1 Interaction between Climate Change and Greenhouse Gas Emissions from Managed Ecosystems in Canada

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CONTENTS

1.1 INTRODUCTION

The world's terrestrial ecosystems are being subjected to climate change on an unprecedented scale, in terms of both rate of change and magnitude. Understanding the ability of terrestrial ecosystems to adapt to change requires fundamental knowledge of the response functions. The changes under consideration in this book include not only the climatic change from increased concentration of greenhouse gases (GHGs) and consequent warming trends especially in the north, but also land use, land-use changes, and alterations in disturbance patterns, both natural and human induced. The interactive nature of climate change is complex and nonlinear because the variables of change are strongly interactive (Figure 1.1) and not independent. To remain viable, agricultural

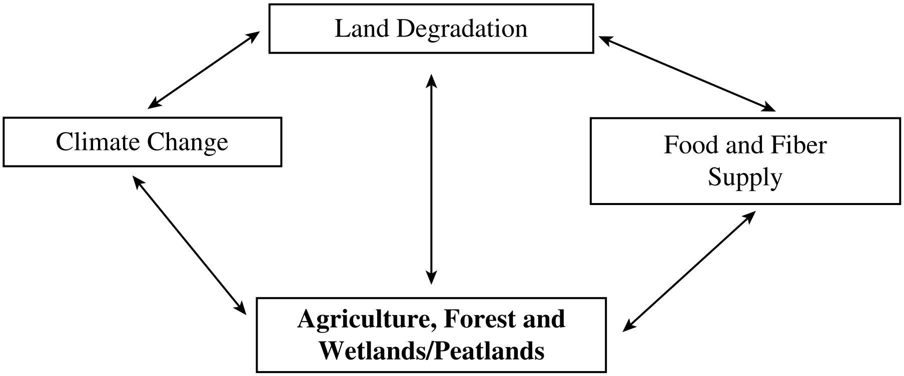

FIGURE 1.1 Linkage between various climate change issues and different ecosystems.

and forest production systems will need to change rapidly to meet the challenge of the inevitable changes in the mosaic of ecosystems across the landscape.

Agricultural ecosystems (including crop and animal production, pastures and rangelands), forest ecosystems, and wetlands (including peatlands) can be regarded as one dimension of the problem, and climate change as another. This book synthesizes our current understanding of the processes of climate change and its impacts on different managed ecosystems. From a human perspective the impacts of climate change lie in the interactions among these different ecosystems: vulnerability must be assessed in terms of the collective impact on these terrestrial ecosystems that supply essential goods and services to society. Humans depend on these ecosystems for food, fiber, and clean air and water, and the adverse impacts of climate change are likely to have far-reaching effects on human lives and livelihoods.

An important indicator of the human interaction with the global climate system is the human perturbations to global carbon cycle. Carbon is exchanged between terrestrial ecosystems and the atmosphere through photosynthesis, respiration, decomposition, and combustion. Terrestrial ecosystems have the capacity for either accelerating or slowing climate change depending on whether these systems act as a net source or a net sink of carbon. This source or sink status is, however, not a static characteristic of the ecosystem, but will change over time as a result of changes in the physical, chemical, and biological processes of these systems,[1] all of which are influenced by human activity. Data on global carbon stocks in major biomes are presented in Table 1.1. Response to climate change will alter these carbon stocks, changing the fluxes among terrestrial ecosystems and the atmosphere differently in different geographical regions. There is a strong need to quantify these fluxes both in relation to different management options and to different environmental pressures. The basic challenge is the detection of very small changes relative to the size of the pools. Thus, it is important to understand the dynamics of these different pools, and identify factors that make these pools either sinks or sources of GHGs.

TABLE 1.1
Global Carbon Stocks and Net Primary Productivity of the Major Terrestrial Biomes

Biome	Area (109 ha)[18]	Carbon Stock (Pg C)[18]	Total C NPP (Pg C yr^{-1})[19]
Tropical forests	1.76	428	21.9
Temperate forests	1.04	159	8.1
Boreal forests	1.37	290	2.6
Northern peatlands	0.26	419	—
Arctic tundra	0.95	127	0.50
Crops	1.60	131	4.1
Tropical grasslands	2.25	330	14.9
Temperate grasslands	1.25	304	4.4
Deserts	4.55	199	3.5

