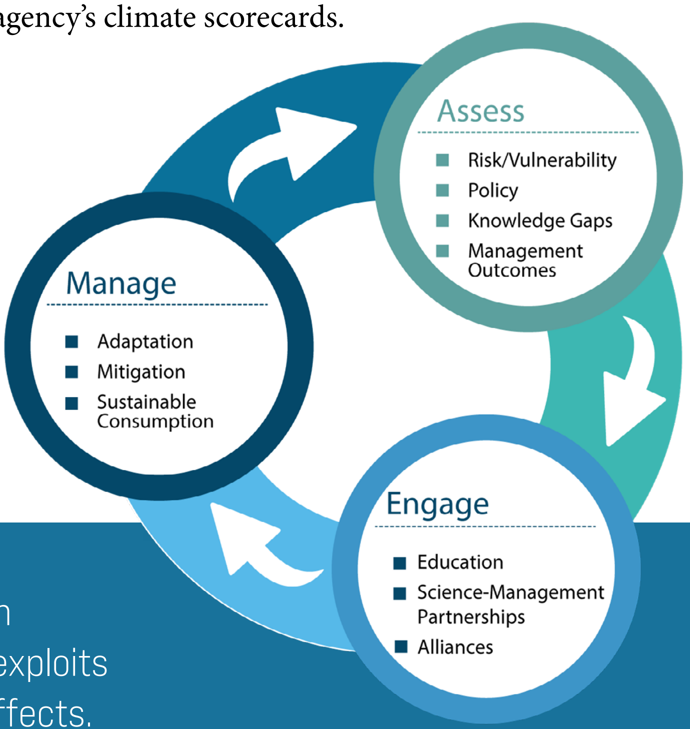
INTRODUCTION

The "USDA Forest Service Climate Adaptation Plan" presents a vision for integrating climate change adaptation into the Forest Service's operations and mission. The plan is part of the Forest Service's response to [Executive Order 14008: Tackling the Climate Crisis at Home and Abroad](), which calls on Federal Departments and agencies to develop climate adaptation plans that secure environmental justice and spur economic opportunity. In October 2021, the U.S. Department of Agriculture (USDA) released its [Action Plan for Climate Adaptation and Resilience]() to describe how the USDA is preparing for and responding to current and future impacts of climate change. As part of developing its plan, USDA issued a new departmental regulation (DR 1070-001), directing each of its agencies to update its adaptation plans. The "USDA Forest Service Climate Adaptation Plan" describes the top risks to the agency's mission, responsibilities, and operations and outlines key actions to manage these risks.

The adaptation plan builds on the modes of action outlined in the Forest Service's "National Roadmap for Responding to Climate Change":

- Assessing current risks, vulnerabilities, policies, and gaps in knowledge.
- Engaging employees and stakeholders to seek solutions.
- Managing for resilience, in ecosystems and well as in human communities, through adaptation, mitigation, and sustainable consumption strategies.

These three modes of action continue to drive the agency's work on climate change. The adaptation plan incorporates the knowledge gained and progress made in the decade since the launch of the climate change roadmap but places a new emphasis on environmental justice. To evaluate progress under the adaptation plan, the Forest Service will use a new Climate Action Tracker, which builds on previous iterations of the agency's climate scorecards.



ADAPTATION - The adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.

The adaptation plan builds on the modes of action outlined in the Forest Service's "National Roadmap for Responding to Climate Change":

Assessing current risks, vulnerabilities, policies, and gaps in knowledge.

Engaging employees and stakeholders to seek solutions.

Managing for resilience, in ecosystems and well as in human communities, through adaptation, mitigation, and sustainable consumption strategies.

ENVIRONMENTAL JUSTICE

The "USDA Forest Service Climate Adaptation Plan" is part of a whole-of-government approach to deliver environmental justice and spur economic opportunity for overburdened and marginalized communities. By meaningfully involving these communities in cocreating climate adaptation actions and treating them fairly, the Forest Service will help ensure that they do not suffer disproportionate adverse impacts from agency decisions and that they benefit equitably from climate adaptation activities. Executive Order 14008 emphasizes environmental justice for historically marginalized communities, including low-income, minority, Indigenous, and other disadvantaged communities. The executive order launched the Justice40 Initiative, which aims to deliver 40 percent of the overall benefits from Federal investments in climate and clean energy to disadvantaged communities. The executive order refers to "disadvantaged communities" but interim implementation guidance for departments and agencies notes that community members prefer different terms, such as "overburdened and underserved communities."[1] The Forest Service can use the USDA Climate Hubs and new and emerging partnerships to build capacity in communities disproportionately affected by climate change. Low-income, minority, and Indigenous communities have experienced decades of disinvestment and institutional inequities that contribute to their vulnerability to climate change. The vulnerabilities include housing insecurity; preexisting health conditions; higher rates of poverty and unemployment; the higher likelihood of living near environmental hazards and contaminated lands; and a lack of access to healthcare, clean air and water, healthy foods, green space, and transportation.

"Our mission is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations—the needs of everyone, from every background and walk of life. Communities of color as well as Tribal, low-income, and minority communities already live with more environmental burdens, and they are disproportionately affected by climate change. Fulfilling our mission means instilling the principles of equity and environmental justice into all of our policies, programs, and practices, including every step we take to reduce climate-related risk."

Chief Randy Moore

[1] See footnote 4, "https://www.whitehouse.gov/wp-content/uploads/2021/07/M-21-28.pdf.

ENVIRONMENTAL JUSTICE (EJ) - The fair treatment and meaningful involvement of all people regardless of race, color, culture, national origin, income, and educational levels with respect to the development, implementation, and enforcement of protective environmental laws, regulations, and policies.

FAIR TREATMENT -The principle that no group of people, including a racial, ethnic, or socioeconomic group, should bear a disproportionate share of the negative environmental consequences from industrial, municipal, and commercial operations or the execution of Federal, State, local, and Tribal programs and policies. In implementing its programs, the U.S. Environmental Protection Agency (EPA) has expanded the concept of fair treatment to include not only consideration of how burdens are distributed across all populations but the distribution of benefits as well.

MEANINGFUL INVOLVEMENT - Potentially affected community residents have an opportunity to participate in decisions about a proposed activity that will affect their environment and/or health. The public's contribution can influence the regulatory agency's decision and the concerns of all participants involved will be considered in the decision-making process. The decision-makers seek out and facilitate the involvement of those potentially affected.

Source: EJ 2020 Glossary | US EPA

TRIBAL ENGAGEMENT

In addition to the Forest Service's formal government-to-government relationships with Tribal Nations, the agency's ability to adapt to climate change depends on building trust and developing strong collaborations with Tribal Nations and other Indigenous peoples. The adaptation plan aligns with actions outlined in the upcoming publication "2022-2024 Forest Service National Tribal Relations Action Plan," a national strategic document that gives agency employees direction and assistance to help them fulfill the Forest Service's Federal Trust responsibility, honor treaty obligations, and support Tribal self-determination. The "USDA Forest Service Climate Adaptation Plan" also supports the 2021 Memorandum on Indigenous Traditional Ecological Knowledge and Federal Decision Making by paving the way for collaboratively developing climate adaptation actions that advance equity with and for the benefit of Indigenous peoples, including American Indians, Alaska Natives, Native Hawaiians, and Indigenous peoples of the U.S. territories. Traditional Ecological Knowledge, a form of Indigenous Knowledge, makes important contributions to scientific, technical, social, and economic progress in the United States. The Forest Service is committed to using this knowledge to shape its climate adaptation policies. Tribal Nations and the Forest Service can work together using their collective knowledge, experience, and resources to costeward Federal lands and contribute to the long-term sustainability of ecological and cultural resources of both Federal and Tribal lands in the face of climate change.

Yavapai-Apache Youth Dancers at Archaeology Discovery Days at V Bar V Heritage Site, Coconino National Forest, Arizona, March 2017. USDA Forest Service photo by Deborah Lee Soltesz.

RELATED INITIATIVES

The adaptation plan builds on and aligns with other department and agency policies, strategy documents, and initiatives at the interface of climate change, sustainability, and environmental justice (appendix 1). In particular, the plan aligns with key actions outlined in the USDA Action Plan for Climate Adaptation and Resilience and the Climate-Smart Agriculture and Forestry Strategy: 90-Day Report. The "USDA Forest Service Climate Adaptation Plan" is supplemental to the Department's goals to build resilience to climate change. By investing in ecosystem health, expanding education and outreach, and continuing research and development, the agency will build on the goals established in USDA's action plan. The Forest Service adaptation plan will use the USDA Climate Hubs to support adaptation science, technology, and tools, as called for in the USDA action plan. The Forest Service plan also echoes the need for a forest and wildfire resilience strategy highlighted in the USDA climate-smart strategy. In addition, the Forest Service plan aligns with key actions described in two recent strategic documents: the "Forest Service Equity Action Plan" and "Confronting the Wildfire Crisis: A New Strategy for Protecting Communities and Improving Resilience in America's Forests."

Pike Mountain Overlook, Minidoka Ranger District, Sawtooth National Forest. October 2015. USDA Forest Service photo by Nancy Brunswick.

OLD-GROWTH AND MATURE FORESTS

Old-growth and mature forests, and other forests with similar characteristics, are an ecologically and culturally important part of the National Forest System. They reside within a continuum of forest age classes and vegetation types that provides for a wide diversity of ecosystem values. Many forests with old-growth characteristics have a combination of higher carbon density and biodiversity that contributes to both carbon storage and climate resilience. They are often viewed as ideal candidates for increased conservation efforts, and are frequently found within areas designated as wilderness or roadless or other management areas where timber harvest is precluded. Even so, as climate continues to deviate from historical norms, many of these forests are expected to be at increasing risk from acute and chronic disturbances such as drought, wildfires, and insect and disease outbreaks. As a result, climate-amplified disturbances like these have become the primary threat to old-growth stands on national forests. In response, Executive Order 14072 *Strengthening the Nation's Forests, Communities, and Local Economies* emphasizes the climate-informed stewardship of mature and old-growth forests on Federal lands, as part of a science-based approach to maintain valued characteristics and reduce wildfire risk. There is no single "right answer" in addressing the complex problem, but the spirit and practice of shared stewardship can help us generate the frank discussions necessary to consider values and risks as we find the best paths forward.

European forests: how climate change, land ownership, and forest-related policies influence future wood supply

International Institute for Applied Systems Analysis – 14 March 2024

IIASA researchers contributed to a new study analyzing factors affecting future wood supply in Europe such as climate change, land use, and policy developments. The authors propose practical response measures for different stakeholder groups, including the wood-based industry, forest management, and policymakers.

The study on Europe's wood supply in disruptive times was released by TEAMING UP 4 FORESTS, a science-business platform founded by the International Union of Forest Research Organizations (IUFRO) and Mondi to connect stakeholders across the forest value chain. The platform comprises a professional network of 100+ scientists (including several IIASA researchers), business representatives, and policymakers.

The new publication captures the factors identified in numerous scientific studies influencing wood supply from European forests, and outlines the impacts of climate change, while also considering other factors, such as political uncertainties and a fragmented forest landscape. Bridging the gap between science and application of insights, the authors highlight practical implications and response measures for the wood-based industry, forest management, and policymakers. The study compiles the findings of a wide range of scientific papers and research, and also includes the perspectives of different stakeholders evaluated during the process.

Challenges for forests and the wood-based industry

Forests in Europe are strongly affected by climate change, with far-reaching consequences for forest health and ecosystem services, including the supply of wood. Tree species of great commercial importance are significantly impacted by disturbances such as extreme drought events, bark beetle infestation, frequent heatwaves, and wildfires. Forests and wood-based industries also face other challenges such as political uncertainties and a fragmented forest landscape caused by alterations in land use.

With forests being highly sensitive to climate change and significantly impacted by disturbances such as drought or heat, forest owners and managers are urged to take adaptive measures.

"We need more mixed and structurally diverse forests, including natural regeneration and active assisted migration of species that are more adapted to future climates," explains study author Manfred Lexer from the University of Natural Resources and Life Sciences in Austria. "In European forests that are available for wood supply we have six dominant tree species: pine, spruce, fir, beech, oak, and birch. Spruce, beech, and pine are among the most vulnerable species, especially to drought," he adds.

The results, for example, indicate that the forest area in Europe suitable for Norway spruce will decrease by about 50% depending on different climate change scenarios, while the suitability for other species will increase significantly. For the wood-based sector, which relies on the sufficient availability of woody biomass, it is key to gradually move away from the current strong dependency on softwoods (such as spruce and pine) and consider the production of new value-added wood-based products. Emerging products such as wood-based plastics, textile fibers or nano-fibrillated cellulose for packaging, for instance, are less dependent on certain tree species than traditional products.

"In view of these challenges and a growing demand for wood-based products, forest-based industries in Europe will need to reflect their current business models. Technological and digital innovation, as well as a cascading use of wood is driving the transition towards a circular economy and supports the adaptation to future changes in wood supply," comments study author Anne-Christine Ritschkoff from VTT Technical Research Centre of Finland Ltd. "The future of research and innovation should be focused on the holistic and resource-efficient use of wood materials," she says.

The role of forest ownership

Other factors impacting the supply of wood include forest ownership and demographic changes among landowners. While there are differences in forest ownership between European regions, the share of private forest ownership has increased since the early 1990s, with 56% of European forest areas now being privately owned. In addition, private ownership has become more heterogeneous with more non-traditional, urban, or passive owners. This often leads to less interest or capacity among forest owners to supply wood to the market.

"Wood harvesting and profit maximization are not the only – or even the primary – motivation for many forest owners and, therefore, are not the main goal of their management practices. It will be important for policymakers to implement initiatives that engage and incentivize private forest owners," comments study author Špela Pezdevšek Malovrh from the University of Ljubljana in Slovenia.

Policies to promote sustainable forest management

The factors affecting forests and wood supply outlined in the study need corresponding policy responses at different levels from global to local, particularly a better harmonization and integration of policies that promote sustainable forest management practices.

"Strategic investments in research and innovation are needed to develop integrated, sustainable wood supply strategies and technologies that can adapt to changing circumstances, including the regionalization of supply chains and evolving market dynamics," notes study coauthor Florian Kraxner who leads the Agriculture, Forestry, and Ecosystem Services Research Group at IIASA. "This will support the development of wood supply strategies and technologies to ensure adaptation and resilience of European forests to climate change in the long-term."

The authors further emphasize that cooperation and partnerships are paramount to successfully navigating the uncertainties and changes ahead for the future of wood supply in Europe. Interdisciplinary, transnational, and cross-sectoral collaborations can facilitate the implementation of successful strategies and guide the wood-based industry towards innovation, adaptability, and resilience amid evolving challenges. Beyond cooperation, the study shows that education and communication within and outside the forest-based sector, are crucial for sustainable forest management and engaging future generations.

CHAPTER 23 - FORESTRY

Almost a quarter of China's land mass is covered by forests, according to official statistics. The Chinese government has ambitious forest conservation programs and highlights growth in forest stock volume as a prominent climate change goal.[1]

Most new forest growth in China is in monoculture plantations. The impact of China's timber and food imports on tropical forests abroad may substantially or completely offset the climate change benefits of China's domestic forestry programs.[2]

Background

Forests cover large parts of southern China, from Fujian Province in the east to Sichuan and Yunnan Provinces in the west. Forests also cover much of China's far northeast. There are fewer forests in the densely populated region between Shanghai and Beijing and almost none in the far western provinces of Xinjiang and Tibet.

Roughly 23% of China's territory is covered with forests, according to the Chinese government and United Nations Food and Agriculture Organization (FAO).[3]

China's forest cover has expanded in recent decades, according to Chinese government sources.

- China's State Council Information Office reports that 36.3 million hectares of forests were planted from 2016 to 2020.[4]
- NDRC reports that roughly 15 million hectares of forests were planted between 2011 and 2015.[5]
- China's State Forestry Administration reports that China's forest cover grew from roughly 13% in 1981 to more than 20% in 2010.[6]

1 State Council Information Office, Responding to Climate Change: China's Policies and Actions (October 2021) at Section III-4; NDRC, 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and Outline of the Vision for 2035 (March 23, 2021) at pp.90-91; People's Republic of China, China's Achievements, New Goals and New Measures for Nationally Determined Contributions (October 2021) at p.2.
2 Fangyuan Hua et al., "Tree plantations displacing native forests: The nature and drivers of apparent forest recovery on former croplands in Southwestern China from 2000 to 2015," Biological Conservation (June 2018); Antje Ahrends et al., "China's fight to halt tree cover loss," Royal Society Publishing (October 7, 2017). See section below on Deforestation Abroad.
3 State Council Information Office, Responding to Climate Change: China's Policies and Actions (October 2021) at Section III-4; U.N. Food and Agriculture Organization, Global Forest Resources Assessment-China (accessed July 10, 2022). See generally, UN Food and Agriculture Organization, Global Forest Resources Assessment 2020: Report-China, World Resources Institute, Global Forest Watch—China country summary.
4 State Council Information Office, Responding to Climate Change: China's Policies and Actions (October 2021) at Section III–4.
5 NDRC, China's Policies and Actions for Addressing Climate Change (October 2016) at p.20.
6 Antje Ahrends, Peter M. Hollingsworth, Philip Beckschäfer, Huafang Chen, Robert J. Zomer, Lubiao Zhang, Mingcheng Wang and Jianchu Xu, "China's fight to halt tree cover loss," Royal Society Publishing (October 7, 2017), citing State Forestry Administration China, 2011 China National Progress Report to the UNFF Secretariat on the implementation of NLBI and other relevant resolutions, Beijing, China: State Forestry Administration China (January 2011).

Figure 23-1: China's Forests (2019)

Source: National Forestry and Grasslands Administration[7]

Several academic studies provide similar estimates for the years prior to 2010.