1.2 PAST AND FUTURE CLIMATE CHANGE

Changes in climate are not new: Earth has long been subjected to sequential glacials, interglacials, and warm periods, and all parts of Canada have been warmer, cooler, wetter, and drier at various times in the past. A number of natural factors control climatic variability, including Earth's orbit, changes in solar output, sunspot cycles, and volcanic eruptions (Chapter 2). However, the present climatic change is unprecedented in character: it cannot be explained by these factors alone. The recently observed increase in global temperature is strongly related to increases in the concentration of GHGs in the recent past,[2] increases that are directly attributable to human activities. Over the course of the 20th century global mean temperature has risen by about 0.6°C, and is projected to continue to rise at an average rate of 0.1 to 0.2°C per decade for the next few decades then increase to a rate of warming of between 1.4 and 5.8°C per decade by 2100.[2] Average temperatures across Canada are expected to rise at twice the global rate. In general, Canadian temperatures have been increasing steadily over the last 58 years, with winter temperatures above normal between 1985 and 2005 (Figure 1.2). At the same time, in general, over the last 58 years, winter precipitation has been decreasing (Figure 1.3) across Canada. In southern Canada, surface temperatures have increased by 0.5 to 1.5°C during the 20th century. The greatest warming has occurred in western Canada, with up to 6°C increase in the minimum temperature. In addition, the frequency of days with extreme temperature, both high and low, is expected to increase, snow and ice cover to decrease, and heavy precipitation events to increase.[3] During the second half of the 21st century, heat sums, measured in growing degree days, across southern Canada are expected to increase by between 40 and 100%.

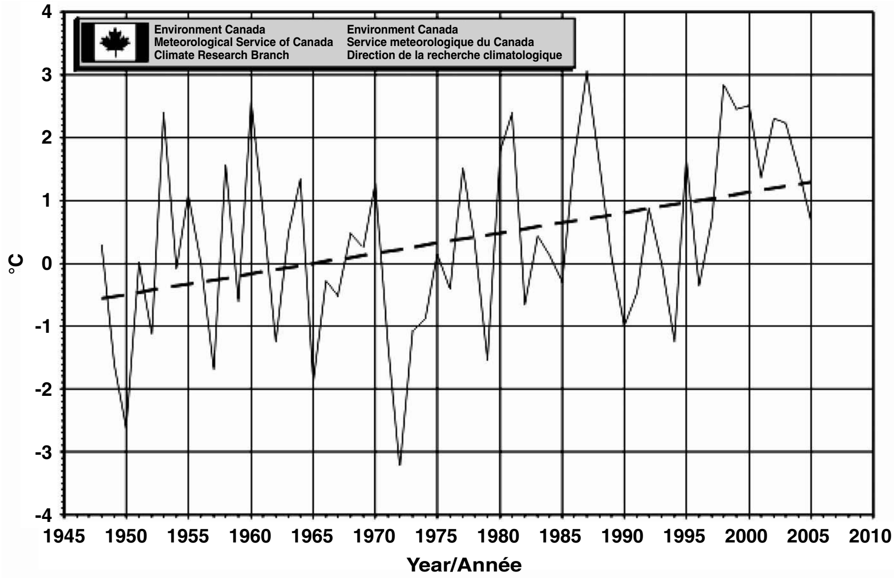

FIGURE 1.2 Canadian winter temperature deviation with weight running mean between 1948 and 2005. (Courtesy of Environment Canada.[7])

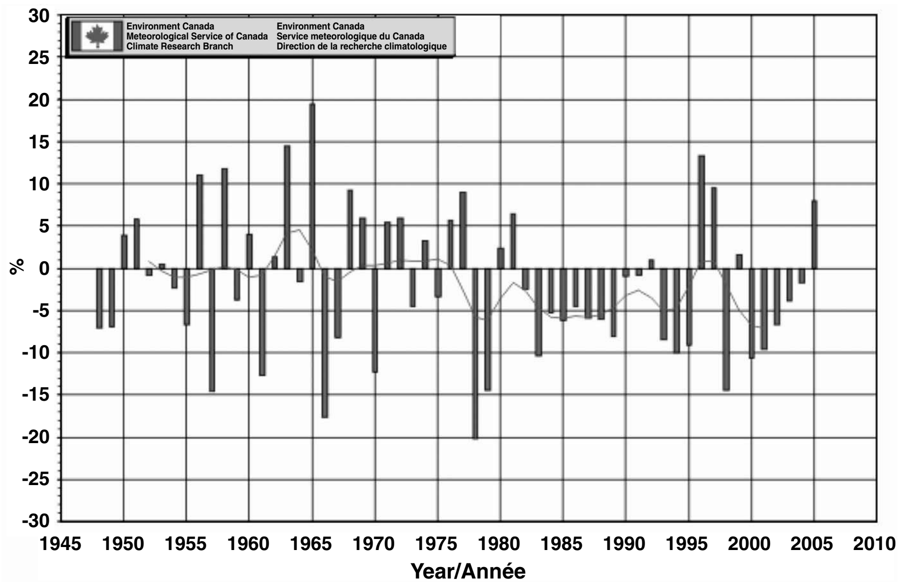

FIGURE 1.3 Canadian winter precipitation deviation from weight running mean between 1948 and 2005. (Courtesy of Environment Canada.[7])

1.3 GREENHOUSE GAS EMISSIONS FROM AGRICULTURE, FORESTRY, AND WETLAND ECOSYSTEMS

Natural processes such as decomposition and respiration, volcanic eruptions, and ocean outgassing are continuously releasing greenhouse gases such as water vapor, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) into the atmosphere. Molecule for molecule, CO_2 is a weak GHG in terms of global warming potential (GWP); most other GHGs have a stronger GWP. Compared to CO_2, on a 100-year timescale, the GWP is 21 times greater for CH_4, 310 times greater for N_2O, and 900 or more times greater for chlorofluorocarbons and hydrochlorofluorocarbons.[4] However, the net contribution of each gas to the greenhouse effect depends on four factors: the amount of the gas released into the atmosphere per year, the length of time that it stays in the atmosphere before being destroyed or removed, any indirect effect it has on atmospheric chemistry, and the concentration of other GHGs. In taking into account all these factors, the net contribution of CO_2 to the greenhouse effect is two to three times higher than that of CH_4 and about 15 times higher than that of N_2O.[4] Over the 20th century there has been a significant increase in GHGs in the atmosphere due to human activities such as fossil fuel burning and land use change. For example, there has been about a 30% increase in the concentration of CO_2 since the pre-industrial era: from 280 ppm in the late 18th century to 382 ppm in 2004.[5]

A global CO_2 emission rate of approximately 23.9 gigatonnes (Gt) has recently been estimated by the Carbon Dioxide Information and Analysis Centre.[6] Deforestation, land use, and ensuing soil oxidation have been estimated to account for about 23% of human-made CO_2 emissions. CH_4 emissions generated from human activities, amounting to ~360 Mt per year, are primarily the result of activities such as livestock and rice cultivation, biomass burning, natural gas delivery systems, landfills, and coal mining. Total annual emissions of N_2O from all sources are estimated to be within the range of 10 to 17.5 Mt N_2O, expressed as nitrogen (N).[4] While Canada contributes only about 2% of total global GHG emissions, it is one of the highest per capita emitters, largely the result of its resource-based economy, climate (i.e., energy demands), and size.[7] The change in Canada's GHG emissions between 1990 and 2002 by a number of different sectors (specifically, energy, transportation, industrial processes, agriculture, land-use change and forestry, and waste and landfills) is presented in Figure 1.4.[7] Total Canadian emissions of all GHGs in 2002 were 20.1% more than the 1990 level of 609 Tg of C. This growth in emissions appears to be mainly the result of increased energy production and fossil fuel consumption for heating in the residential and commercial sectors, as well as increases in the transportation, mining, and manufacturing sectors. The average annual growth of emissions over the 1990–2002 period was 1.7%.

Historically, agricultural activities have been a source of atmospheric enrichment of GHGs. In 2002, agriculture-related GHG emissions totaled 59 Tg of C, representing 8% of total Canadian emissions.[7] This sector accounted for 66% of Canada's total emissions of N_2O and 26% of CH_4 emissions. On a category basis, agricultural soils contributed 50% of the sector's emissions (29.6 Tg of C) in 2002 with the other half coming from domestic animals (32% or 18.8 Tg) and manure management