- A 2016 study by scientists at Michigan State University found that between 2000 and 2010, 1.6% of China's territory experienced a significant increase in forest cover

7 National Forestry and Grasslands Administration, Forest Resources in China–The Ninth National Forest Inventory (March 2019) at p.1.

and 0.38% experienced significant forest loss.[8]

- A 2011 study by scientists at Peking University found that forest cover in China increased an average of roughly 0.5% annually between 1980 and 2010.[9]

However, at least one source finds that tree cover has declined in China in the past several decades. Global Forest Watch, an online platform that provides forest data, reports that:

- From 2001 to 2020, China lost 10.9 million hectares of tree cover—a 6.7% decrease—resulting in roughly 4.7 Gt of CO_2 emissions (slightly less than half of China's CO_2 emissions last year).
- From 2013 to 2021, China lost 3.7 million hectares of natural forest—a 2.7% decrease—resulting in roughly 1.5 Gt of CO_2 emissions.
- From 2002 to 2021, China lost 77,300 hectares of humid primary forest—a 4.5% decrease.[10]

The different estimates may in part be due to different definitions. A 2017 study found that:

> "If 'forest' is defined according to the FAO criteria (including immature and unstocked areas), China's forest cover gains between 2000 and 2010 were larger than the combined area of Germany, The Netherlands, Belgium and Luxembourg. If forest is defined according to China's own criteria…, China has gained an area smaller than size of Germany; and if forest is defined according to what non-specialists would view as forest (contiguous blocs of tall (higher than 5 m) and closed (minimum 50%) crown cover), the detectable gains are smaller than the size of The Netherlands."[11]

Data quality may also be a problem. Some studies have found systemic over-reporting of tree cover in China, in part because tree cover goals are included in the performance criteria for many local and provincial officials.[12]

Monoculture plantations dominate new forest growth in China. One study found that, although tree cover grew 32% in southwest China between 2000 and 2015, all that growth was due to the conversion of croplands to tree plantations. During the same period, native forests in

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8 Andrés Viña, William J. McConnell, Hongbo Yang, Zhenci Xu and Jianguo Liu, "Effects of conservation policy on China's forest recovery," Science Advances (March 2016).
9 Lei Shi et al., "The Changes in China's Forests: An Analysis Using the Forest Identity," PLOS ONE (June 9, 2011).
10 Global Forest Watch—China country summary, World Resources Institute (accessed July 23, 2022). Global Forest Watch defines "tree cover" as "all vegetation greater than 5 meters in height," which "may take the form of natural forests or plantations across a range of canopy densities." Global Forest Watch–Tree Cover Loss, World Resources Institute (accessed July 23, 2022)
11 Antje Ahrends, Peter M. Hollingsworth, Philip Beckschäfer, Huafang Chen, Robert J. Zomer, Lubiao Zhang, Mingcheng Wang and Jianchu Xu, "China's fight to halt tree cover loss," the Royal Society Publishing (October 7, 2017) at p.7. See also Yan Li et al., Inconsistent estimates of forest cover change in China between 2000 and 2013 from multiple datasets, *Scientific Reports* (August 2017).
12 Hong Jiang, "Taking Down the 'Great Green Wall': The Science and Policy Discourse of Desertification and Its Control in China," The End of Desertification (2016) at p.528

southwest China declined by 6.6%. Monoculture tree plantations provide significantly less carbon storage and biodiversity value than natural forests.[13]

Policies

China's Nationally Determined Contribution (NDC) gives high prominence to a forest goal. One of the six principal goals in China's October 2021 NDC is "to increase the forest stock volume by around 6 billion cubic meters from 2005 levels" by 2030. This builds on the forest goal in China's 2015 NDC—to increase the forest stock volume by around 4.5 billion cubic meters from 2005 levels by 2030. (The 2015 NDC forest goal was achieved in 2019, 11 years ahead of schedule.)[14]

During the *14th Five-Year Plan* (2021–2025), the Chinese government aims to increase forest cover to 24.1% of the country's total land area. This builds on the forest cover goal in the *13th Five-Year Plan*—to increase forest cover from 21.66% to 23%. The *13th Five-Year Plan* forest goal was met in 2020.[15]

The 14th Five-Year Plan sets goals for the protection and restoration of important ecological zones. Six of these goals relate to forestry.[16] (See table below.)

Figure 23-2: 14th Five Year Plan Forest Goals

Area	14th Five-Year Plan Goals
Tibetan Plateau ecological shield zone	Additional 1 million hectares of land will be protected from desertification; additional 3.2 million hectares of grassland will be protected from degradation.
Yellow River ecological zone	800,000 hectares of forest and grass vegetation will be restored; additional 2 million hectares of land will be protected from soil erosion; 800,000 hectares of land will be protected from desertification.
Yangtze River ecological zone	1.1 million hectares of land will be afforested; additional 5 million hectares of land will be protected from soil erosion; 1 million hectares of land will be protected from stony desertification.

13 See Fangyuan Hua et al., "Tree plantations displacing native forests: The nature and drivers of apparent forest recovery on former croplands in Southwestern China from 2000 to 2015," Biological Conservation (June 2018); Antje Ahrends et al., "China's fight to halt tree cover loss," Royal Society Publishing (October 7, 2017); Simon Lewis et al., "Restoring natural forests is the best way to remove atmospheric carbon," Nature (April 2, 2019).
14 People's Republic of China, China's Achievements, New Goals and New Measures for Nationally Determined Contributions (October 2021) at p.2; People's Republic of China, Enhanced Action on Climate Change: China's Intended Nationally Determined Contributions (June 2015) at p.5; Li Keqiang presided over the National Leading Group Meeting on Climate Change, Energy Conservation and Emissions Reduction," (in Chinese) Chinese Government Network (July 11, 2019). "Forest stock volume" is "the sum of the stem volumes of all the living trees" in an area. See Yang Hu et al., "Estimating Forest Stock Volume in Hunan Province, China," Remote Sensing (January 2020).
15 State Council Information Office, "China's forest coverage rate to reach 24.1% by 2025" (December 17, 2020); State Council, Work Plan for Controlling Greenhouse Gas Emissions in the 13th Five-Year Plan at 3(D); State Council, Second Biennial Update Report (December 2018)
16 NDRC, 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and Outline of the Vision for 2035 (in Chinese) (March 23, 2021) at pp.90–91.

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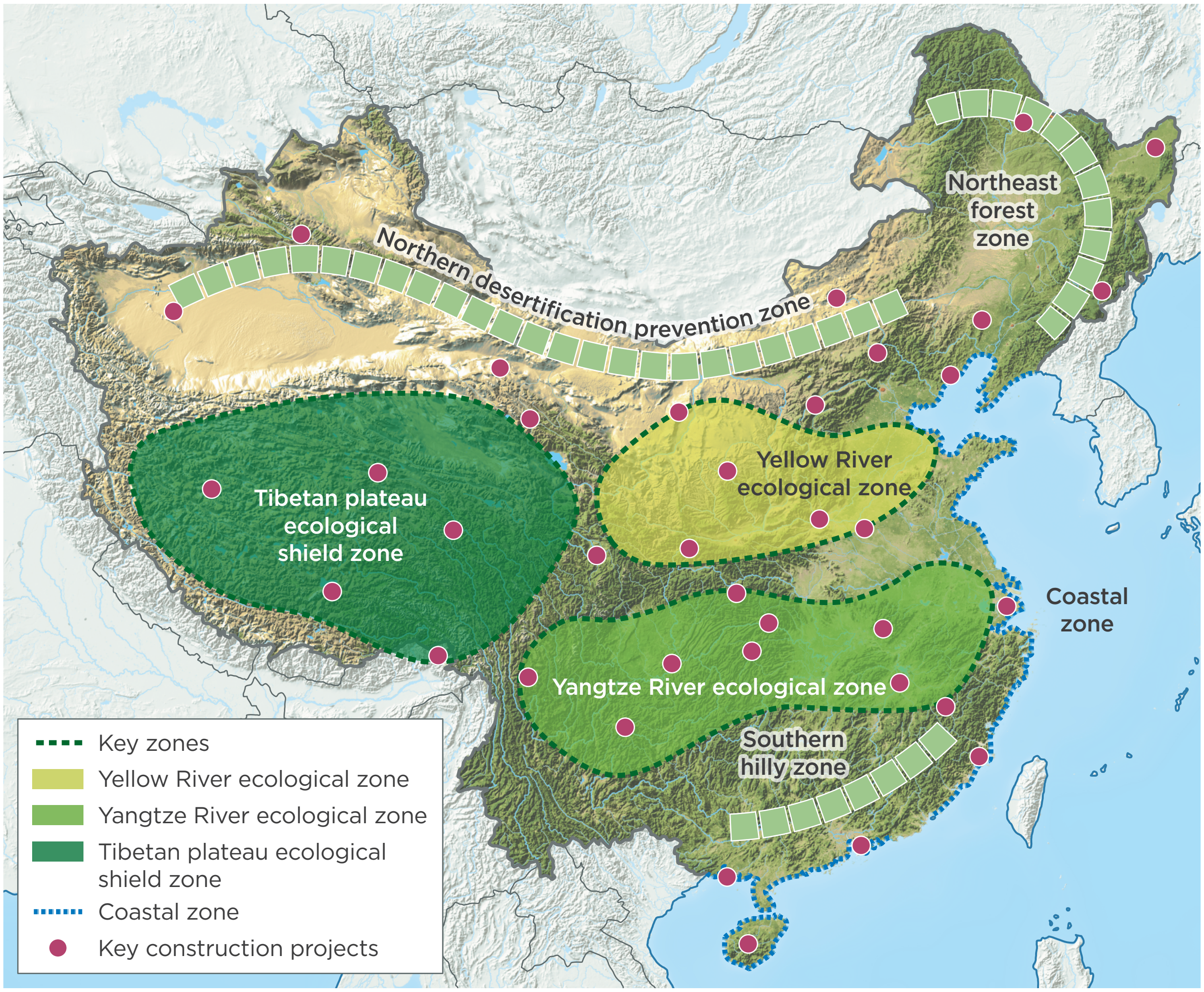
Northeast forest zone	700,000 hectares of land will be cultivated as potential natural forest; 300,000 hectares of degraded grassland will be improved.
Northern desertification prevention zone	2.2 million hectares of land will be afforested; additional 7.5 million hectares land will be protected from desertification; 2.7 million hectares of grassland will be protected from degradation.
Southern hilly zone	90,000 hectares of shelter forest will be built; 300,000 hectares of land will be protected from stony desertification.

Source: NDRC[17]

17 NDRC, 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and Outline of the Vision for 2035 (in Chinese) (March 23, 2021) at pp.90–91.

Figure 23-3: 14th Five-Year Plan: Major Projects for Protection and Restoration of Important Ecosystems



Source: NDRC[18]

The Chinese government has extensive domestic forest conservation programs. The largest, known as the Natural Forest Conservation Program, includes large-scale tree-planting, an expansion of forest reserves and a ban on logging in primary forests. From 1998 to 2018, the

18 NDRC, 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and Outline of the Vision for 2035 (in Chinese) (March 23, 2021) at p.89.

central government spent more than RMB 475 billion (roughly $72 billion) on the program.[19]

Historically, the goal of China's forest conservation programs included preventing floods and fighting desertification. The Three-North Shelterbelt Program, launched in the late 1970s, is a multidecade program to plant a 4,500-kilometer wall of trees through the Gobi Desert to reduce sandstorms. The National Forest Conservation Program was launched in the wake of the catastrophic Yangtze River floods of 1998. In recent years, the goals of China's forest conservation programs have expanded to include fighting local air pollution and climate change as well.[20]

In December 2019, the National People's Congress revised China's Forest Law for the first time in 10 years. The amendments banned buying, transporting or processing illegal timber and require processing companies to establish a data record of raw materials and products. Environmental advocates praised the amendments, while saying the impacts would depend on how actively the new provisions are enforced. The amendments also strictly control the logging of natural forests and limit annual harvest volumes.[21]

Official documents setting forth China's forest policies include:

1. *National Afforestation and Greening Plan* (2016–2020)[22]
2. *National Forest Management Plan* (2016–2050)[23]
3. *Action Plan for Climate Change in Forestry in the 13th Five-Year Plan*[24]
4. *Action Plan for Forestry to Adapt to Climate Change* (2016–2020)[25]
5. *14th Five-Year Plan for Protection and Development of Forestry and Grassland* (2021–2025)[26]

The National Forestry and Grassland Administration (NFGA) within the Ministry of Natural Resources has principal responsibility for forest management in China. The NFGA was

19 Hui Wang et al., "China's Key Forestry Ecological Development Programs," (in Chinese) Forests (January 2021); Ahrends et al., "China's fight to halt tree cover loss," (October 7, 2017); Andrés Viña, William J. McConnell, Hongbo Yang, Zhenci Xu and Jianguo Liu, "Effects of conservation policy on China's forest recovery," Science Advances (March 2016). See also Zihao Ma et al., "Cost-Benefit Analysis of China's Natural Forest Conservation Program," Journal for Nature Conservation, Vol. 55 (June 2020), 125818.

20 Ahrends et al., "China's fight to halt tree cover loss," (October 7, 2017); Miao-miao Li, An-tian Liu, Chunjing Zou, Wen-duo Xu, Hideyuki Shimizu and Kai-yun Wang, "An overview of the 'Three-North' Shelterbelt project in China," Forestry Studies in China (February 2012); Viña et al., "Effects of conservation policy on China's forest recovery" (March 2016); "Lessons from China on Increasing Forest Cover," Unravel (March 3, 2021).

21 Ministry of Ecology and Environment, Forest Law of the People's Republic of China (December 28, 2019); "China introduces new law to safeguard forests and improve governance," Client Earth (July 8, 2020); Ashoka Mukpo, "China's revised forest law could boost efforts to fight illegal logging," Mongabay (March 19, 2020).

22 State Forestry Administration, National Afforestation and Greening Plan (2016–2020).

23 State Forestry Administration, National Forest Management Plan (2016–2050) (in Chinese).

24 State Forestry Administration, Action Plan for Climate Change in Forestry in the 13th Five-Year Plan (in Chinese).

25 State Forestry Administration, Action Plan for Forestry to Adapt to Climate Change (2016–2020) (in Chinese).

26 National Forestry and Grassland Administration, NDRC, "14th Five-Year Plan for Protection and Development of Forestry and Grassland," (in Chinese) (July 2021).

established in 2018 as part of government-wide institutional reforms, assuming the functions and responsibilities of the former State Forestry Administration at that time.[27]

Several provinces, including Sichuan, Guangdong and Guizhou, have launched pilot carbon sink trading for poverty alleviation programs. Under these programs, poor households can receive compensation for planting and cultivating trees in part for the carbon storage value.[28]

Sequestration Estimates

China's forest programs sequester significant amounts of carbon.

- A 2020 study estimated that, between 2020 and 2050, forest vegetation in China will absorb roughly 22% of Chinese CO_2 emissions from fossil fuels during the same period.[29]
- A 2018 study that sampled thousands of plots across China found that each year China's forests sequester carbon equivalent to roughly 5% of the country's CO_2 emissions.[30]
- A 2016 study estimated that carbon storage in China's forests would reach almost 28 Gt by 2033. (This is equal to roughly nine years of China's CO_2 emissions.)[31]
- A 2015 study estimated that China's forests had absorbed more than 22 Gt of carbon since 1973. (This is equal to roughly seven years of China's CO_2 emissions.)[32]

The Chinese government has provided official estimates of the carbon sequestered in land use change and forestry activities combined.

- In its *Second Biennial Update Report* submitted to the UN Framework Convention on Climate Change in December 2018, the Chinese government estimated that 1150 Gt of CO_2 (roughly 11% of China's annual CO_2 emissions) were sequestered by land use change and forestry activities in 2014.[33]
- In its *First Biennial Update Report* submitted to the UN Framework Convention on

27 See "A Brief Account of the National Forestry and Grassland Administration," National Forestry and Grassland Administration website (accessed September 24, 2022).
28 "Carbon sink trading sheds new light on China's poverty relief," XinhuaNet (July 10, 2018).
29 Qiu, Zixuan, Zhongke Feng, Yanni Song, Menglu Li and Panpan Zhang. 2020. "Carbon Sequestration Potential of Forest Vegetation in China from 2003 to 2050,"Journal of Cleaner Production 252 (April 2020).
30 Jingyun Fang et al., "Climate change, human impacts, and carbon sequestration in China," Proceedings of the National Academy of Sciences of the United States, April 17, 2018 (163.4 TgC/year of carbon sequestration for the past decade). 1 Tg = 1 Mt; 1 Mt C = 3.67 Mt CO_2; 163.4 TgC = 598 Mt CO_2.
31 Zhang Xufang. Yang Hongqiang and Zhang Xiaobiao, "Development level and trend in Chinese forestry carbon pools from 1989 to 2033," Resources Science (February 2016). 28 Gt C = 103 Gt CO_2.
32 Lu Ni-ni, Wang Xin-jie, Ling Wei, Xu Xue-lei and Zhang Yan, "Estimation of forest carbon storage in China based on data of National Inventory of Forest Resources," Journal of Central South University of Forestry & Technology (November 2015). China's 2018 CO_2 emissions = roughly 11 Gt. See Chapter 1–Emissions at note 2. 22 Gt C = 81 Gt CO_2,. On C v. CO_2, see Joe Romm, "The Biggest Source of Mistakes: C. v. CO_2," Think Progress (March 25, 2008).
33 People's Republic of China, Second Biennial Update Report on Climate Change (December 2018) at p.16.

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Climate Change in December 2016, the Chinese government estimated that 576 Gt of CO_2 (roughly 6% of China's annual CO_2 emissions) were sequestered by land use change and forestry activities in 2012.[34]

A 2020 study examined different methods for estimating forest carbon storage in China, finding that better survey data are needed.[35]

Deforestation Abroad

China is the world's largest timber importer. In 2019, 56% of logs and sawn wood bought in China were imported.[36]

China's footprint on tropical forests is especially large.

- In 2018, roughly two-thirds of the world's tropical forest logs were exported to China.[37]
- China is also the world's largest importer of soy and beef, and the world's second-largest importer of palm oil. Growing global demand for each of these products causes significant tropical deforestation.[38]

In addition, some Belt and Road Initiative projects are through forested areas, which has led to deforestation.[39]

From a global perspective, these trends may substantially or completely offset the climate change benefits of China's domestic forest conservation policies. China's impacts on tropical forests around the world are especially important with respect to climate change. Tropical deforestation can lead to significant warming, due to both the release of carbon dioxide from vegetation and biophysical effects such as changing the albedo of the Earth's surface.[40]

34 People's Republic of China, First Biennial Update Report on Climate Change (December 2016) at p.22.
35 Sun, Wanlong, and Xuehua Liu, "Review on Carbon Storage Estimation of Forest Ecosystem and Applications in China," Forest Ecosystems (2020)
36 Zhu Chunquan and Jin Zhonghao, China's Role in Promoting Global Forest Governance and Combating Deforestation, World Economic Forum (July 2022) at p.6, 12. See generally Steven Lee Myers, "China's Voracious Appetite for Timber Stokes Fury in Russia and Beyond," New York Times (April 9, 2019); Bo Li, "2 Ways for China to Play a Bigger Role in Protecting Global Forests," World Resources Institute (April 17, 2018); Xiufang Sun, Kerstin Canby and Lijun Liu. China's Logging Ban in Natural Forests, Forest Trends (March 2018).
37 Zhu Chunquan and Jin Zhonghao, China's Role in Promoting Global Forest Governance and Combating Deforestation, World Economic Forum (July 2022) at p.6.
38 Global Green Value Chains, China Council for International Cooperation on Environment and Development (September 2020) at p.7; Pietro Bertazzi and Sabrina Zhang, "Soy: China's deforestation dilemma," Carbon Disclosure Project (March 21, 2019); "What Are The Biggest Drivers Of Tropical Deforestation?," World Wildlife Fund Magazine (Summer 2018); "8 Things To Know About Palm Oil," World Wildlife Fund website (accessed July 24, 2022).
39 Elizabeth Losos, Alexander Pfaff and Lydia Olander, "The deforestation risks of China's Belt and Road Initiative," Brookings (January 28, 2019).
40 Deborah Lawrence et al., "The Unseen Effects of Deforestation: Biophysical Effects on Climate," Frontiers in Forests and Global Change (March 2022). On China's forest conservation policies and global deforestation, see generally Zhu Chunquan and Jin Zhonghao, China's Role in Promoting Global Forest Governance and Combating Deforestation, World Economic Forum (July 2022).

In September 2020, the China Council for International Cooperation on Environment and Development (CCICED), "a high-level international advisory body with the approval of the Government of China,"[41] released a report finding that:

> "The Chinese government could strengthen measures to reduce the import of soft commodities that are illegally harvested or produced in their country of origin. This could build upon a provision regarding the legality of timber in the latest revision of the Forest Law."[42]

In 2021, the Chinese government signaled attention to deforestation abroad in several international fora.

- At the Second EU–China High-Level Environment and Climate Dialogue in September 2021, China and the EU agreed "to engage collaboratively in support of reducing global deforestation through enhancing cooperation in conservation and sustainable management of forests, making supply chains more sustainable, and combating illegal logging and associated trade."[43]
- At the 26th Conference of the Parties to the UN Framework Convention on Climate Change in November 2021 (COP26), China signed the *Glasgow Leaders' Declaration on Forests and Land Use* together with 140 other countries. The Declaration includes a commitment to "halt and reverse forest loss" by 2030.[44]
- Also at COP26, China and the United States issued the *Joint Glasgow Declaration on Enhancing Climate Action in the 2020s*, pledging to "engage collaboratively in support of eliminating global illegal deforestation through effectively enforcing their respective laws on banning illegal imports."[45]

41 China Council for International Cooperation on Environment and Development website – About Us (accessed July 24, 2022).
42 *Global Green Value Chains*, China Council for International Cooperation on Environment and Development (September 2020) at p.vi;
43 Joint Press Communiqué following the Second EU–China High Level Environment and Climate Dialogue (October 10, 2021) at Para. 11.
44 Glasgow Leaders' Declaration On Forests And Land Use (November 2, 2021).
45 U.S.–China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s (November 10, 2021) at para.10.