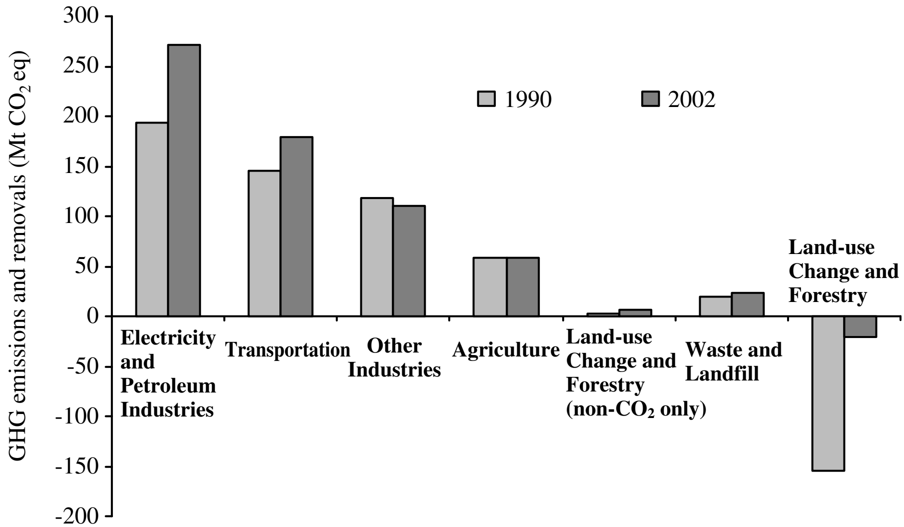

FIGURE 1.4 Change in GHG emissions and sinks for Canada between 1990 and 2002 for different sectors. (Courtesy of Environment Canada.[7])

(17% or 10.2 Tg of C). While total sector emissions rose 2% between 1990 and 2001, emissions from manure management rose 22% and enteric fermentation emissions increased by 18%. Net CO_2 emissions from agricultural soils partially offset these increases, changing from a net source of 7.6 Tg of C in 1990 to a net sink of 0.5 Tg of C in 2002. The N_2O emissions from soils, however, rose 15% over the same period.[7]

The profile of GHG emissions from the agricultural sector is very different from other sectors. For this sector, N_2O emissions associated primarily with N sources (fertilizer and animal manure) represent 61% of GHG emissions, CH_4 from ruminants and other sources represent another 38%, while net CO_2 emissions account for less than 1% of agricultural GHG emissions. N_2O is released during the biological process of denitrification, and CH_4 is released from enteric fermentation by ruminants, most specifically cattle, grazing the forage produced on these grasslands (Chapter 12). Digestive processes involving the breakdown of plant materials under conditions that are oxygen free, or oxygen limited, result in CH_4 production and account for 28% of agricultural emissions. Indirect emissions from livestock operations such as handling, storage, and land application of farm manure account for 14% of agricultural emissions. Microbial decomposition of manure can result in CO_2, CH_4, and N_2O emissions, with their relative contributions dependent on factors such as manure dry matter, C and N contents, as well as temperature and oxygen availability during storage.

The forest sector, limited to productive managed forest lands in Canada, was a net sink in 2002, as it removed 15 Tg of C from the atmosphere.[7] This estimate represents the sum of the net CO_2 flux and non-CO_2 (CH_4 and N_2O) emissions. The net CO_2 flux alone amounted to a sink of 21 Tg, which reduced total Canadian emissions in 2002 by 3%. Non-CO_2 emissions were about 6.0 Tg in 2002. However, the source/sink relationship for the forest sector is strongly influenced by disturbances, especially fire and insect outbreaks, which makes the GHG uptake or emissions of Canadian forests in a given year hard to predict[8] (Chapter 9).

In terms of greenhouse gases, wetlands can either be sources or sinks. Due to the complex biogeochemistry of peatlands/wetlands, they may function as sinks for one gas while acting as sources for others (Chapters 4 and 10). Peatland/wetlands may also change from sinks to sources due to anthropogenic impacts such as increased nutrient loading, drainage, flooding, burning, and vegetation change.

1.4 CLIMATE CHANGE IN RELATION TO AGRICULTURE, FORESTRY, AND WETLANDS

1.4.1 Agricultural Ecosystems

Arable agriculture occurs on only 7% of Canada's landmass due to climatic and soil limitations, and about 70% of Canada's arable acreage is located in Alberta and Saskatchewan.[9] Even under current conditions, climate has a major influence on the year-to-year variation in agricultural productivity in this region. Climate change can be expected to lead to more extreme weather conditions (i.e., conditions outside the range of previous norms), increases in weed and pest problems, and severe water shortage. On the other hand, these impacts will vary on a regional basis,[10] and some Canadian agricultural regions will benefit from a warmer climate and longer growing season, while others will be adversely affected.

With agricultural intensification to meet increases in food demand, soil degradation emerges as a major threat under climate change[11] (Chapters 4 and 6). Degradation of soil quality under climate change could result from decreases in soil organic matter (SOM), nutrient leaching, and soil erosion. Soil erosion is a major threat to agricultural productivity and sustainability as well as having adverse effects on air and water quality (Chapters 4 and 6). Wind and water erosion may increase significantly in agricultural soils due to increases in extreme weather condition such as heavy precipitation events or prolonged droughts.[12] Warmer winters may result in lower snow cover, and the reduction in soil moisture content could further increase the risk of wind erosion. Land-use change from natural vegetation to croplands potentially exacerbates these impacts due to increased vulnerability of the landscape to erosion.

1.4.2 Forest Ecosystems

Forests cover more than one third of the land surface of the Earth. Almost half (410 Mha) the total landmass of Canada is forestland.[9] Boreal forests are the dominant forest type, spanning the complete width of the country (Figure 1.5). About 51% of Canada's forests are deemed suitable for timber production. The productivity of forest ecosystems largely depends upon the climate, nutrient, and moisture regimes.[13] Climate affects the distribution, health, and productivity of the forest and has a strong influence on the disturbance regime. The realization

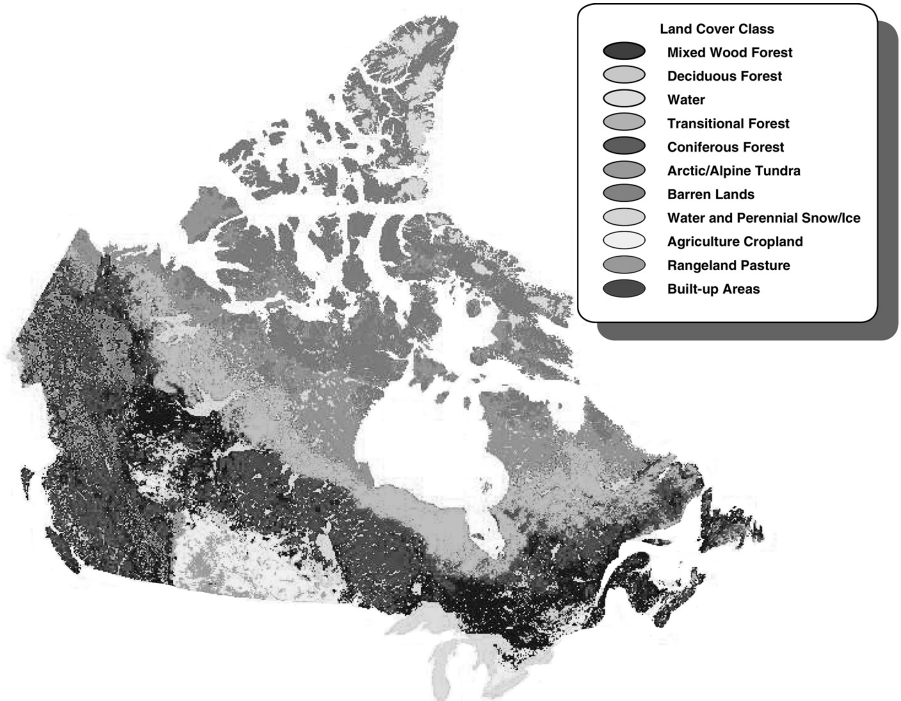

FIGURE 1.5 Land cover map of Canada. (Courtesy of Natural Resources Canada.[9])

of the potential increase in plant productivity due to climate change depends on a variety of factors such as changes in species and competitive interactions, water availability, and the effect of temperature increase on photosynthesis and respiration (Chapter 16). In addition to the direct influence of climate change, other variables such as land-use change and existing land cover have profound influences on the forest distribution and productivity.