Closing Adaptation Knowledge Gaps in Asia-Pacific

UN Climate Change News, 29 November 2023 – In a bid to address critical gaps in adaptation planning and implementation, UN Climate Change and the UN Environment Programme (UNEP) have joined efforts to close knowledge disparities, at a time when – according to the 2023 UNEP Adaptation Gap Report launched November 2 – adaptation progress appears to be stagnating.

The Lima Adaptation Knowledge Initiative (LAKI), a collaboration between UN Climate Change and UNEP, brings together governments, non-governmental organizations and experts to tackle adaptation knowledge gaps.

At the 2023 Asia-Pacific Climate Week, UN Climate Change in partnership with UNEP and the International Centre for Integrated Mountain Development (ICIMOD) convened governments, experts and partners to discuss progress, share case studies and highlight concrete actions taken to bridge knowledge gaps in the Hindu Kush Himalayas (HKH) and Pacific Small Islands Developing States (SIDS) subregions.

Integrating Traditional Knowledge into Early Warning Systems

In Vanuatu, the Secretariat of the Pacific Regional Environment Programme (SPREP) and the Australian Bureau of Meteorology (BOM) worked with local communities to integrate traditional knowledge into climate information services, developing the Vanuatu Climate Watch App, which combines Indigenous knowledge with meteorological data to enhance the effectiveness of early warning systems.

To address the lack of access to early warning systems in Pacific Island countries, graduate students from the University of Michigan conducted a study addressing adaptation knowledge gaps in Samoa and Vanuatu. Under the UN Climate Change and Universities Partnership Programme, they developed recommendations on the use of climate information services, traditional knowledge integration and capacity building to benefit Pacific islands.

ICIMOD's The Green Resilient Agricultural Productive Ecosystems (GRAPE) project in Nepal focuses on improving climate-resilient agriculture, Indigenous crop management and water resource management. Similarly, the "Skill Up!" project empowers marginalized populations, particularly young people, through capacity building and awareness raising to respond to the fact that there is limited access to traditional knowledge on agricultural adaptation.

In Bangladesh, the Sustainable Forests and Livelihoods (SUFAL) project repackages baseline data on climate change impacts on forests and biodiversity. By involving communities in forest management and conservation, SUFAL has supported research and knowledge-building efforts, thereby contributing to policy development and the restoration of natural resources using traditional knowledge.

"Adaptation is a lifeline; it is what keeps people from losing their livelihoods and losing lives. Therefore, initiatives such as the LAKI in the Pacific SIDS are very relevant in advancing adaptation action by fostering collaboration, including the sharing of knowledge and practices," said Christopher Bartlett, Chief of Climate Diplomacy, Vanuatu.

"Our collaborative efforts with partners have resulted in tangible benefits for the HKH subregion, enabling communities to access and apply traditional knowledge in agriculture, make informed decisions about climate change related, agriculture, forest, water and biodiversity conservation policies, amongst others," said Dr. Pem Kandel, Chief Policy Advisor and Interim Strategic Group Lead, ICIMOD.

Recommendations and Next Steps

The Asia-Pacific Climate Week event laid the groundwork for the future roadmap of the LAKI. Key recommendations include:

- Repositioning adaptation knowledge to address the full spectrum of adaptation and resilience and ensuring that communities and countries are equipped with relevant knowledge and tools.
- Building long-term strategic partnerships with sub-regional partners, academia, local communities, and the public and private sectors.
- Integrating context-specificity in adaptation interventions.
- Ensuring locally led adaptation solutions through knowledge and capacity enhancement.
- Integrating Indigenous knowledge into the design of adaptation solutions.
- Developing partnerships with knowledge brokers, including youth and academia.
- Promoting gender-responsive approaches to address inequality and technology gaps.

Building on the successes and lessons learned in Asia-Pacific, UN Climate Change and UNEP are planning to scale up the LAKI in other subregions to ensure locally led adaptation is prioritized for a sustainable and resilient future.

Forestry Cooperation

Association of Southeast Asian Nations, 2024

Overview of The Sector

ASEAN cooperation in forestry was initiated in 1993 on the Ministerial Understanding (MU) on ASEAN Cooperation in Food, Agriculture and Forestry. The backbone of ASEAN cooperation in forestry is sustainable forest management (SFM). Sustainable forest management involves the application of best practices based on current scientific and traditional knowledge that allow multiple objectives and needs to be met without degrading forest resources. It also requires effective and accountable governance and the safeguarding of the rights of forest-dependent peoples. FAO defined sustainable forest management as a "dynamic and evolving concept, which aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations".

Considering the above, ASEAN has set up the vision of ASEAN Cooperation in Forestry 2025 of which *"Forest resources are sustainably managed at the landscape level to meet societal needs, both socio-economically and culturally, of the present and future generations, and to contribute positively to sustainable development".* Inline with this Vision, ASEAN has identified key areas/priorities which include sustainable forest management, forest law enforcement and governance (FLEG), forest products development, conservation and wildlife enforcement, social forestry and forest and climate change.

The goal for the forestry sector in ASEAN is to "enhance sustainable forest management for the continuous production of forest goods and services in a balanced way and ensuring forest protection and biological diversity conservation, as well as optimise their utilisation, compatible with social and ecological sustainability".

Priority Areas of Cooperation

Based on the vision and goal of ASEAN Cooperation in Forestry, key priorities of the cooperation are elaborated into five strategic thrusts that includes:

- Enhancing sustainable forest management
- Enhancing trade facilitation, economic integration and market access
- Enhancing the forestry sector resilience and role in climate change
- Institutional strengthening and human resources development
- Strengthening ASEAN's joint approaches on regional and international issues affecting the forestry sector.

Strategic Plan of Action for ASEAN Cooperation in Forestry 2016-2026 has been constructed referring to the vision, goal and strategic thrusts that are focusing on supporting policy developments, exchange best practices and experiences, capacity and institutional development as well as partnership.

Some activities, program and initiatives have been implemented to achieve the Forestry Vision 2025 such as i) the development of ASEAN Criteria and Indicator for Sustainable Management of Tropical Forest, ii) the development of the Work Plan for Forest Law Enforcement and Governance (FLEG) Implementation in ASEAN 2016-2025, iii) the development of regional capacity building tools (Regional Community Forestry Participatory Assessment Tool, Regional Agroforestry for Climate Change Resilient Landscape Manual), iv) the development of regional policy tools (e.g. ASEAN Guidelines for Agroforestry Development, ASEAN Guidelines for Detecting and Preventing Wildlife Trafficking, ASEAN Voluntary Code of Conduct on Imports for Forest and Timber Companies). ASEAN has also been actively involved in UNFCCC and UNFF by submitting several joint submissions on the issues that become common concern such as reducing emissions from deforestation and forest degradation (REDD+).

ASEAN has also developed partnership and collaboration with several dialogue partners and international development partners such as Republic of Korea, Switzerland, Germany, China, Asian Forest Cooperation Organisation (AFoCO) and FAO. Some international institutions such as RECOFT, CIFOR, ICRAF, SEARCA and Non-timber Forest Products-Exchange program have also provided ASEAN with technical expertise.

Major Sectoral Bodies/Committees

ASEAN Ministers on Agriculture and Forestry (AMAF) mandated ASEAN Senior Officials on Forestry (ASOF) oversee the implementation of ASEAN cooperation in forestry. ASOF is supported by five working groups (subsidiary bodies) namely:

1. ASEAN Working Group on Forest Management (AWG-FM): provides specific policy-oriented research results and policy analysis on sustainable forest management, forest law enforcement and governance.
2. ASEAN Working Group on Forest Products Development (AWG-FPD): provides specific recommendations and policy analysis on trade in forest products and their development including forest certification, enhancing competitiveness of forest products.
3. ASEAN Working Group on Social Forestry (AWG-SF): provides specific policy recommendations on the effects of social forestry in enhancing sustainable forest management, to enhance welfare and livelihoods of indigenous people, local communities, forest dwellers and other forest-dependent communities.
4. ASEAN Working Group on CITES and Wildlife Enforcement (AWG CITES and WE): provides recommendation on trade in wild fauna and flora and to strengthen networking of the ASEAN Wildlife Enforcement, address challenges of transboundary trafficking of wildlife and timber.
5. ASEAN Working Group on Forest and Climate Change (AWG-FCC): provides specific recommendation on forest and climate change especially related to the effort to reduce emissions and strategy in adaptation and mitigation from forestry sector.

Name	Year of establish-ment	Function
ASEAN Working Group on Forest Products Development	1998	1. *Respond to emerging issues on trade in forest products;* 2. *Enhance ASEAN cooperation in forest products development and the alignment of national standards and testing protocols in accordance with International Standard;* 3. *Enhance intra- and extra-ASEAN trade and competitiveness of ASEAN forest products including through inter-alia timber certification;* 4. *Support the development of medicinal and aromatic plant industries, including their conservation and sustainable use;* 5. *Promote cooperation with ASEAN Dialogue Partners, regional and international organisations and the private sector in marketing and image building for ASEAN forest products.*
ASEAN Working Group on CITES and Wildlife Enforcement	2005	1. *Respond to emerging issues on trade in wild fauna and flora;* 2. *Strengthen law enforcement and support good governance in combating illegal trade in wild fauna and flora,* 3. *Promote networking amongst relevant law enforcement authorities in AMS to curb illegal trade in wild fauna and flora;* 4. *Coordinate regional response to illegal trade in protected species that threatens biological diversity, endangers public health, and undermines economic well-being;* 5. *Encourage industry groups, trade associations and traders, and local communities to comply with legality and sustainability requirements of CITES and national legislation and regulations on trade in wild fauna and flora; and* 6. *Increase capacity building, and support co-ordination and resources to combat illicit trafficking and illegal trade in wild fauna and flora throughout the region.*

ASEAN Working Group on Forest Management	2005	1. *Respond to emerging issues on forest management;* 2. *Enhance sustainable management of forest resources, including forest protection and biological diversity conservation, that are compatible with social and ecological sustainability;* 3. *Combat illegal forest harvesting and its associated trade in timber and timber products through FLEG;* 4. *Adopt and articulate ASEAN common positions and influence the outcomes of the deliberations at international and regional fora;* 5. *Provide effective networking and partnering with other institutions, agencies, instruments and processes working on forest management issues at the regional and global levels.*
ASEAN Working Group on Social Forestry	2006	1. *Promote sustainable forest management involving community living within and surrounding the forest;* 2. *Strengthen coordination to undertake joint approaches to develop and seek better market access for ASEAN community-based forest products and services;* 3. *Facilitate cross-learning and knowledge sharing in enhancing sustainable forest management and addressing safeguards within the REDD+ architecture, iv) adopt and articulate ASEAN common positions on issues related to social forestry at international and regional fora, especially on sustainable forest management that are based on local communities' needs and well-being;* 4. *Explore the role of social forestry/community forestry to the climate change adaptation and mitigation.*
ASEAN Working Group on Forest and Climate Change	2009	1. *Promote ASEAN common understanding and exchange of information and knowledge on best practices in addressing climate change issues;* 2. *Coordinate regional response to issues of climate change and their impacts on forests and the environment and to enhance effective implementation of the outcomes of United Nations Framework Convention on Climate Change and related conventions;* 3. *Increase capacity building, including research and development (R&D), mobilizing resources to further strengthen the implementation of forests and climate change activities in AMS, and promote public awareness; iv) respond to emerging issues on forests and climate change as identified in the agenda and work programs of ASOF and AMAF*

Executive Summary

Allen Blackman

Forests are among Latin America and the Caribbean's (LAC's) crown jewels. The region boasts roughly a third of the world's forests, half of its tropical forests, and a quarter of its mangroves (Blackman et al. 2014). This rich natural capital provides vital ecosystem services. At the global level, LAC forests remove vast quantities of carbon dioxide from the atmosphere (1.2 ± 0.4 Pg C per year), store almost half of the aboveground carbon in the tropics, circulate moisture at a continental scale, provide habitat for roughly half of the world's terrestrial species, and host seven of the world's 25 biodiversity hotspots (UNEP 2010; Gibbs et al. 2007; Werth and Avissar 2003; Meyers et al. 2000). At the local level, LAC forests regulate surface and groundwater quality, moderate temperature, and provide valuable economic and cultural goods and services, including 8 percent of the world's industrial wood products (Baker and Spracklen 2019; Anderson-Teixeira et al. 2012).

However, LAC's forests are confronting at least three serious challenges. The first is continuing rapid clearing and degradation. LAC deforestation rates have slowed somewhat over the past 15 years but are still alarmingly high. Between 2015 and 2020, South America lost almost 3 million hectares of forest per year, the second-highest total for any of the world's regions (FAO 2020). Of the 10 countries with the highest average annual net loss of forest area during the same period, 3 were in LAC: Brazil (1.5 million hectares per year), Paraguay (0.3 million), and Bolivia (0.4 million) (FAO 2020). Forest degradation is also an urgent problem. An estimated 240 million hectares of tropical forest in LAC is in a critical state of degradation (Armenteras et al. 2016).

Second, forest loss and degradation in LAC exacerbate climate change, which in turn has adverse effects on forests. LAC countries contribute almost a quarter of global greenhouse gas emissions from land-use change, mostly generated when forest is converted to cropland and pasture (IPCC 2019; WRI 2017). Climate change entails increases in both temperature and rainfall variability that alter forest functioning, plant growth, and tree mortality (Cusack et al. 2016; Scheffers et al. 2016). Barring significant intervention, many researchers believe, climate change, along with continued regional deforestation and fire, will trigger a self-reinforcing downward spiral that results in the loss of up to 60 percent of the Amazon Basin's forest by 2050 (Lovejoy and Nobre 2018).

Finally, the economic outlook for LAC's managed forests is mixed. Although LAC's share of the global timber market has increased significantly in the past 50 years, that growth has not benefited most of the region's countries—it has been almost exclusively due to expanded production of plantation forests in Brazil, Chile, and Uruguay (Sohngen 2020). In addition, LAC's managed forests face increasing competition from Asia, declining global demand, lagging sustainability certification, and persistent illegal logging (Sohngen 2020).

The good news is that at least some facets of the current political climate favor meaningful policy action. Forest conservation and restoration have attracted unprecedented attention in recent years in large part because of emerging consensus that averting the worst effects of climate change will require step changes in forest conservation and restoration (Griscom et al. 2017; Seymour and Busch 2016). For example, since 2011, 61 countries have signed on to the Bonn Challenge of bringing 150 million hectares of degraded and deforested landscapes into restoration by 2020 and 350 million hectares by 2030 (NYDF Assessment Partners 2019). In 2014, the 190 signatories of the 2014 New York Declaration on Forests, which include governments, companies, and nongovernmental organizations, pledged to help cut tropical deforestation by 50 percent by 2020 and 100 percent by 2030 (Verdone and Seidl 2017). The Inter-American Development Bank Group (IDBG) has invested US $1.5 billion in forest and forest-related projects since 2006 (Bauch 2020). And unilateral and bilateral action is encouraging. For example, Norway alone has committed more than half a billion dollars to address forest carbon issues (Hermansen 2015).

How can these financial and political resources best be used to promote conservation, restoration, and efficient management of LAC's forests in the 2020s? This monograph aims to help answer that question. It presents four expert assessments that tackle different facets of the issues.

In Chapter 1, Dan Nepstad and coauthors distill lessons from case studies of the application of three major approaches to forest conservation and restoration in four countries: Brazil, Costa Rica, Ecuador, and Peru. The three approaches are (1) *domestic* policies and programs led by national and subnational governments, including fiscal policies, land-use regulations, energy and transportation infrastructure, and import-export policies; (2) *market transformation* policies and programs, such as Forest Stewardship Council certification for sustainable forest management, the Brazilian Soy Moratorium, and the above-mentioned New York Declaration on Forests, that encourage consumers and traders to shift away from commodities produced in ways that cause deforestation or are otherwise unsustainable; and (3) *results-based* payment policies and programs, such as payments for ecological services and reducing emissions from deforestation and degradation (REDD) initiatives, that compensate governments and landholders for the ecosystem services provided by tropical forests. The authors offer the following observations:

- Domestic policies and programs can be quite effective but are hampered not only by the limited ability and willingness of governments to undertake meaningful sustained action but also by strong pushback from land managers, a dynamic that has played out in Brazil over the past decade. As a result, these types of policies can have short-term benefits but are unsustainable over the long term unless accompanied by positive incentives for land managers and other stakeholders.

- As for market transformation policies, unfortunately, certification programs rarely offer price premia or other financial incentives sufficient to engage the "dirty" producers whose participation is needed to spur large-scale change—they mainly attract producers that already meet the standards. Boycotts and moratoria can be effective in the short term but, like domestic policies and programs, may alienate farm sectors, triggering a backlash against efforts to slow deforestation.
- Results-based payment policies and programs can be cost-effective in promoting conservation and restoration when contracts are developed directly with subnational governments and when the benefits to land managers are clear. However, these interventions have so far been limited by the relatively small scale of financing available to tropical forest governments.
- Finally, strong synergistic links between forest conservation and economic development—as in the case of Costa Rica and the tourism industry—generate political will for regulation that facilitates conservation.

In Chapter 2, Carlos Nobre and coauthors examine the two-way links between forests and climate change. They summarize what we know about the effects of climate change on forests and human migration in LAC, and the effects of forest loss and degradation on global and regional climate change. In addition, they present case studies of some of these links for Brazil and Costa Rica. The authors report these findings:

- LAC regions have warmed an average of 1 degree C since 1900, and for many LAC regions the dry season has become longer and weather extremes more frequent. Climate projections for 2100 indicate an intensification of these changes, partially due to forest loss.
- Even leaving aside the effects of global climate change, deforestation is altering the regional climate. Deforestation alone could warm eastern Amazonia by more than 3 degrees C, decrease July-to-November precipitation by as much as 40 percent, and delay the onset of the rainy season by 0.12 to 0.17 day for each 1 percent increase in deforestation.
- Human-induced global and regional phenomena have triggered shifts in the dynamics and biodiversity of forests, reducing their resilience and productivity and culminating in large-scale diebacks. The combined effects of global climate change, regional deforestation, and increased forest fire are expected to cause up to 60 percent of the Amazon rainforest to disappear by 2050.
- As a result of climate change, some 17 million people in LAC may be forced to migrate over the next 30 years.
- LAC countries are responsible for roughly a quarter of the global emissions attributed to land-use change. Cutting these emissions will be critical to global efforts to avoid the worst effects of climate change.
- The climate challenges for LAC in the next decades will demand mixed climate policies based on forest restoration and protection, new technologies for sustainable agriculture, green infrastructure for risk reduction, and better communication between scientists and stakeholders.