The future C balance of the forest will largely depend on the type and frequency of disturbances, changes in species composition, and alterations to the nutrient and moisture regimes under changing climate conditions (Chapter 9). It will also depend on forest management practices that affect both the disturbance regime and nutrient status. Projected climate change scenarios for the boreal forest generally predict warmer and somewhat drier conditions, posing questions about regeneration as well as productivity. In addition, the disturbance patterns are also expected to change. With more frequent disturbances (Figure 1.6), more of the stands will move into younger age classes where the uptake by regrowth is initially more than offset by CO_2 efflux from the decomposition of soil pools and elevated detritus left by the disturbance. This situation is expected to worsen as climatic change proceeds, especially if the conditions for successful regeneration are adversely altered. Altered boreal forest disturbance regimes — especially increases in frequency, size, and severity — may release CO_2 from vegetation, forest floors, and soils at higher rates than the rate of C accumulation in the regrowing vegetation.[8]

FIGURE 1.6 Boreal forest under fire. (Courtesy of Canadian Forest Service.)

The precise balance of C uptake and release depends on the detailed processes, and especially the outcome of interactions among climate, site variables, and vegetation over the changing life cycles of forest stands. Quantifying life-cycle dynamics at the stand level is essential for projecting future changes in forest level C stocks (Chapter 9). Forest management options to enhance or protect C stocks include reducing the regeneration delay through seeding and planting, enhancing forest productivity, changing the harvest rotation length, the judicious use of forest products, and forest protection through control and suppression of disturbance by fire, pests, and disease.

1.4.3 Wetland/Peatland Ecosystems

Canada contains the world's second largest area of peatlands (after Russia). In Canada these peatlands cover approximately 13% of the land area and 16% of the soil area (Figure 1.7).[14] The largest area of peatlands (96%) occurs in the Boreal and Subarctic peatland regions. The dominant peatland types are bogs (67%) and fens (32%), with swamps and marshes together accounting for less than 1% of the Canadian peatlands. Overall, the most important controls of the carbon cycle in peatlands are plant community, temperature, hydrology, and chemistry of plant tissues and peat.[15] Limited data and understanding of the influence of changing environmental conditions and disturbance (including fires and permafrost melting) on the carbon cycle of peatlands over short and medium timescales (10 to 100 years)

FIGURE 1.7 Land-use change from natural peatlands to agricultural activities. (Courtesy of Steve Zoltai, Canadian Forest Service.)

hinder predictions of the changes in the carbon sink/source relationships under a changing climate. The projected warming and associated changes in precipitation will influence both net primary production and decomposition in peatlands, but how global warming will directly influence peatland carbon dynamics remains uncertain (Chapters 10 and 17). Melting of permafrost tends to increase peatland carbon stocks through increased bryophyte productivity but also appears to increase heterotrophic respiration.[16] Peatland fires result in decreased net primary production and elevated post-fire decomposition rates, but little is known about the recovery of the carbon balance after peatland fires (Chapters 10 and 17).

1.5 PURPOSE OF THIS BOOK

The major objective of this book is collation and synthesis of the current state-of-knowledge of the impacts of climate change on agriculture, livestock, forestry, and wetlands. Although many of the specific examples draw on Canadian studies, these examples have lessons that are useful in other parts of the world, especially in the Northern Hemisphere. The sustainable management of northern regions is a critical objective in terms of human needs for food and fiber. Climate change, along with land-use change and increased disturbance regimes, will be a significant threat to meeting this objective, and will require significant improvements in understanding and modification to present management practices.

Another objective of global importance is to help policy makers and land managers to reach informed choices regarding the relationships between carbon sources and sinks and the potential to increase sink capacity and reduce emissions for the regional landscapes under their jurisdiction. Terrestrial ecosystems are very diverse, ranging from highly managed agricultural systems to natural northern peatlands. How will these ecosystems respond to climate change and how can these ecosystems be managed under changing conditions? Are there management options that could be implemented to increase the sink capacity or to minimize the GHGs emissions? Are there strategies that minimize future vulnerabilities, while maintaining present supply needs?

Different components of the terrestrial ecosystems as well as issues of climate change are discussed in detail to address the following points:

- The vulnerability of the systems to climate change
- Specific impacts of changing climate on agriculture, forestry, or wetland systems
- Forms or methods of mitigation
- Adaptation measures or options to reduce the impacts on different ecosystems, and the goods and services we require from them

This synthesis presents the current scientific understanding of carbon dynamics in different ecosystems for Canada and identifies major knowledge gaps that hinder our ability to forecast responses to future climate change. Understanding the sink/source relationships and quantifying the contributions of different ecosystems are essential steps toward bridging the gap between policy need (increased sinks of atmospheric carbon) and science.