In Chapter 3, Brent Sohngen explores LAC forest management, including LAC trends in international trade in timber and bioenergy, sustainable forest management, nontimber forest products, illegal logging, property rights, and climate change as it affects managed forests. In addition, Dr. Sohngen summarizes an original analysis of future timber supply potential using the Global Timber Model (Sohngen et al. 1999). His findings:

- Growth in LAC's wood products sector has exceeded the world's average since the 1960s, and the region now contributes 13 percent of the world's production. However, virtually all of this growth has been due to expansion in three countries, Brazil, Chile, and Uruguay, which have invested in fast-growing plantations.
- LAC plantations face competitive pressure because of declining world markets for paper products. It is therefore important for LAC to explore opportunities for new markets, new products, and enhanced productivity. Countries other than Brazil, Chile, and Uruguay, particularly those in Central America, have opportunities to expand timber production in both natural forests and plantations.
- LAC currently lags other regions in the area of forestland certified as sustainably managed by the Forest Stewardship Council and other organizations. Brazil and Guyana, however, have required reduced-impact logging and lower harvesting rates on their timber concessions, so elements of sustainable forest management are nonetheless being implemented in many LAC forests.
- Community forest management has promise for LAC. Although its effects on livelihoods is uncertain, evidence suggests it likely cuts deforestation in many locations and may provide opportunities to expand production of nontimber forest products.
- Illegal logging has slowed in recent years in many LAC countries. Efforts to regularize property rights via community forest management or timber concessions likely will help reduce illegal logging in the long run.
- Current estimates suggest that productivity gains in managed forests due to climate change may outweigh the losses due to dieback, leading to higher overall timber output. However, these results do not hold for every location. The eastern Amazon forest, for instance, appears particularly vulnerable to drought and possibly more forest fires because of climate change.
- Global Timber Model projections suggest that LAC forest product output will increase from 2020 through 2040–2050. However, pulpwood output is sensitive to assumptions about future policies and market conditions. This sensitivity illustrates why it is important to evaluate investments in improving plantation productivity.

Finally, in Chapter 4, Simone Bauch presents an analysis of the IDBG's experience with forest projects over the past 13 years. Having reviewed IDBG documents on all 99 forest projects approved by the bank during this period and interviewed 23 current and former bank staff, Dr. Bauch presents a brief recent history of IDBG forest projects, an overview of the major determinants of project development, and an analysis of trends in forest projects, including their number, funding, objectives, themes, and locations. Her findings can be summarized as follows:

- Starting in the 1980s, IDBG forest projects were managed alongside rural development projects, often in order to compensate for potential environmental damage from dams, roads, and other infrastructure. Starting in the 1990s, however, forest projects focused increasingly on forest conservation, restoration, and disaster prevention.
- Since 2006, the IDBG has invested almost US $1.5 billion in LAC forest projects aimed at conserving, restoring, or sustainably managing natural forest resources, as well as promoting forest plantations and agroforestry.
- The primary determinant of the types of projects funded has been country priorities.
- Both the number of IDBG forest projects and their funding have increased significantly since 2006, mostly because of the increased availability of climate finance, which accounted for 14 percent of all forest funding approved by the IDBG in the study period.
- The focus of the investments in forests has not changed significantly over time, with sustainable forest management, governance, and conservation being the lead project objectives.
- Carbon, biodiversity, and livelihoods have been the most common topics or themes used to justify forest projects.

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2025 NCF-Envirothon Alberta

Current Issue Part A Study Resources

Key Topic #6: The Boreal Forest

26. Describe an ecozone or ecological land classification, and identify how different types are anticipated to shift based on climate change projections.
27. Identify ecosystem services provided by boreal forest ecosystems, including environmental, economic, social, and cultural values.
28. Differentiate the types of wetlands found in the boreal forest, explain their importance, and describe the anticipated effects from a changing climate on these ecosystems.
29. Identify boreal forest-dependent species, and explain how climate change may threaten their populations.
30. Analyze the wildfire regime in the boreal forest and describe how it is changing in response to climatic shifts.

Study Resources

Resource Title	Source	Located on
Alberta's Natural Subregions Under a Changing Climate: Past, Present and Future, excepts	*Richard Schneider - Alberta Biodiversity Monitoring Institute, 2013*	Pages 165-174
Canada's Boreal Forest	*Natural Resources Canada, 2006*	Pages 175-180
Boreal Forests and Climate Change - From Impacts to Adaptation	*United Nations Economic Commission for Europe, 2023*	Pages 181-185
Boreal Ecosystem Services	*Ducks Unlimited Canada, 2024*	Page 186
Wetland Wonders	*Boreal Songbird Initiative, 2017*	Pages 187-192
Impact of climate change on wetland ecosystems	*Salimi, Almuktar, and Scholz – Journal of Environmental Management, 2021*	Pages 192-195
Canada's boreal wetlands are key to fighting climate change: report	*Alexandra Pope – Canadian Geographic, 2017*	Pages 196-198

<u>Study Resources begin on the next page!</u> ➡

Alberta's Natural Subregions Under a Changing Climate: Past, Present and Future

Executive Summary

The Natural Regions and Subregions classification represents the state-of-the-art in ecological land classification in Alberta. This classification provides a valuable baseline for resource management and conservation planning in the province. It is becoming increasingly apparent, however, that current landscape patterns are destined to change in coming decades as a consequence of global warming. In this report I place the Natural Regions and Subregions into a dynamic framework, describing how they have responded to climate change in the past and how they are expected to change over the next hundred years. Understanding how Natural Regions and Subregions will change over time will improve conservation planning and facilitate adaptation efforts.

The Past

Temperatures in Alberta have been both far colder and far hotter than those we currently experience. The warm climate of the Hypsithermal period (4,000-8,000 years ago) is of particular interest because the ecological patterns of that time can be reconstructed using sediments from lakes and ponds across the province. Most studies suggest that Hypsithermal summer temperatures in Alberta were 1.5-3 °C warmer than at present, which is on the low end of what is expected later this century as a result of global warming. Conditions were also substantially drier at that time, reflecting the combined impact of increased evapotranspiration from higher temperatures and reduced precipitation. Winter temperatures during the Hypsithermal were colder than what is expected for the future, so the Hypsithermal should not be considered a perfect analog for the future climate. Nevertheless, it is the climate during the summer growing season that is most important ecologically.

Reconstructions of Hypsithermal vegetation suggest that Natural Subregions generally shifted one Subregion northward relative to their present distribution. In the Boreal, there is clear evidence of a conversion of Dry Mixedwood to Central Parkland. There is also evidence of a transition of Central Mixedwood to Dry Mixedwood, at lower elevations. Higher elevation sites in the Boreal remained stable during the Hypsithermal.

Pollen records from the Grassland and Parkland are very limited, so it is not known how species composition changed in these Regions during the Hypsithermal. We do know that most lakes were dry, even in the Parkland, which suggests that little more than a dry grassland could have been supported. Evidence of increased aeolian activity implies that active sand dunes were present, and vegetation may have been sparse in some areas.

Compared to the Boreal and Grasslands, the Foothills and Rocky Mountain Regions were relatively stable during the Hypsithermal. There is evidence of upslope movement of tree species, and in some areas there was an increase in the proportion of pine, together with an increase in the rate of fire. The water table decreased, but lakes did not become saline or dry out.

The Present

Mean annual temperature (MAT) is inversely related to latitude and elevation. The spatial

pattern is fairly simple, with the mountains and Boreal hill system providing the only significant variations in an otherwise uniform north-south gradient.

Precipitation is highest in the mountains and foothills, where it increases fairly uniformly with elevation. In the rest of province, the highest rates of precipitation are found at mid latitudes and decline as one moves north or south. The northern boundary of Wood Buffalo National Park receives about the same amount of precipitation as Medicine Hat.

The amount of moisture that is available to plants is a function of both temperature and precipitation. Increased temperature causes an increase in the rate of evapotranspiration, which dries out the soil. The Climate Moisture Index (CMI) provides an index of the amount of available moisture on an annual basis. In the southern half of the province CMI increases rapidly with latitude. In the north, CMI is relatively uniform across very large areas, with the notable exception of the hill system. The hills are both cooler and wetter than the surrounding lands and have significantly higher CMI values.

These broad climatic patterns are responsible for most of Alberta's ecological diversity when viewed at the regional scale. Factors other than climate, such as soil type, topography, and disturbance history, become increasingly influential in determining ecosystem type as one moves from the regional scale to the local scale. Subregions represent an intermediate scale — climate is generally the dominant factor in determining Subregion type, but not in all cases.

Bioclimatic envelope models statistically define the unique climate space, or "envelope", of individual ecosystems, based on current eco-climatic associations. Once developed, these models can be used to predict ecosystem type given the future climate as an input. This is the most commonly used approach for predicting changes in the distribution of ecosystems resulting from global warming.

I constructed a suite of bioclimatic envelope models to define the climate space of Alberta`s Subregions, using the mean climate from1961-1990 as the baseline. I limited the development of these models to Subregions for which evidence exists of a strong causal relationship between climate and ecosystem type. These Subregions fall into two main groups: Subregions that are primarily influenced by moisture limitation and Subregions that are primarily influenced by the climatic changes associated with rising elevation. In both groups the Subregions represent points along an ecocline.

The Northern Mixedwood Subregion is another climate-associated ecosystem, but it does not belong to either of the previous two ecoclines. The climate envelope in this case was based on a proxy for the presence of permafrost, the defining feature of this Subregion.

Three Subregions in northeast Alberta — the Kazan Upland, Athabasca Plain, and Peace-Athabasca Delta — experience a boreal climate but are vegetatively quite distinct from the adjacent Central Mixedwood. Unique parent materials are primarily responsible for the distinct vegetation patterns in the Kazan Upland and Athabasca Plain (Precambrian granite and sandstone, respectively). In the case of the Peace-Athabasca Delta it is the extensive delta that is responsible for the unique vegetation patterns. The overriding influence of non-climatic factors on vegetation patterns in these three Subregions means that bioclimatic envelope modeling could not be used for these areas.

Future Climatic Patterns

The climate data for this study were obtained from the ClimateWNA model, which provides downscaled climate data from 24 General Circulation Models (GCMs) used in the Intergovernmental Panel on Climate Change Fourth Assessment. Projections are provided for three 30-year time periods: 2011–40, 2041–70, and 2071–2100 (hereinafter referred to as 2020s, 2050s, and 2080s). Various greenhouse gas emission scenarios are available for each model, and for this study I focused on the high emission A2 scenario and the low emission B1 scenario.

Averaging across all models, the MAT for Alberta is projected to rise by 4.2 °C by the end of the century under the high-emission A2 scenario, and 2.8 °C under the more restrained B1 scenario. None of the models projects an increase of less than 2.0 °C. Accompanying this increase in temperature is an associated 33-56% increase in growing degree-days, which comes largely as a result of an earlier onset of spring.

The average increase in mean annual precipitation (MAP) across all models is 9.4% for the A2 scenario and 7.2% for the B1 scenario. None of the models predicts a decline in MAP. Although overall annual precipitation is projected to increase, most models predict a decline during the summer months. The average decline is 2.4% in July and 6.5% in August for the A2 models and 0.2% in July and 2.3% in August for the B1 models.

Although overall precipitation is projected to increase, most climate models predict that Alberta will become substantially drier in the coming decades. Averaging across all models, CMI decreases from a historical norm of 5.9 cm to -5.1 cm under the A2 scenario and to -0.6 cm under the B1 scenario. The main reason for this decline is that warmer temperatures increase the rate of evapotranspiration from soils and vegetation. In addition, the duration of winter snow cover will be shortened, leading to earlier ground warming and a longer period of evaporative moisture loss. Finally, although total precipitation is projected to increase, precipitation during midsummer, when moisture stress is greatest, is expected to decline.

Future Ecological Patterns

For the detailed analysis of ecological patterns I focused on five GCM-scenario combinations, selected to represent the full range of potential climate outcomes. For readability I labelled these five models on the basis of the defining feature of each: Cool, Median, Hot, Dry, and Wet.

The modeling results suggest that there are two main climate trajectories that need to be considered: dry and wet. The dry trajectory, which is most likely, involves GCMs in which the effects of increased temperature predominate. Increased evapotranspiration from higher temperatures overwhelms any increases in precipitation that may occur, leading to progressive drying of the landscape relative to historic conditions. The Cool and Hot models are representative of minimum and maximum amount of change expected on this trajectory and the Median model represents an intermediate case.

Under the wet climate trajectory, represented by the Wet model, the effects of increased precipitation predominate. Only three GCMs support this outcome, suggesting that it is not likely. Succession under a climate that is both hotter and wetter is difficult to predict because it implies a transition to a climate space that does not currently exist in Alberta. Species from warmer climes would eventually arrive, but major shifts in ecological composition are not likely before the end of the century. This trajectory is not considered in any detail in this report.

The following sections summarize the climatic and successional changes expected in Alberta's major ecosystems under the dry trajectory, which is most likely. Though the rate of change varies among the models, a comparison of the spatial patterns over time indicates that they share a common trajectory. That is, there is a consistent order to the sequence of changes in both the raw climate parameters and the associated climate envelopes. This means that we are not faced with choosing among dozens of potential climatic outcomes arising from different model and scenario combinations. Rather, there is a common pathway of change and the main uncertainty lies in how fast and how far the Subregions will progress along that path.

Most of the information on successional changes is derived from the empirical literature and from information gathered at two expert workshops. The focus is on describing the basic trajectory of ecological change that is expected for each Subregion. Successional pathways are emphasized over specific endpoints because there are too many uncertainties about the timing of changes. An attempt is made to bound the minimum and maximum amount of change expected by the end of the century, using the Cool and Hot models as examples.

Grassland and Parkland

Under the Cool model, representing the least amount of predicted climate change, the Subregion climate envelopes in the Grassland and Parkland shift roughly one Subregion northward by the 2050s. It is reasonable to expect that climatic changes of this extent could be accommodated by changes in the proportions of existing plant communities within each Subregion. That is, communities representing the warm and dry end of the environmental spectrum within a given Subregion will increase, at the expense of communities on the cool and wet end of the spectrum. The mechanism underlying these changes is mainly competition.

Under the Hot model, climatic changes are more extreme than under the Cool model, particular after mid-century. The Parkland will experience the climate of the Dry Mixedgrass by the 2080s. The Dry Mixedgrass in turn will become similar to the driest parts of Wyoming and southern Idaho, where the vegetation is dominated by sagebrush species that are adapted to extreme aridity. This suggests that immigration of species exotic to Alberta will become an important factor under the Hot model. What is unclear is whether the rate of species migration will be able to keep up with the rate of climate change.

Under a warmer climate prairie wetlands will experience reduced runoff and groundwater flows because of regional drying due to increased evapotranspiration. They will also experience increased losses to evaporation, caused by earlier spring melt and higher summer temperatures. As a result, it is expected that the average water level of wetlands will decline and the amount of time that seasonal wetlands are dry will increase. The amount of change will be directly proportional to the amount of warming. It is worth noting that most Grassland and Parkland lakes were dry during the Hypsithermal.

Dry Mixedwood

Under the Cool model the Dry Mixedwood will experience a Parkland climate by mid-century. This will cause an expansion of the small grasslands that already exist along the Peace River lowlands, as well as the appearance of scattered grassy openings elsewhere in the aspen forest.

Under the Hot model, the climate envelope progresses to that of the Dry Mixedgrass in the latter half of the century. Under these conditions aspen would have limited capacity for regeneration. Therefore, widespread transitions to grass are possible after mid-century, at a rate largely determined by the rate of disturbance. Drought, insects, and possibly fire, will be the leading agents of disturbance, opening and expanding gaps in the aspen forest.

Central Mixedwood

Rather than a simple shift northward, as described for the Grassland, the pattern of change in the Central Mixedwood will be strongly influenced by elevation. Lower elevation areas are warmer and will become moisture limited first, beginning with the lowlands along the Peace and Athabasca Rivers. Higher elevation areas will follow. The change from moisture surplus to moisture deficit will affect very large areas once the tipping point is reached because CMI values are relatively uniform across the Boreal.

Under the Cool model, the Dry Mixedwood climate envelope appears in low elevation regions along the Peace and Athabasca Rivers by the 2020s and extends across most of the Subregion by the 2050s. The Parkland climate envelope appears after 2050 in low elevation regions. The loss of most of the white spruce on mesic sites in lower elevation areas seems likely by the end of the century given current rates of fire. At higher elevations the permanent loss of white spruce from mesic sites would be minimal prior to 2050. The timing and distribution of white spruce transitions thereafter would largely depend on the pattern of future fires. It also seems reasonable to expect some expansion of the grasslands that exist along the course of the Peace River.

Under the Hot model, almost the entire Central Mixedwood experiences a Grassland climate envelope by the 2050s. This will preclude white spruce regeneration. However, mature white spruce can withstand dry conditions, as evidenced by hand-planted shelterbelts around farmyards throughout the prairies. Therefore, successional transitions will mainly manifest after the mature trees have been killed by fire or other disturbance. This means that at least half of the original Central Mixedwood forest should still be intact by the end of the century, even if the current rate of fire doubles because of global warming. Additional mortality could occur from severe and prolonged drought if that becomes a significant feature of the climate.

In stands that have been killed by fire the successional patterns are expected to be complex. There is likely to be some influx of pioneer species and those adapted to dry conditions, but also some regeneration back to spruce and aspen. It should be noted that forest losses will continue after 2100 if greenhouse gas emissions are not controlled, leading to the eventual transition of the entire Boreal to grassland.

Peatlands occupy 45% of the Central Mixedwood but only 15% of the Dry Mixedwood. Therefore, a transition to the warmer and drier climate of the Dry Mixedwood, as expected under the Cool model, implies that approximately two-thirds of the peatlands in the Central Mixedwood will dry out and undergo succession to a wooded ecosystem. Given the large extent of the Central Mixedwood (~25% of Alberta), this translates into more than 50,000 km^2 of new terrestrial habitat. It is unclear how quickly the drying will occur — a time lag can be expected because of the ability of peat to absorb and store water during wet periods. As the drying progresses, succession to shrubs and then black spruce forest will follow rapidly. Subsequent transition to a white spruce and aspen mixedwood will occur at a slower pace. Similar transitions can be expected under the Hot model, though succession to forest may become progressively limited once the Subregion is subject to a Grassland climate in the latter half of the century.

Northern Mixedwood and Boreal Subarctic

Successional trajectories in the Northern Mixedwood and Boreal Subarctic will largely be dictated by the dynamics and ecological consequences of permafrost degradation. Permafrost thawing is already underway, but complete melting will take time. Melting is likely to be complete by the end of the century under the Hot model, but some permafrost may remain under the Cool model. The first stage of successional change in areas where melting has occurred will be a transition from open black spruce forest (on frozen ground) to bogs and fens. A gradual drying of the Subregions can be expected as temperatures rise, but this is unlikely to be significant by the end of the century.

Boreal Highlands

Under the Cool model, the Upper and Lower Boreal Highlands both transition to the climate envelope of the Central Mixedwood by the 2020s. This should provide sufficient time for aspen to replace most of the pine at higher elevations by the end of the century, and for the overall character of the Boreal Highlands to become comparable to that of the Central Mixedwood.

Under the Hot model the climate becomes similar to that of the current Dry Mixedwood after 2050 and some of the lower hills eventually experience a Parkland or even Grassland climate. Under this scenario, the Boreal Highlands could transition directly to aspen forest by the end of the century, without white spruce ever becoming prominent. The rate of successional change will be limited by the rate of fire and the rate of aspen dispersal.

Foothills

The Lower Foothills present a challenge because a suitable analog for the predicted hot and wet future climate does not exist in Alberta. Under the Cool model the MAT of the Foothills rises by 2.5 °C by the 2080s. A regional moisture deficit resulting from increased evapotranspiration is unlikely because of the high precipitation inputs. Therefore, the Foothills should remain forested. The main change that can be expected by the 2080s is a general increase in ecological diversity, as species from the Central Mixedwood, Montane, and the Foothills Fescue (to a limited degree) increase in abundance while a legacy of existing Foothills species (especially lodgepole pine) remains intact in favourable sites and in areas that have escaped disturbance. Fire and mountain pine beetle are both important agents of change.

Under the Hot model, the southern part of the Lower Foothills becomes moisture limited as a result of increased evapotranspiration by the 2050s and the entire Subregion is moisture limited by the 2080s. Because successional transitions are limited by the rate of disturbance, it is unlikely that there will be sufficient time for the widespread loss of forest to occur by the end of the century. However, the northward expansion of grasslands from the Foothills Parkland and Foothills Fescue into the southern part of the Foothills is likely under this model.

Rocky Mountains

Vegetative communities in the Rocky Mountains will generally just shift to higher elevations as the climate warms. However, species do not all move at the same rate, and local site conditions, snow pack, and disturbance history can affect pattern of advance, both at treeline and at lower elevations. Therefore, the Alpine, Subalpine, and Upper Foothills will not move upslope as intact units. Instead, the vegetative patterns of the Subregions will blend as the climate warms, increasing ecological diversity (though not permanently).

Other Subregions

The Montane lies at the interface between the prairies and mountains, and is characterized by complex climatic and ecological patterns. With climate warming, the grasslands found at lower elevations and dry sites within the Montane will expand into higher elevations. Under the Cool model at least some parts of the Subregion should remain forested by the 2080s. But under the Hot model it is likely that most of the Subregion will transition to grassland.

In the Peace-Athabasca Delta, climate warming is expected to have two main effects: 1) midwinter thaws in the collecting basins for the Peace and Athabasca Rivers will reduce the volume of peak flows in the spring, and 2) ice will form later and be thinner, lowering the probability of ice jams. These factors are likely to be exacerbated by increasing human withdrawals from the rivers, especially for oil sands extraction. The expected ecological response is a reduction in the extent of wetlands and a progressive conversion of the sedge meadows to shrublands, and eventually to forest.

In the Athabasca Plain, insight into the potential response to climate warming can be gained from the vegetation gradients within the Subregion. The driest sites are open sand, or sand stabilized with grasses. On the windward side of dunes, open jack pine-lichen woodlands develop, with discontinuous lichen mats and widely scattered pine of short stature. On better sites the jack pine stands become continuous and there is more of an understory. As temperatures warm and evapotranspiration increases, a shift to the warm and dry end of this ecological gradient can be expected. This transition could be gradual, but severe and prolonged drought might hasten the process, should it occur.

Successional changes in the Shield as a result of warming will be limited, mainly because the majority of the Region is comprised of bedrock outcroppings that are unvegetated. The pine forests on the coarse sandy soils between the outcroppings will follow the same successional patterns as described for the Athabasca Plain. The overall effect will be the gradual expansion of the unvegetated bedrock outcroppings.

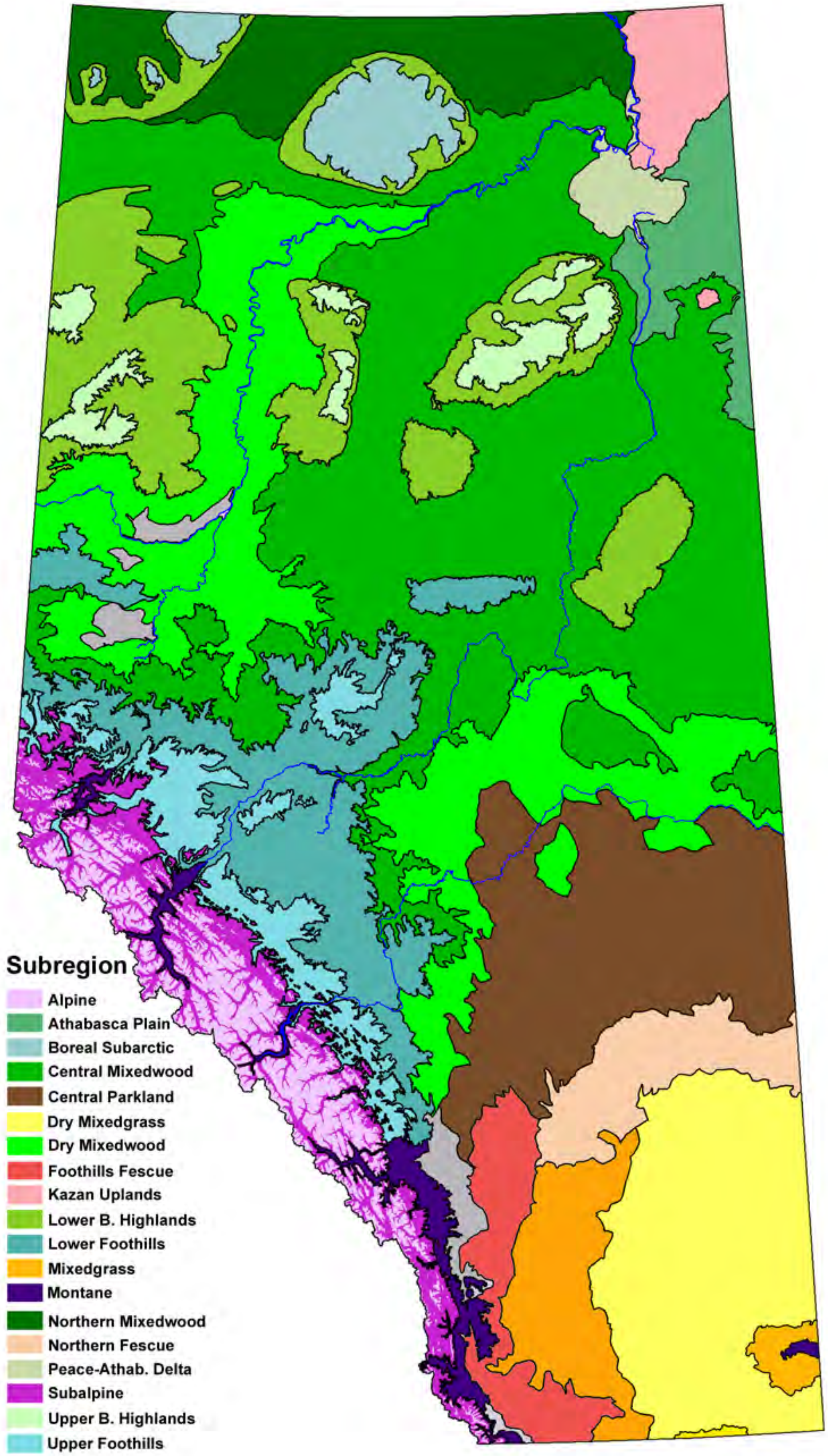


Fig. 1.1. The Natural Subregions of Alberta.

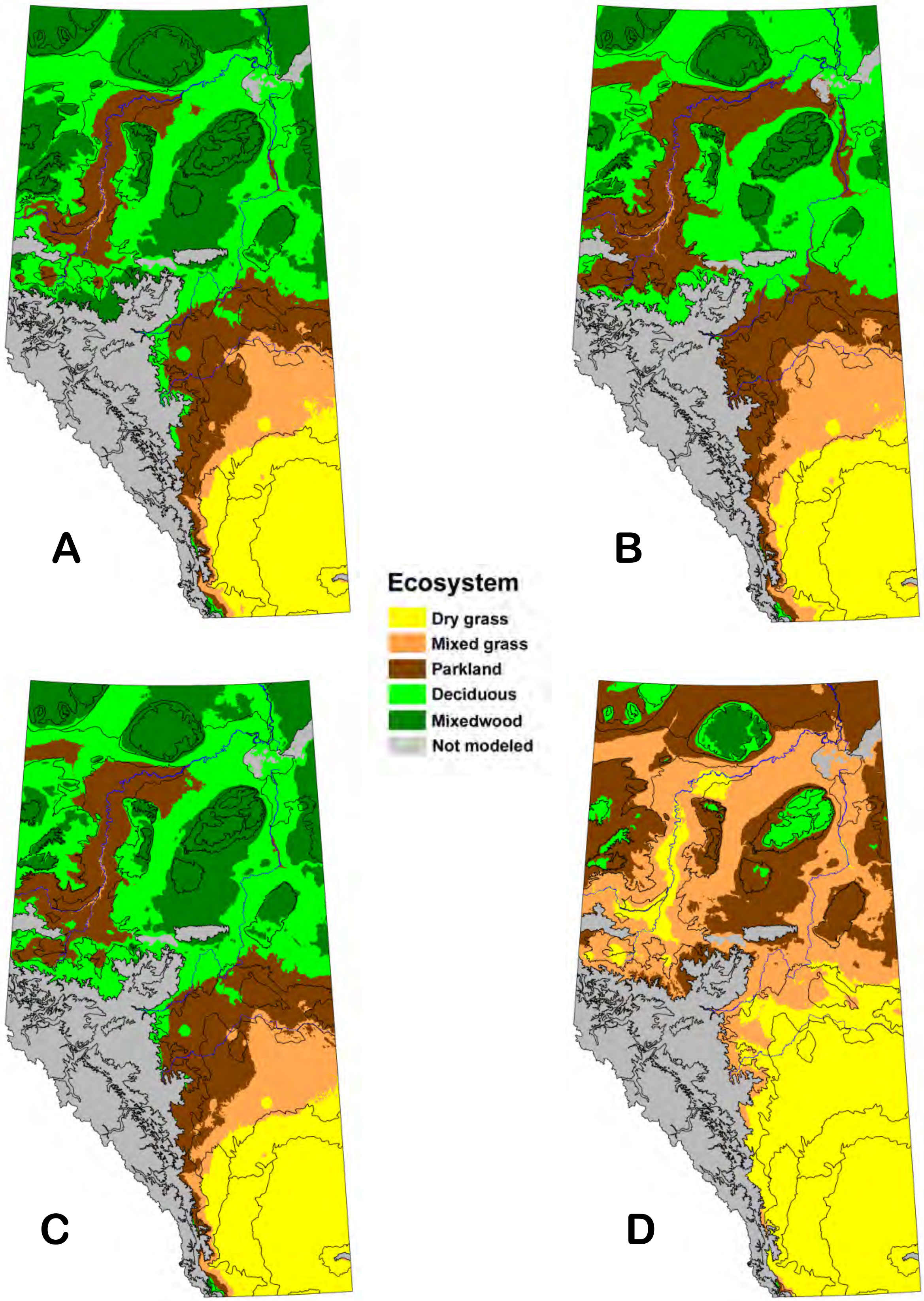


Fig. 4.14. Grassland to Boreal Bioclimatic Envelope Model for the **2050s**: Panel A= Cool model; Panel B = Median model; Panel C = Dry model; Panel D = Hot model. See Fig. 3.7 for historical reference.

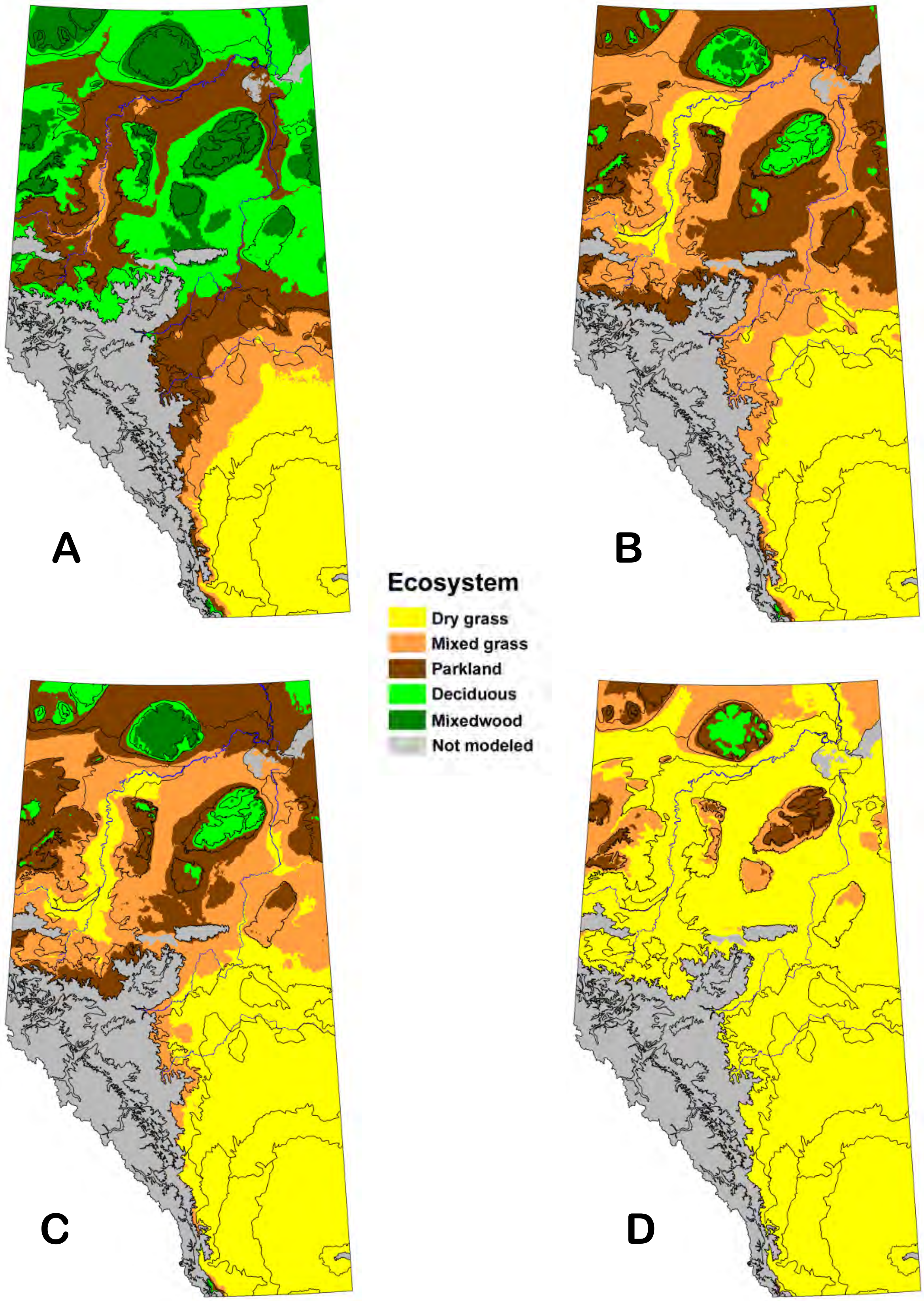


Fig. 4.15. Grassland to Boreal Bioclimatic Envelope Model for the **2080s**: Panel A= Cool model; Panel B = Median model; Panel C = Dry model; Panel D = Hot model. See Fig. 3.7 for historical reference.

HINTERLAND WHO'S WHO

CANADA'S BOREAL FOREST

Description

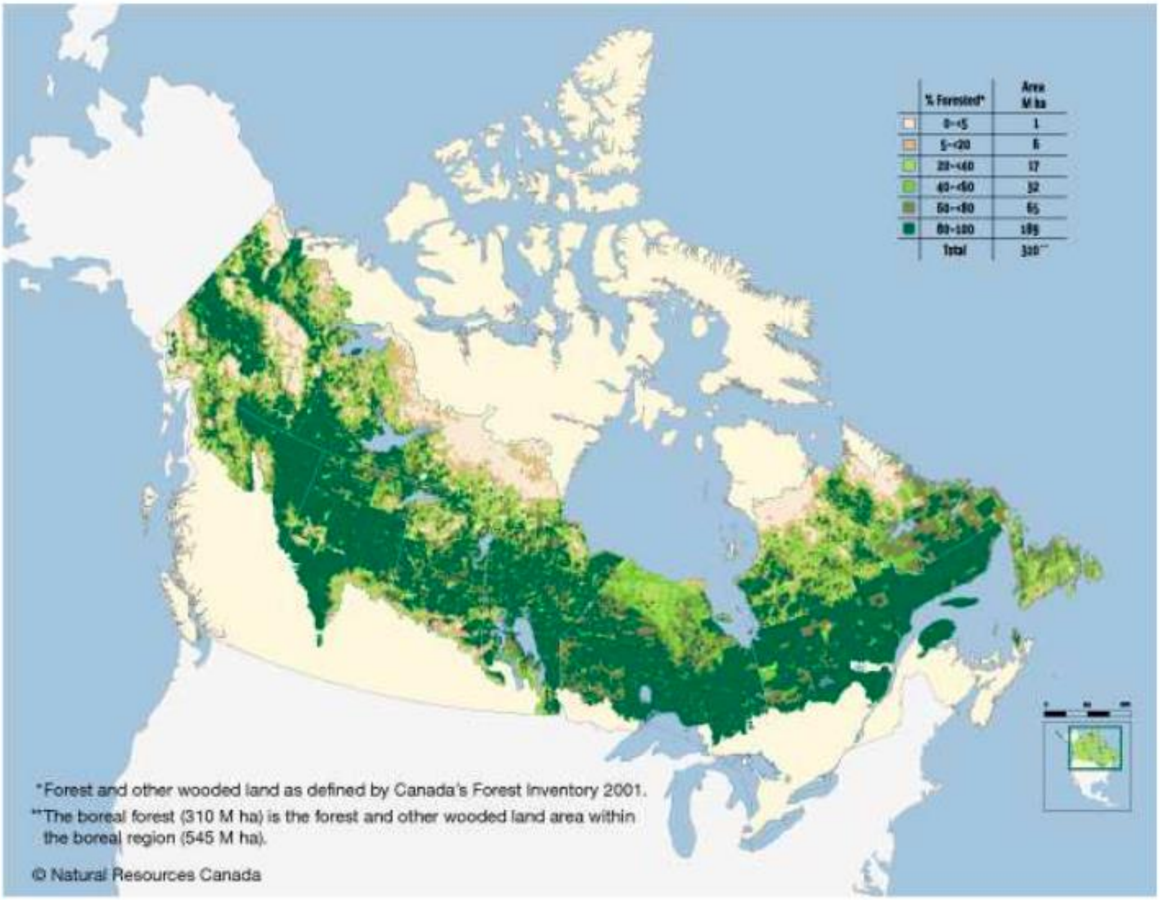
1 Black spruce peatland

If you had a clear view of Earth from space, you might wonder at the green band encircling the northern reaches of the globe. You would probably guess that it was an enormous expanse of woodland. What you might not know is that it is called the "boreal forest" and that it makes up almost one third of the world's forests, stretching as it does round the northern parts of North America and Eurasia.

You might also be surprised to learn that it is one of the largest forest ecosystems on the planet, and it shelters thousands of wildlife species.

Canada contains about a third of this northern forest, named after Boreas, the Greek god of the North Wind. Stretching more than 5 000 km from Newfoundland and Labrador in the east to Yukon in the west, and extending south 1 000 km from the edge of the arctic tundra, the boreal region occupies more than half of Canada's land area. Many of the species that we think of as being particularly Canadian—black spruce, jack pine, moose, caribou, gray jays, loons, wood frogs, and lake trout—are part of the boreal ecosystem. The boreal region also contains more than 1.5 million lakes and many of the main river systems in the country. It is home to more than four million people, including most of Canada's Aboriginal people. It is rich in natural resources too, with extensive mineral, oil, and gas deposits, as well as waterways for hydroelectric power. The climate in the boreal forest is characterized by long, very cold, dry winters and short, cool, moist summers.

2 The world's boreal forests



3 The boreal forest in Canada

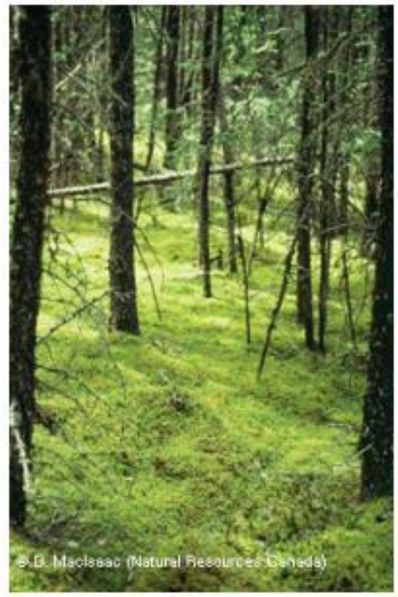
Boreal Species

Plants

The boreal forest is teeming with life. To describe it, let's begin with the trees that make up the forest canopy. There are about 20 species of them, and most are coniferous, which means that they produce their seeds in cones. Spruce, fir, pine, and tamarack are the main species found in the Canadian boreal forest. Except for tamarack, which drops its needles every fall, they remain green all year. Broad-leaf deciduous trees, such as trembling aspen, balsam poplar, and birch, are also widely distributed across the boreal forest.

Coniferous trees are particularly well suited to the harsh boreal climate. Their conical shapes reduce snow buildup on branches in winter, so that they do not break under the snow load. Their narrow needles have thick waxy coatings which protect the trees from drying winds. These needles have tiny pores which allow gases to move in and out of the trees: this is how they “breathe.” These pores are sunken into the waxy layer, to help reduce water loss.

In order to grow, plants need to photosynthesize—a process that converts energy in sunlight into food for the plant. To thrive in the short boreal summers, conifers have adaptations to help maximize photosynthesis. For example, because their foliage remains green year-round, conifer trees can photosynthesize in the spring without having to grow leaves first. In fact, they can even photosynthesize on warmer days in the winter.



4 Black spruce and feathermoss

The deciduous trees, such as aspen, are also adapted to the boreal conditions. They grow leaves to photosynthesize in the summer, and then shed them before it gets cold in winter. In this way, the trees are less damaged by heavy snowfalls. Before the leaves fall, the trees take back some of the nutrients from the leaves, to use in the next year's growth. Aspens also have chlorophyll (green cells that are needed for photosynthesis) in their bark, so that they can make some food in winter on warmer days.

All of these tree species support a range of birds, mammals, and other wildlife. They also store large amounts of carbon and produce a great deal of oxygen, so much that in the spring and summer in the northern hemisphere, when the boreal trees are growing most vigorously, worldwide levels of carbon dioxide fall and global levels of oxygen rise.

While trees are the dominant plant species, many other plants thrive in the boreal forest, including shrubs, mosses, and lichens. Some shrubs, such as willow, alder, blueberry, red-osier dogwood, and honeysuckle, produce bright-coloured or conspicuous berries that attract fruit-eating birds and provide food for mammals from small rodents to bears.

5 Aspen

Under coniferous trees, mosses grow so thickly that they form a complete carpet on the soil's surface, keeping the soil moist and cool and preventing many other types of plants from growing. Open areas are carpeted with yellow, green, and light grey lichens. Some lichens grow on wood too. Lichens are combinations of fungi and algae that benefit each other: the underlying fungus provides structural support for the lichen, while the algal layer on top has chlorophyll which provides food for the lichen through photosynthesis. Lichens remain intact all year long, and are an important food source in winter for species such as caribou.

Wetlands—bogs, fens, and marshes—occupy 30 percent of Canada's boreal forest. Boreal wetlands are often referred to as muskegs or peatlands. These peatlands are usually on poorly drained, flat terrain. Plant material decomposes slowly in the cool, wet soil conditions, forming a blanket of material that is often several metres thick. Sphagnum and other mosses, sedges, and low shrubs make up the peatland vegetation. Treed peatlands, composed mostly of tamarack and black spruce, are also widespread. Some mosses, such as sphagnum, are especially important in peatlands where they can create acidic environments.

These wetlands are invaluable: they filter millions of litres of water every day, and they provide breeding, moulting, and staging (resting and feeding) habitat for more than 13 million ducks—about 40 percent of the North American duck population.

Birds

Nearly half of the birds in North America rely on the boreal forest at some time during the year. It is estimated that at least 3 billion landbirds, water birds, and shorebirds breed in the boreal forest each year, representing more than 300 species. Another 300 million birds, including several species of shorebirds, swans, and geese, breed farther north and travel through the boreal forest during migration.

6 Cape May Warbler

Many of the birds that we see in our communities have bred in the boreal forest or passed through it travelling north or south, and many of these are the singers of the forests—small birds such as warblers, vireos, thrushes, kinglets, grosbeaks, sparrows, and flycatchers—which are hard to see but wonderful to hear. Ducks, loons, grebes, rails, gulls, kingfishers, and cranes depend on Canada's boreal waters for nesting and for food.

Other bird species, such as woodpeckers, finches, nuthatches, chickadees, owls, grouse, and ravens, can live in the boreal forest year-round, having adapted to the climate. Black-capped chickadees, for example, have black and white feather patterns that are designed to absorb heat and provide the best insulation when they are sleeping. They can also sleep in holes in the snow which act like tiny igloos to keep them warm. In winter, Great Gray Owls use their extremely sensitive ears and silent flight to locate and capture small mammals under the snow, and Ruffed Grouse grow scales on the sides of their toes that turn their feet into snowshoes.

Mammals

The boreal forest shelters more than 85 species of mammals, including some of the largest and most majestic—wood bison, elk, moose, woodland caribou, grizzly and black bears, and wolves—and smaller species, such as beavers, snowshoe hares, Canada lynx, red squirrels, lemmings, and voles.

7 Beaver dams

Of these, the snowshoe hare is the most ecologically important. It is a food source for many of the boreal forest's predators (both mammals and birds) and feeds on the forest's various plants and shrubs, linking all of these species in a tight food web.

Like other species, many mammal species have adapted to conditions in their boreal home. For example, the snowshoe hare turns from brown-grey in the summer to white in the winter, so that it always blends with its surroundings. Moose, wood bison, and other large mammals have a low surface area-to-volume ratio, which minimizes the amount of body heat they lose in winter.

The beaver is one of the most important animals in the boreal forest. Using its ever-growing front teeth, it fells trees and eats the leaves, twigs, and bark, using the wood to build dams and lodges. Beaver dams flood parts of the forest, creating ponds and wetlands that are used by fish, waterfowl, and amphibians.

Reptiles and amphibians

The boreal forest is a challenging home for reptiles and amphibians, which depend on environmental conditions to regulate their body temperatures. Spring and summer temperatures likely limit how far north many species are found, since temperatures must be high enough for eggs to hatch and young to grow. In summer, reptiles and amphibians choose appropriate habitat and bask in the sun to reach body temperatures that allow them to hunt effectively and digest prey. In winter, most amphibians and reptiles that hibernate on land seek out sites underground where temperatures consistently remain above freezing, although wood frogs and chorus frogs simply burrow in the leaf litter and depend on chemicals to make them freeze-tolerant; during hibernation, more than 40 percent of their body fluids can consist of ice. Other frogs and turtles hibernate at the bottom of ponds and lakes.

Insects

Insects are critical components of boreal food webs and play important ecological roles as pollinators and decomposers, yet as a group, they are among the most poorly understood organisms in the boreal region. Except for relatively few species, mainly those considered "pests" because of the economic losses they cause by damaging or killing trees, or highly conspicuous groups such as butterflies, little more than the names and general habitat preferences is known.

It is estimated that 32 000 insect species inhabit Canada's boreal forest, although about one third of these species have yet to be described. Among the known species, several are particularly well adapted to their habitat. For example, black fire beetles have infrared sensing organs on their bodies that allow them to track the heat of forest fires as they search for freshly burned trees on which to lay their eggs. Other species, like the white-spotted sawyer beetle, use their long antennae to sense chemicals in smoke and charcoal to achieve the same goal. Like many other insect species, in addition to starting the decomposition of fire-killed trees, these two beetle species are an important part of the diet of several bird species commonly found in burned forests.

Fish

Canada's boreal forest is home to about 130 species of fish. Most fish species in the boreal region are small, like minnows and stickleback. Larger species, including walleye, northern pike, lake trout, Arctic grayling, yellow perch, brook trout, whitefish, and burbot, are some of the most common game fish.

Fish living in the boreal forest are a hardy bunch, as they have to contend with long winter months and cold temperatures. Numerous fish species also migrate between different areas of rivers and lakes at different times of the year. For instance, many populations of bull trout live in different areas of the river during the winter, summer, and fall. Perhaps the largest migrations are completed by chum salmon and chinook salmon in the most northwestern portion of the boreal forest. These species are born in small streams, but migrate to the ocean, where they grow and mature, before migrating back into rivers to reproduce and die. The majority of them return to the same area where they were hatched, and migrations of several hundred kilometres are common.

Some fish, like northern pike and walleye, feed on other fish species; species such as lake trout, white sucker, lake sturgeon, and lake whitefish eat aquatic insects and other invertebrates; still others, such as yellow perch, cisco, and many minnow species, feed on tiny zooplankton in the water. In turn, fish are food for eagles, osprey, herons, loons, mergansers, bears, and otters.

Benefits

The boreal region not only supports the species that live within it; it also provides benefits that extend beyond its borders. The forest's extensive wetlands lessen the effects of floods and droughts by storing and moderating the flow of water between upland areas and lowland regions. Its wetlands also act as water filters by removing impurities from the water that flows through them.

The boreal forest's trees and other vegetation help to control erosion, improve the cycling of nutrients, and promote the formation of soil. Sometimes natural disturbances, such as forest fires, contribute to plant growth. Fires release nutrients that were tied up in leaves, logs, and needles on the forest floor, which can aid in the vigorous regeneration of vegetation following fire. The forest also helps to regulate the earth's climate by storing carbon in peat deposits, soils, lake sediments, and trees. This prevents atmospheric carbon from being released as carbon dioxide and methane, two gases linked to climate change.

As one of the few remaining relatively intact ecosystems on our planet, the boreal forest helps to preserve biodiversity, or the variety of life on Earth. Every living thing plays an essential role in maintaining a balance in Earth's natural processes. That's why biodiversity is so important. And that is why the boreal forest is important too. The Canadian boreal forest is home to about two thirds of Canada's 140 000 species of plants, animals, and micro-organisms.

Economic activity in the boreal forest sparks other benefits. It brings products to people around the world and supports the people who live and work in the boreal region. Much of the world's forestry, mining, oil and gas production, hydroelectric generation, tourism, and harvesting of natural products occur in the boreal forest. About 14 percent of Canadians living in hundreds of communities located in the boreal region rely on these industries. Others make their livings on land at the southern edge of the boreal forest that has been converted into farmland. The boreal forest is home for about 80 percent of Canada's Aboriginal peoples, whose rich heritage is strongly linked to the forest.

Distrubances and Threats

Unfortunately, there are negative aspects to development in the boreal forest. The main consequences are habitat loss and fragmentation. These occur when land is cleared for farmland or flooded to make reservoirs for hydroelectric generating stations or when seismic lines, pipeline rights-of-way, forestry roads, and mine sites are cut into the forest. These activities in some cases weaken its natural systems and disturb wildlife species that depend on large, intact areas or require a specific habitat to survive. These impacts or changes to

Boreal Forests and Climate Change

From Impacts to Adaptation

Policy Brief

To date, the largest recent-increases in temperature resulting from climate change have been recorded in the Arctic region, and as a result, boreal forests are one of the first places where the complex effects of climate change can be observed. These effects, and the dynamic response of boreal forests to them, will have important implications for the world as a whole in terms of atmospheric carbon and a host of other values and outputs associated with this major biome.

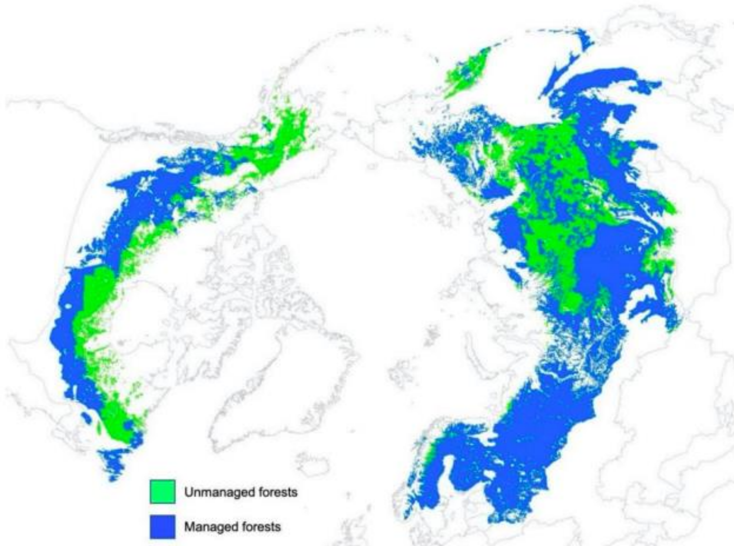
The circumboreal zone has already been observed to be warming more than the world average.[d] This trend is likely to continue, [e] even if current targets for global emissions and climate warming are met. Published evidence so far suggests that fundamental long-term changes in some ecosystems are likely to be long-lasting. Boreal forests are one such ecosystem where climate-related biophysiological changes have already been observed.

1. Introduction

Boreal forests (also referred to as "taiga") grow in the Northern Hemisphere, between latitudes of 50- and 70-degrees north (see Figure 1), where temperatures are generally very low, and precipitation falls primarily in the form of snow. Boreal forests consist mostly of cold-tolerant evergreen conifers with needle-like leaves, such as pine, fir and spruce. The boundaries of the boreal forest belt are usually marked by the July isotherms: the northern border is the 13° Centigrade July isotherm; the southern border is the 18° Centigrade July isotherm.[a]

As part of one of the world's largest terrestrial carbon sinks[b] and covering about 27 per cent of the global forest area,[c] boreal forests have an essential role to play in addressing climate change. With globally increasing concentrations of atmospheric greenhouse gas (GHG) and longer growing seasons due to climate warming, circumpolar boreal forests may experience increased growth rates and thus increasing carbon sequestration. However, these forests are also subject to a substantial risk of decreased productivity and tree cover loss due to drought, wildfires, windstorms, diseases and insect outbreaks, which could result in large releases of carbon into the atmosphere.

Figure 1 **Boreal forest extent (managed forests (in blue) and unmanaged forests (in green))**



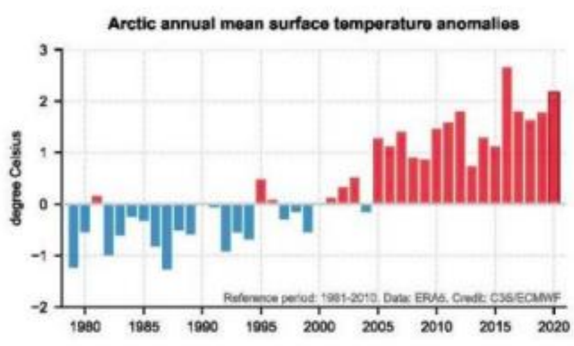
Source : The International Boreal Forest Research Association (IBFRA). Map © www.ibfra.org.

A. The Arctic is warming

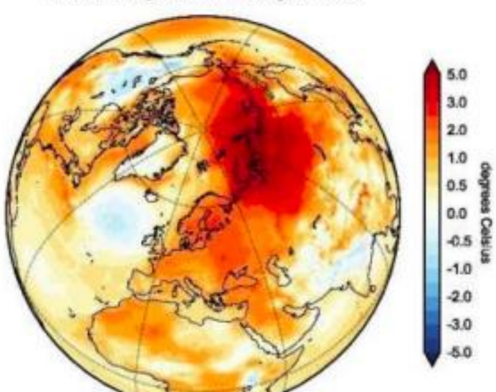
In recent decades, the average temperature in the Arctic has increased two times faster than that for the rest of the planet. Different regions where boreal forests and Arctic ecosystems interact show past average annual temperature increases from 0.4 to 2 degrees C, as can be seen in Figure 2.

Figure 2

a. Left: **Time series of annual mean surface temperature anomalies from 1979 to 2020 averaged over the Arctic region (66.6°N–90°N).**
b. Right: **Map of the annual mean surface temperature anomaly in 2020. All anomalies are calculated relative to the 1981–2010 mean.**



Source: ERA5.©C3S/ECMWF.[1]



According to the latest draft report of the Intergovernmental Panel on Climate Change (IPCC), "it is virtually certain that the Arctic will continue to warm more than global surface temperature, with high confidence above two times the rate of global warming". [g] This has significant implications for the boreal region, where these high rates of warming will influence forested systems.

B. Impacts of warmer temperatures on boreal forests

The sensitivity of boreal forests to warming has significant implications for the climate system due to the effects on the exchange rates of water, carbon and energy between the biosphere and the atmosphere.

The immediate and most obvious response of boreal forests to global warming is drier conditions. This leads to physiological stress in trees resulting in an increase in the outbreak of pest insects and diseases, and an increase in the areas burned by wildfires. Each of these disturbances is interconnected: stressed trees, for example, are more susceptible to pests, and accumulated dead trees lead to more frequent and severe wildfires. According to the FAO Forest Resources Assessment (FRA), insects, diseases and severe weather events damaged about 40 million hectares of forests in 2015, mainly in temperate and boreal forests.[h]

Ecologically, the displacement of plant habitats and, ultimately, bioclimatic zones towards the north, is expected to have significant effects on the species composition of boreal forest ecosystems. Over the past few decades, boreal forests and plants have continuously shifted north. This has been accompanied by earlier blooming and leafing of plants, and poleward shifts in tree-feeding insects. According to modelling of different climate scenarios,[i] the impact of climate change on hardwood forests would be less significant than on conifers; at the same time, the recession of conifers would free up space for their replacement with small-leaved species.[1]

Many of the observed and expected effects of climate change on boreal forests are interrelated and synergistic. Some of them include:

- Changes in biological diversity;
- Change of hydrological regime and deterioration of moisture availability in the south of the boreal biome;
- Change in growth of growing stock;
- Changes in accessibility and quality of wood;
- Changes in the range and migration of certain animals;
- Change to animal habitats.

An increase in the length of the growing season or the growing degree-days[2] may have a positive effect on the annual average tree growth.[j] However, this positive effect on boreal forests could be offset by negative effects due to the specificity of climate change (e.g. warming and drought in summer with increased rainfall in winter), increased variability and extremes of weather conditions, and an increase in the area and intensity of natural disturbances.

Role of boreal forests in climate change mitigation

Boreal forests provide critical services locally, regionally and globally. Indigenous peoples and other communities depend on ecosystem services provided by boreal forests for fishing, hunting, gathering, recreation, spiritual activities, medicines and economic opportunities. Boreal Forests also host many species of flora and fauna, and unique wildlife. Globally, boreal forests help regulate the climate through the exchange of energy and water.[t]

Boreal forests also constitute a large reservoir of biogenic carbon on a level comparable to, if not greater than, that of tropical forests. According to various estimates, carbon reserves in the terrestrial biomass of boreal forests amount to 40.7,[u] 53.9,[v] or 57[w] billion tons of carbon. In addition, estimates suggest that the total carbon reserve in the circumboreal zone (including vegetation, soil and peatlands) ranges from 272[x] to 1715[y] billion tons. A review study[z] showed that mid-point estimates of total circumboreal carbon stores, including peatlands, are 1095 billion tons of carbon, which is larger than any previous mean estimates.

Temperature increases will likely have an impact on the carbon storage capacities of the circumboreal zone: as more permafrost areas thaw and more areas of boreal forests burn, large amounts of GHGs are likely to be released. The carbon storage potential of boreal forests continues to be a topic of debate, with ongoing research looking into the impacts of forest management on the carbon balance of boreal forests (see Box 2). Some scientists argue for instance that boreal forested peatlands may have been overlooked as unproductive ecosystems, due to their semi-open structure and low stem density. As a result, the carbon sequestration potential of forested peatlands is inaccurately evaluated and peatlands' role in climate mitigation therefore underestimated.

Carbon sequestration rates of boreal forests are also likely to be significantly influenced by a warming climate, although the net positive or negative effects are highly uncertain. As previously described, higher temperatures and atmospheric CO^2 concentrations combined with longer growing seasons are likely to promote higher growth and thereby sequestration rates. In turn, more severe fire seasons may offset those positive gains, but create younger forests across the boreal region, forests which tend to have higher sequestration rates than older forests. Combined with sustainable forestry activities and their potential to create areas of higher sequestration rates and lower fire risk, the overall sequestration picture for the boreal ecosystem is uncertain.

Wildfires

Boreal forests are adapted to burning. Less frequent fires help create habitat mosaics of various ages and stages of regeneration. With the increasing occurrence of wildfires in the circumboreal zone, forests are losing their resilience to recover from large fire events. Improving forest fire awareness and resilience can include limiting the occurrence and spread of forest fires to prevent possible carbon emissions, loss of forest biomass and negative impacts to boreal forest ecosystem services.

In some instances, however, fire suppression and the planting of non-native tree species in open habitats can lead to larger and hotter fires due to the risk of fuel accumulation. Solutions can include restoring natural fire regimes by integrating information on climate impacts in fire management responses[ee] and removing non-native species[ff] to decrease the vulnerability of people and ecosystems to the exacerbated fire risk that results from climatic changes (including temperature increases and changing rainfall patterns). Restoring peatlands and wetlands through strategic re-wetting, selective spruce tree removal and replanting with fire-resistant mosses have proven to mitigate carbon losses from wildfires in Canada.[gg]

In addition, it is often those communities that are directly impacted by wildfires that lack financial means to put in place preventative measures. Financial and technical support to, for example, thin forests surrounding settlements, encourage the construction of fire-proof homes and develop evacuation plans could enable such communities to become more fire resilient. Sustainable forest management in these communities can result in improved fire management, as well as fire resilience and awareness activities.

Boreal Ecosystem Services

The boreal forest and its wetlands provide many benefits.
These ecosystem services include:

- Producing food, freshwater and wood and peat resources for fuel
- Regulating climate, water quality and quantity to reduce the economic consequences of floods and droughts
- Providing cultural value for Indigenous and non-Indigenous communities through educational, recreational and spiritual opportunities
- Supporting wetland ecosystems through soil and nutrient cycling, creating a broad range of habitats for species, plants and animals.

Many conservationists believe these services have intrinsic value that are worth protecting. Economists and ecologists have demonstrated that these services also have economic value. Their calculations include market value, such as hydro-electricity, timber and oil and gas. They include non-market value, such as carbon sequestration, water regulation and pest control.

The Canadian Boreal Initiative estimates $50.9 billion* of market value services are extracted from the boreal forest annually. The non-market value is an estimated $703 billion, nearly 14 times greater. Carbon storage by forests and wetlands has the highest value of all ecosystem services at $582 billion, followed by flood control and water filtering by peatlands at $77 billion and other wetlands at $33.7 billion. DUC researchers are developing methods to apply the value of ecosystem services in conservation, policy and land use planning. (*2002 value)

Wetland Wonders

From Climate Change to Caribou and Common Loons, Canada’s Boreal Wetlands Offer Surprising Solutions

Canada’s Boreal Forest is home to 25 percent of the world’s wetlands. These vibrant reserves of clean water and biodiversity provide rich habitat for wildlife and store enormous amounts of carbon.

Conserving wetlands solves several problems at once.

Now is the time to act. Around the globe, species are going extinct 1,000 times faster than the historic rate while the hazards of climate change increase rapidly each year. Canada is striving to meet several international targets aimed at confronting climate change and preserving biodiversity. Wetlands can help meet those goals.

Not only do Canadian wetlands hold some of the largest natural banks of carbon on Earth, they purify water by filtering out contaminants and can dramatically reduce the extent of droughts and floods when left unaltered. They also act as critical hotspots for biodiversity and are essential in the life cycles of a vast proportion of Canada’s plants and wildlife. Protecting a wetland ecosystem achieves many benefits through just a single act of conservation.

And no country has a greater opportunity to conserve wetlands on a large scale than Canada.

Canada’s Boreal Forest contains the largest concentration of wetlands on Earth. Extending 1.19 million square kilometres, these wetlands represent an area larger than the province of Ontario. This preponderance is a large part of why the Boreal has been dubbed the ‘Forest of Blue’.

Peatlands, a type of wetland formed out of layers of vegetation that never fully decay, are widespread throughout the Boreal. These regions are immensely rich in stored carbon; Canada’s boreal peatlands alone hold a minimum of 147 billion tonnes of carbon, an amount equivalent to 736 years’ worth of Canada’s industrial greenhouse gas emissions. The Hudson and James Bay Lowlands is considered by many researchers to be one of the largest intact, carbon-rich peatlands in the world. Keeping these carbon-absorbing regions intact and free of development is no less critical than reducing emissions from industry, transportation, or from other sources.

When it comes to conserving wetlands, Canada has some impressive initiatives underway. For example, Ontario and Quebec have both pledged to protect at least 50% of their wetland-rich northern boreal regions, consistent with the visionary Canadian Boreal Forest Conservation Framework that has been advocated for by 1,500 scientists worldwide.

Increasingly, Indigenous communities and governments across Canada are taking the lead on protecting the Boreal Forest and its vast wetland networks. They are also leveraging a variety of tools and channels to achieve such protections. Among the most notable is the development of formal land-use plans that proactively conserve areas of cultural and ecological importance, some of which have already protected millions of hectares of habitat. Indigenous Guardians, who serve as stewards on the land, help Indigenous communities conserve and manage the land based on traditional knowledge, cultural values, and Western science. Canada can do its part to curb climate change and habitat loss by strengthening efforts to protect its giant share of wetland treasures.

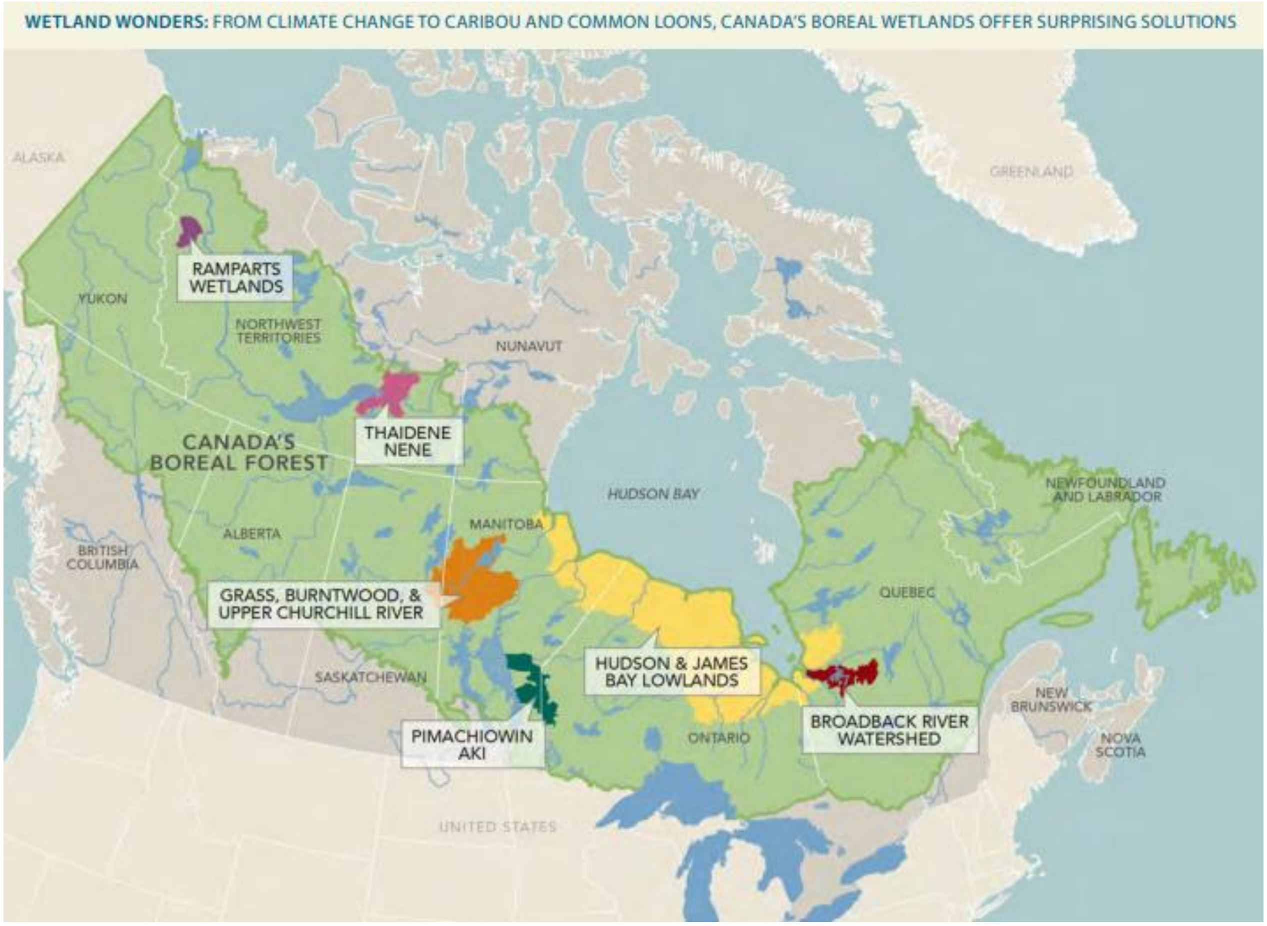


Figure1. Boreal Wetlands of Conservation Focus

RAMPARTS RIVER AND WETLANDS

Better known as Ts'ude niline Tu'eyeta to the Dene and Métis peoples of the Sahtu Region, Ramparts River and Wetlands is internationally acclaimed for its high volume of carbon-dense wetlands and its importance for migratory bird populations.

Enormous concentrations of waterfowl converge upon this intricate mosaic of tree stands interspersed with open wetlands each spring and early summer. Overall, it is one of the top three most populated areas within the broader Mackenzie River Valley in terms of waterfowl. This including large populations of Surf and White-winged Scoters as well as both Greater and Lesser Scaup, the latter being species of conservation concern given their long-term population declines. Several species are particularly dependent on the region: at least one percent of the entire Canadian population of Scaup, Scoters, and Pacific Loons breed in just this area alone, which qualifies it as a Key Habitat Site.

In terms of caribou, the region is unique in the sense that it supports both mountain and boreal populations of woodland caribou, the former being a species of Special Concern and the latter listed as Threatened under the Canadian Species at Risk Act (SARA). Additional species of Special Concern that rely heavily on the region include Peregrine Falcon, wolverine (western population), and grizzly bear (northwestern population), demonstrating the region's important value in retaining healthy populations of a number of Canada's species facing population declines.

Beaver, one of the North's best-known icons, flourish in its deep networks of wetlands as well. As many as 58 to 86 active beaver dams per 100 square kilometres were found in one surveyed region.

Ramparts River and Wetlands (under its traditional name Ts'ude niline Tu'eyeta) was identified as a candidate protected area under the Northwest Territories' previous conservation planning strategy. However, it still only retains interim protection status and will need permanent designation to ensure the region remains ecologically intact for generations to come.

THAIDENE NENE

Water is the dominant theme throughout much of Thaidene Nene. Wrapping around the East Arm of Great Slave Lake—the world's 9th largest lake—Thaidene Nene extends far to the northeast and encircles a vast region speckled with wetlands and small and medium lakes.

If conserved, it would be one of the only protected areas in Canada that contain portions on both sides of the tree line, where northern trees and greenery of the Boreal Forest slowly fade into vast expanses of vibrant yellow and red Arctic tundra. The variability of this area provides a critical buffer for northern plants and animals struggling to cope with climate change, acting as a transitional bridge for species in pursuit of better habitat should their current habitat become unsuitable.

Thaidene Nene is at the heart of barren ground caribou country, a rare example of a planning region providing not one but three distinct major herds with significant habitat: the Bathurst, Beverly, and Ahiak herds. Not to be confused with their boreal woodland counterparts further south, barren ground caribou have become of great conservation concern due to enormous population declines among numerous herds across Canada's North.

From a bird perspective, it is a crucial nesting region for several raptor species and a home to countless numbers of songbirds. The shores and cliffs overlooking the East Arm of Great Slave Lake hold the nests of Ospreys, Bald Eagles and Peregrine Falcons, the latter being a species of Special Concern under the Canadian Species at Risk Act. Thousands of ducks, geese, and swans flock here each spring, summer, and fall, making it an important region for waterfowl as well.

The Lutsel K'e Dene First Nation has been working with both the Government of the Northwest Territories and the federal government to enshrine Thaidene Nene as an interconnected protected area consisting of a national park reserve, a territorial park, and potentially a specially managed caribou zone. Indigenous people with Section 35 rights will be respected and northerners will continue to enjoy the East Arm like they always have. The Lutsel K'e Dene First Nation will be managing Thaidene Nene in equal partnership with both crown governments.

GRASS, BURNTWOOD, AND UPPER CHURCHILL RIVER WATERSHEDS

While this mosaic of dense forest interspersed with open and mixed wetlands lacks the formal name and official boundaries of other conservation planning regions, it is right up there with some of Canada's most famous parks and refuges when it comes to preserving biodiversity.

Black spruce-dominated peatlands and expansive fens featuring sedge and alder are intricately woven into this northern landscape. The region's many islands that are surrounded by small lakes and open wetlands provide ideal calving grounds for boreal woodland caribou, a species of great conservation concern across Canada.

Despite accounting for only a small proportion of the species' overall range geographically, the region is home to one of the densest clusters of caribou populations in Canada. No less than 7 of the 51 population units (14%) delineated under the federal recovery strategy reside there: the Boreal Shield population in Saskatchewan and the Kississing, Naosap, Reed, Wabowden, Wapisu, and Manitoba North populations in Manitoba. This high concentration of distinct herds in a limited area means that returns on investment from a conservation perspective are enormous, especially given three of the populations are among only 14 in all of Canada deemed to be self-sustaining if habitat is left untouched.

Strong fish populations support significant populations of colonial nesting waterbirds such as Common Tern, Herring Gull, and Double-crested Cormorant. Bald Eagles and Common Loons also feast on the abundance of aquatic organisms present. It also provides important breeding habitat for a number of waterfowl, including Bufflehead, Common Goldeneye, Ring-necked Duck, and Green-winged Teal.

The provincial government has committed itself to funding First Nations in Manitoba that want to develop community-based land use plans, which identify areas of cultural and ecological importance for protection while allowing for sustainable development where appropriate. These plans have the potential to protect large portions of the province's boreal region, including parts of these adjacent watersheds.

PIMACHIOWIN AKI

Nestled in the heart of the Boreal Forest and spanning the ManitobaOntario border east of Lake Winnipeg, Pimachiowin Aki lives up to its Anishinaabe name that translates to “the land that gives life.”

It offers a perfect embodiment of what much of the Boreal Shield— one of the Boreal’s seven major ecozone types—resembled before the expansion of European influence. Pimachiowin Aki is one of the only large expanses of Boreal Shield remaining in Canada that has yet to be impacted by fragmentation associated with industrial development, agriculture, settlements, or roads.

This is reflected in the wildlife that can be found throughout Pimachiowin Aki, especially woodland caribou. The region accounts for a large proportion of the habitat used by the Atikaki-Berens herd—Manitoba’s largest at 300-500 individuals—and more importantly is one of the herds that have been deemed as self-sustaining if its habitat is left undisturbed (only 28% of caribou planning regions earned similar designation in the most recent federal recovery strategy).

Birds also relish this vast expanse of unspoiled wilderness. More than 200 species commonly rely on the region for habitat, including at least eight Species at Risk that are faring poorly in more developed parts of the Boreal (Piping Plover, Short-eared Owl, Common Nighthawk, Whip-poor-will, Olive-sided Flycatcher, Barn Swallow, Canada Warbler, and Rusty Blackbird). Many birds that breed further north converge in the region during fall migration, acting as a migratory ‘funnel’ for birds before they continue down through the Mississippi Flyway.

It is also home to a higher concentration of wetlands than is typically found elsewhere in the Boreal Shield. The more than six million cubic metres of pristine freshwater that flow through the region’s wetlands annually and its four major rivers that flow into Lake Winnipeg help ameliorate the lake’s ailing condition—which stems largely from agricultural runoff to the south and west—from worsening.

The First Nations of Pimachiowin Aki have, over the last decade, developed and implemented land management plans that have conserved vast areas and are now leading an effort, in partnership with the governments of Manitoba and Ontario, to establish Pimachiowin Aki as a UNESCO World Heritage Site.

HUDSON AND JAMES BAY LOWLANDS

If the Boreal Forest is the global ‘king’ of carbon, the Hudson and James Bay Lowlands would be the crown jewel. Wetlands dominate this open, expansive region in a way that is rarely found anywhere on Earth. It forms the third largest wetland region globally and contains the single largest carbon-rich peatland system on Earth. Peatlands are particularly rich in carbon, meaning the Hudson and James Bay Lowlands are potentially the most carbon-dense terrestrial ecoregion on Earth. This 373,000-km^2 expanse of mostly pristine wetlands and rivers is also mostly intact.

Its vast area provides habitat for perhaps the world’s highest abundance of the peat-loving Palm Warbler and very likely a high proportion of the global population of the mysterious Yellow Rail—a small, chicken-like marsh bird that is rarely seen and little studied. The marine shores of the region are among the world’s most important migratory feeding concentrations for shorebirds and waterfowl.

In fact, the region as a whole likely hosts a large proportion of the global populations of many shorebird and waterfowl species during migration. Unusually high counts of species like Red Knot, Hudsonian Godwit, Ruddy Turnstone, Black Scoter, and Lesser Snow Goose indicate incredibly high use of these shoreline habitats. These lowlands are also unique as the host of the southernmost population of polar bears in the world—the only known population that regularly dens in burrows in earth rather than snow and ice. Both migratory tundra caribou and woodland caribou occur within the Hudson and James Bay Lowlands. Estuaries along the coast are also vital habitat for beluga whales, walrus, ringed seals, and bearded seals.

Land-use planning is underway in many Indigenous communities in Ontario, Quebec, and Manitoba. The provincial governments of Ontario and Quebec are committed to protecting at least 50% of the northern portions of both provinces while the Manitoba government has pledged to provide financial support for First Nations to carry out land-use planning. Currently, vast proportions of the area are unprotected and are currently open to mineral exploration and staking without the benefit of regional land planning for development and associated infrastructure.

BROADBACK RIVER WATERSHED

The easiest way to see the special nature of Quebec's Broadback River Watershed would be to fly over the region immediately south of it. Clearcuts and roads dominate the landscape leading up to the fertile watershed, which straddles the northern limit of where forestry is allowed.

The Broadback River glides west through the region, descending through a series of dramatic waterfalls before reaching Lake Evans. One of the remaining undammed rivers in the region, it continues to the James Bay coastline, flowing through a large concentration of carbon-rich wetlands, including much muskeg.

The region is in many ways at the frontline of the effort to save boreal woodland caribou given its location and their sensitivity to human-related habitat disturbances. Two of the three populations identified by the Cree in the James Bay region, both of which face population declines, depend heavily on the watershed. Moose, another staple for many residents of the region, have more recently become a concern as well.

Several of Canada's most threatened songbirds return to the watershed for summer breeding habitat each year, including Canada Warbler, Evening Grosbeak, and Rusty Blackbird. The area also supports large populations of waterfowl, such as Common Goldeneye and the increasingly threatened American Black Duck.

The region's waterways and wetlands support species seldom found elsewhere, such as the Quebec emerald—a dragonfly only found in Quebec and parts of the Maritimes. They also produce large populations of brook trout and trophy-size northern pike.

Several Nations within the Grand Council of the Crees have collaborated to create the Broadback Watershed Conservation Plan, which calls for an extensive network of protected areas and special management zones throughout the watershed. Recent progress has seen important cultural sites for the Cree First Nation of Nemaska as well as Lake Evans obtain protection. Other areas remain unprotected, however, including the last remaining tracts of intact forest within the traditional territories of the Cree First Nation of Waswanipi

Impact of climate change on wetland ecosystems: A critical review of experimental wetlands

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Abstract

Climate change is identified as a major threat to wetlands. Altered hydrology and rising temperature can change the biogeochemistry and function of a wetland to the degree that some important services might be turned into disservices. This means that they will, for example, no longer provide a water purification service and adversely they may start to decompose and release nutrients to the surface water. Moreover, a higher rate of decomposition than primary production (photosynthesis) may lead to a shift of their function from being a sink of carbon to a source. This review paper assesses the potential response of natural wetlands (peatlands) and constructed wetlands to climate change in terms of gas emission and nutrients release. In addition, the impact of key climatic factors such as temperature and water availability on wetlands has been reviewed. The authors identified the methodological gaps and weaknesses in the literature and then introduced a new framework for conducting a comprehensive mesocosm experiment to address the existing gaps in literature to support future climate change research on wetland ecosystems. In the future, higher temperatures resulting in drought might shift the role of both constructed wetland and peatland from a sink to a source of carbon. However, higher temperatures accompanied by more precipitation can promote photosynthesis to a degree that might exceed the respiration and maintain the carbon sink role of the wetland. There might be a critical water level at which the wetland can preserve most of its services. In order to find that level, a study of the key factors of climate change and their interactions using an appropriate experimental method is necessary. Some contradictory results of past experiments can be associated with different methodologies, designs, time periods, climates, and natural variability. Hence a long-term simulation of climate change for wetlands according to the proposed framework is recommended. This framework provides relatively more accurate and realistic simulations, valid comparative results, comprehensive understanding and supports coordination between researchers. This can help to find a sustainable management strategy for wetlands to be resilient to climate change.

1. Introduction

A wetland is an area with a water table, at, near or above the land surface either seasonally or permanently throughout the year. Wetlands exist globally in every country (except Antarctica) and also in all different types of climates. Depending on different definitions and estimates, they cover only about 5–8% of the world’s land surface, but comprise 20–30% of the world’s carbon pool (2500 Pg) (Mitsch et al., 2013). Compared to all terrestrial ecosystems, wetlands have the highest carbon density, which makes them play an important role in global biogeochemical and carbon cycles and climate change (Kayranli et al., 2010). Wetlands are ecosystems that are vital both for humankind and nature. They are commonly the most valuable ecosystems in a landscape providing many beneficial ecosystem services (Table 1). Among all wetland services, water purification, flood control and climate change mitigation are the most important services for the human communities (Mitsch and Gosselink, 2007; Scholz, 2015). Since the 1950s, global climate systems have shown an unprecedented change. The earth’s surface has experienced warmer climate for each of the past three decades successively. Between 1880 and 2012, the land and ocean surface temperatures have increased by approximately 0.85 ◦C (range between 0.65 and 1.06 ◦C) according to Pachauri et al. (2014). Wetlands play an important role in climate change, because of their capacity to modulate atmospheric concentrations of greenhouse gases such as methane, carbon dioxide and nitrous oxide, which are dominant greenhouse gases contributing to about 60%, 20% and 6% of the global warming potential, respectively (IPCC, 2007). There are many different factors (biotic and abiotic) that influence the function of wetlands. Climate change has been identified as a major threat to wetlands. It can influence a wetland ecosystem by increasing temperature and also by changing hydrological patterns, which in turn can alter the biogeochemistry of the ecosystem (Erwin, 2009; Stewart et al., 2013). Wetlands have been identified as one of the most productive ecosystem types; i.e. through photosynthesis, they can actively sequester and accumulate carbon as plant biomass or organic matter in soil. The waterlogged condition of wetlands causes inefficient decomposition that exceeds the rate of production. This anoxic state results in a vast amount of carbon accumulation in wetlands, which makes them a sink of carbon (Laiho, 2006). Since wetlands are often located in a transition zone between an aquatic and a terrestrial ecosystem, their hydrological fluctuation is inevitable. Although they have been known to be resilient to change in general, they may still be highly susceptible to hydrological changes, especially when this change is exacerbated by other sources of disturbance such as climate change, pollution, urbanization and changes in land use (IPCC, 2007). Climate change can affect wetlands by direct and indirect effects of rising temperature, changes in rainfall intensity and frequency, extreme climatic events such as drought, flooding and the frequency of storms. Altered hydrology and rising temperature can change the biogeochemistry and function of the wetland to the degree that some important services might be turned into disservices. This means that they will no longer provide a water purification service and adversely they may start to decompose and release nutrients to the surface water causing problems such as eutrophication, acidification and brownification in the water bodies (Roulet and Moore, 2006; Stets and Cotner, 2008; Corman et al., 2018). A higher rate of decomposition than production (photosynthesis) in a wetland as a result of climate change might result in a shift from a sink to a source of carbon; i.e., carbon dioxide and methane emissions to the atmosphere (Laiho, 2006; Flanagan and Syed, 2011). With warmer conditions, more nitrous oxide emissions from wetlands might happen due to higher microbial activity and higher nitrification and denitrification rate as well (Huang et al., 2013; de Klein and van der Werf, 2014). To analyse all of these changes in a wetland, a comprehensive monitoring system is needed to understand how the system responds to the stresses and how they can be adapted to future climate change. The study of climate change impact on a wetland environment is one of the most critical challenges scientists are facing. According to Stewart et al. (2013), the impact of climate change on a wetland system can be predicted by using various approaches such as modelling, field survey and experiments. A mesocosm experiment is an approach that can be used for climate change studies on ecosystems. This scale of experiment can provide a link between microcosm (which is smaller and of limited realism) and the natural system, which is of high complexity resulting in difficulties to identify processes and interactions. Moreover, mesocoms allow for experiments to be conducted with replication at costs considerably lower than field studies (Kangas and Adey, 1996). Mesocosm experiments under controlled conditions provide scientists with more reliable and consistent findings than field experiments. Isolating the impact of variables from other confounding variables (i.e. those that influence both the dependent variables and independent variables, causing spurious associations) is almost impossible in the field, while mescosm experiment often provide this possibility. Thus in field experiments, it is difficult to attribute an ecosystem response to a particular factor (Stewart et al., 2013). It is not clear how wetlands, as key contributors to global greenhouse gas budgets, will respond to climate change. There is uncertainty as to whether wetland functions are positive or negative to climate change. It is not also clear which climate factors are more important for changing the role of wetlands from sink to source in terms of greenhouse gases. Finding a sustainable management strategy that addresses the negative responses of wetlands to climate change is challenging. Understanding the response of wetlands to climate change requires primarily a perception of the complexity of wetlands and the interaction of parameters affecting this ecosystem. In order to develop a comprehensive understanding of the response of wetlands to climate change and also to identify effective management actions to enhance wetland resilience in the catchment landscape, an appropriate methodology needs to be identified. This methodology will help researchers to resolve controversial discussions and reduce uncertainties regarding the effect of climate change on wetlands and the management strategies.

6. Discussion, conclusions and key recommendations

6.1. Discussion and conclusions

With a warmer climate in the future, the upper part of the peatland would experience more water loss than the lower part. This former is more vulnerable to moisture as it is more exposed to oxygen, making it more susceptible to decomposition (Updegraff et al., 2001). The rate of heterotrophic respiration in the lower part of the peatland profile depends to some extent on how much oxygen can be diffused and oxidize the organic matter. The amount of oxygen diffusion in the peat profile mainly depends on the peat water content. However, the rate of the autotrophic respiration might be relatively independent of water content. The rate of carbon dioxide emission relies on how primary production and respiration competes in the future. Mitsch et al. (2008) claimed that in future the general positive role of wetlands in terms of carbon sequestration will be more pronounced compared to negative methane emission with climate change. However, climate change in the future might result in droughts that can increase the ecosystem respiration substantially and decrease primary production (Lafleur et al., 2009). Therefore, it will be difficult to predict the role of wetlands in climate change without the consideration of drought. S. Salimi et al. Journal of Environmental Management 286 (2021) 112160 11 Our critical review concludes that drought might decrease primary production of the system and elevates aerobic respiration. However, a wetter condition accompanied by a warmer climate might promote photosynthesis to a degree that might exceed the respiration and maintain the role of a peatland as a sink. In another review study, Bu et al. (2011) noted that climate warming would have negative effects on the role of peatlands as carbon sinks due to lower water availability and higher temperatures, which would increase the rate of peat decomposition more than net primary production. Moreover, they reported that climate change would be resulting in succession, shifting from Sphagnum to vascular plants, and this would lead to an increase in methane and carbon dixiode emission in the long-term. A higher production of methane is linked to a high water table and anaerobic conditions. Higher temperatures on the other hand might lower the production of methane through methane oxidation. Concurrently, higher microbial activity in the water and sediment due to higher temperatures can result in higher emissions of methane. A substantial decline in water level, which influences the deeper zone of the peatland, can significantly reduce methane emissions (Blodau et al., 2004). A higher production of methane is linked to a high water table and anaerobic conditions. Higher temperatures on the other hand might lower the production of methane through methane oxidation. Concurrently, higher microbial activity in the water and sediment due to higher temperatures can result in higher emissions of methane. A substantial decline in water level, which influences the deeper zone of the peatland, can significantly reduce methane emissions (Blodau et al., 2004). This literature review indicates that the response of methane to climate change may vary greatly from one type of wetland to another, and the combination of biotic and abiotic factors makes the peatland response to methane emissions rather unpredictable and complex (Updegraff et al., 2001). In line with our review, another critical literature review by Kayranli et al. (2010) shows that the role of many wetland plants and microorganisms in carbon turnover and methane emission is unclear and needs further study. They suggested that more process-level research is needed to predict methane emissions from wetlands. Moreover, they indicated that the differentiation between the production and consumption processes of methane is essential. The assessment of constructed wetlands showed that the potential contribution of free water surface constructed wetlands to global warming in the future is considered to be small as they have been linked to the lowest carbon dioxide and nitrous oxide emissions compared to other types of constructed wetlands. However, it has been shown that free water surface constructed wetlands can have a high methane emission compared to other types of constructed wetlands due to their predominant anoxic condition. Therefore, the rapid increase in the number of free water surface constructed wetlands should alarm stakeholders and designers to manage these systems properly. Mander et al. (2014b) proposed future studies focusing on hydrological regimes and the development of vegetation and microbial communities to improve the efficiency and management of constructed wetlands in the face of climate change. In addition, Kayranli et al. (2010) found in their literature review that constructed wetlands have a higher carbon sequestration capacity than natural wetlands. They did, however, state that if they were not properly designed and managed, they would function as sources of greenhouse gasses to the atmosphere. Contradictory results regarding the impact of water levels on methane emissions in constructed wetlands demand further studies. In addition, the impact of vegetation on constructed wetland gas emission has to be studied more as assessments have shown that they can both increase and decrease the carbon sink role of constructed wetlands (Maltais-Landry et al., 2009). It seems that the role of vegetation in constructed wetland gas emission is more important when the water level drops (Henneberg et al., 2016). Therefore, with a higher risk of drought in the future, it would be important to select more suitable plant species with an adequate density to tolerate water shortage and combat climate change through carbon sequestration. After reviewing 224 articles, Maucieri et al. (2017) found that the presence of vegetation increases constructed wetland greenhouse gas emissions relative to non-vegetated ones. However they assumed that vegetated constructed wetland could absorb atmospheric carbon by photosynthesis and act as a carbon dioxide sink and mitigate climate change, but they were uncertain about the impact of plant species on methane emissions. A comprehensive consideration of the most important wetland services, such as climate change mitigation and water purification, is essential to suggest sustainable and efficient management. However, conducting experiments to find such an approach will often be challenging, mainly because of financial and time constraints (Cools et al., 2013). One way to overcome this challenge is to use process-based models and/or machine learning techniques to analyse experimental data (Olden et al., 2008) (Fig. 2). If the numerous datasets generated in the experiment can be sufficiently representative of the pattern of change in the systems, then a sophisticated algorithm should be capable to recognize and predict the response of the system properly and save money, time and resources (Maleki et al., 2019). Machine learning approaches are flexible in capturing the complexity of the interactions and relationships between variables, making it an ideal approach for modelling a wetland ecosystem (Berry et al., 2003). In a literature review, Blodau et al. (2002) also suggested the development of models capable of capturing interaction dynamics and processes for predicting greenhouse gas emissions from wetland. However, the improvement of model parameterization is supported by the result of a robust and sophisticated experiment. Consistent with the suggested framework (see section 7), Bu et al. (2011) indicated that mesocosm experiments involving multiple factors and allowing environmental conditions is important for understanding of mechanistic relationship between variables in the wetland. Therefore, it can be concluded than conducting our suggested mesocosm experiment allows for the simulation of more realistic (based on RCP) and high-resolution (based on RCM) climate variables. Employment of an advanced simulator will simulate dynamics of climate change; i.e. the simulation of various climate variables as well as the cold season. This coordinated mesocosm experiment facilitates consistency and provides a more valid comparison between different mesocosm experiments. Any uncertainty about the impact of change in temperature and water level as well as their interactions might be resolved over time using the proposed framework. In addition, multi-variable monitoring provides a comprehensive insight into both positive and negative feedback from wetlands on climate change. This helps to find appropriate management actions that can be used by the environmental managers to maintain the wetland services and mitigate climate change. However, it is important to note the limitations of our proposed framework associated with the mesocosm experiment, as it is performed on a limited spatial and temporal scale. Simplification is unavoidable in most forms of mesocosm experiments. Therefore, they cannot represent all the complexities of natural ecosystems. Hence, researchers should use the results of mesocosm experiment cautiously for generalization purposes.

ENVIRONMENT

Canada's boreal wetlands are key to fighting climate change: report

A new report from the Boreal Songbird Initiative calls for enhanced protection of wetlands within Canada's boreal forest

FEB 02, 2017 436 WORDS 2 MINUTES

BY ALEXANDRA POPE

As one of the largest and last intact wildernesses on Earth, Canada's boreal forest provides crucial habitat for millions of species, supports a thriving resource industry and, according to a new report, contains what could be Canada's — and the world's — best asset in the fight against climate change: wetlands.

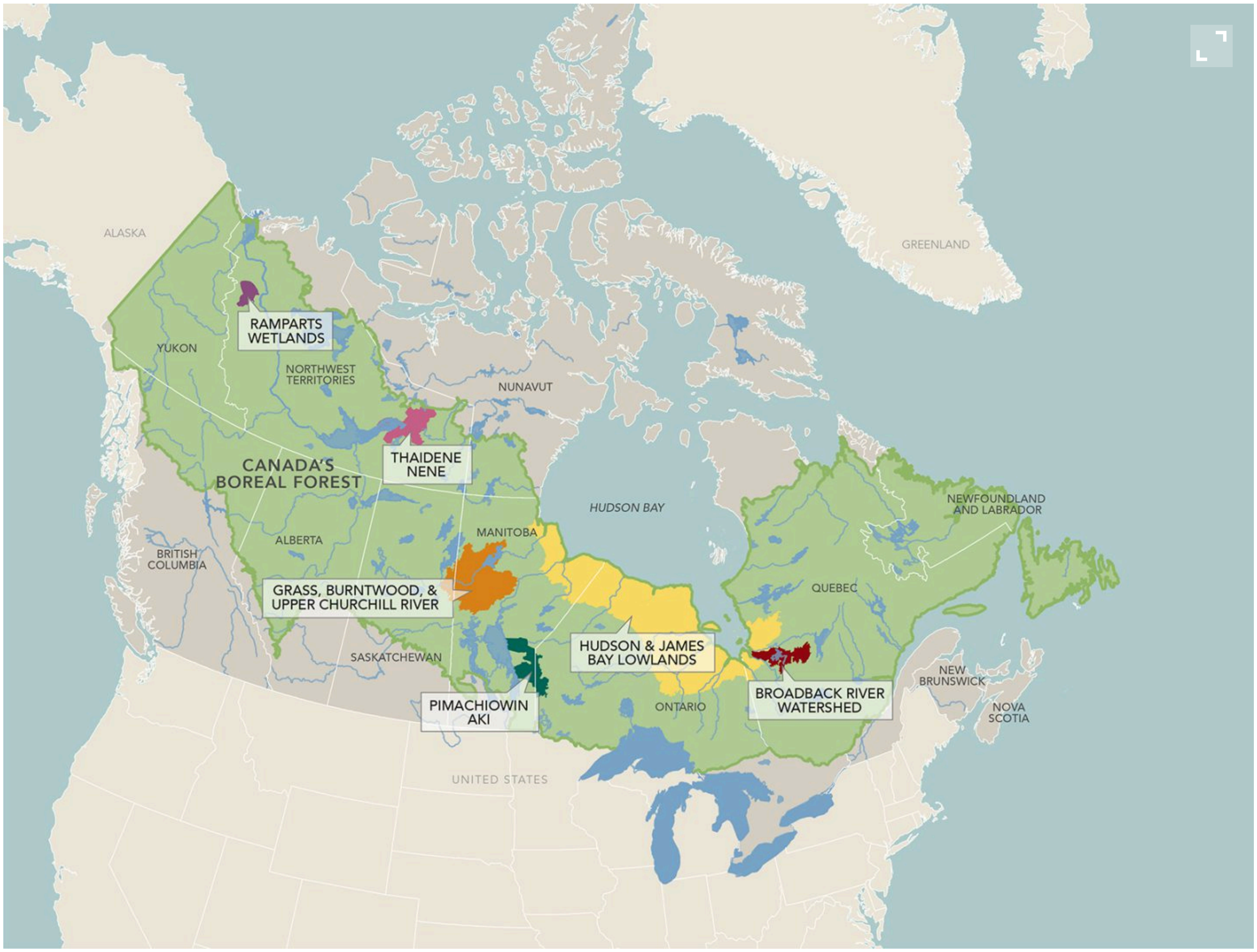
The report, released this week by the Boreal Songbird Initiative, highlights six distinct wetland areas within the boreal forest and calls on government and other groups with a stake in the forest to act now to protect them.

"Unlike most of the world, the [boreal] wetlands are still very intact and pristine," says Jeff Wells, science and policy director with the Boreal Songbird Initiative. "There's still the opportunity to get things right in terms of how they're taken care of into the future."

A quarter of the world's wetlands are found within Canada's boreal forest and cover a total area of 1.19 million square kilometres — larger than the province of Ontario. These wetlands help moderate river flows and cleanse polluted water, and support a complex web of species, from microscopic zooplankton to migratory seabirds to large mammals like moose and caribou. They also store massive amounts of carbon, particularly the boreal peatlands, a type of wetland formed by layers of undecayed vegetation. At minimum, the peatlands store 147 billion tonnes of carbon, equivalent to 736 years' worth of Canada's industrial greenhouse gas emissions, so it is in Canada's best interest to see those areas protected from development and fragmentation, the report notes.

Wells says he's encouraged by recent efforts, many of them led by indigenous peoples, to study the role of the boreal in carbon sequestration and protect large swaths of the boreal. First Nations in Ontario and Manitoba have been trying for years to get Pimachiowin Aki, a vast tract of forest straddling the border between the two provinces, declared a UNESCO World Heritage Site and are hopeful that this will be the year their plans come to fruition, while in the Northwest Territories, discussions are ongoing around the creation of a new national park reserve, Thaidene Nene.

"One of the things we're most hopeful about is that provincial and federal governments will show strong support for these indigenous efforts and give them what they need to carry out their plans and be the managers of those lands," Wells says.



A map highlighting important wetland areas within Canada's boreal forest. (Map courtesy Boreal Songbird Initiative)