1.6 SUMMARY AND CONCLUSIONS

There is growing evidence that climate change is already occurring. At the global scale, average surface temperatures rose about 0.6°C over the 20th century and is expected to increase by another 1.4 to 5.8°C by the year 2100 — a rapid and profound change, with only dimly perceived consequences. The major factor responsible for this unprecedented increase in temperature and change in climate is an increase in the concentration of GHGs in the atmosphere, caused by human activities. Climate change is expected to bring both advantages and disadvantages for the agricultural and forest sectors in Canada. For example, although warmer temperatures would increase the length of the growing season, they may also increase crop damage due to heat stress and water and pest problems. Changes in the frequency and intensity of extreme events (e.g., droughts, floods, and storms) have been identified as the greatest challenge that would face the agricultural industry as a result of climate change. Drought and extreme heat have also been shown to affect livestock production operations.

Climate change has the potential to greatly influence Canadian forests and wetlands/peatlands, since even small changes in temperature and precipitation can significantly affect tree regeneration, survival, and growth. For example, the 1°C increase in temperature over the last century in Canada has been associated with longer growing seasons, increased plant growth, shifts in distribution, permafrost melting, and changes in plant hardiness zones. Future climate change is expected to further affect species distribution, forest productivity, and disturbance regimes. Regenerating trees today will grow and mature in a future climate that will be very different, and one to which they may be poorly adapted. Therefore, understanding the vulnerability of terrestrial ecosystems to these changes is essential for management of resources and need for food and fiber.

REFERENCES

1. Kauppi, P.E., Sedjo, R.A., Apps, M.J., Cerri, C.C., Fujimori, T., Janzen, H., Krankina, O.N., Makundi, W., Marland, G., Masera, O., Nabuurs, G.J., Razali, W., and Ravindranath, N.H., Technical and economic potential of options to enhance, maintain and manage biological carbon reservoirs and geo-engineering. In *IPCC Working Group III Contribution to the Third Assessment Report on Mitigation of Climate Change,* van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A., Eds., Cambridge University Press, New York, 2001, 301–323.
2. IPCC (Intergovernmental Panel on Climate Change), *Climate Change 2001: The Scientific Basis*, *Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change,* Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A., Eds., Cambridge University Press, New York, 2001.
3. Folland, C.K., Karl, T.R., Christy, R., Clarke, R.A., Gruza, G.V., Jouzel, J., Mann, M.E., Oerlemans, J., Salinger, M.J., and Wang, S.W., Observed climate variability and change. In *Climate Change 2001: The Scientific Basis*, *Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change,* Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A., Eds., Cambridge University Press, New York, 2001, 99–182.
4. IPCC (Intergovernmental Panel on Climate Change), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and Greenhouse Gas Inventory Reference Manual, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.
5. Keeling, C.D. and Whorf, T.P., Atmospheric CO_2 records from sites in the SIO air sampling network. In *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, 2005.
6. Marland, G., Boden, T.A., and Andres, R.J., Global, regional, and national CO_2 emissions. In Trends: A Compendium of Data on Global Change, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, 2005.
7. Environment Canada, *Canada's Greenhouse Gas Inventory 1990–2002*, submission to the UNFCCC Secretariat, Ottawa.
8. Kurz, W.A. and Apps, M.J., A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector, *Ecol. Appl.*, 9, 526, 1999.
9. Natural Resources Canada, *The State of Canada's Forests 2003–2004*, Natural Resources Canada, Ottawa, 2004.

10. Cohen, S., et al., North America. In *Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the IPCC,* McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., and White, K.S., Eds., Cambridge Press, New York, 2001, chap. 15.
11. Gitay, H., Brown, S., Easterling, W.E., Jallow, B., Antle, J., Apps, M. J., Beamish, R., Chapin, T., Cramer, W., Franji, J., Laine, J., Erda, L., Magnuson, J.J., Noble, I., Price, C., Prowse, T.D., Sirotenko, O., Root, T., Schulze, E.-D., Sohngen, B., and Soussana, J.-F., Ecosystems and their services. In *IPCC,* Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A., Eds., Cambridge University Press, New York, 2001, 235–342.
12. Lal, R., Soil erosion and global carbon budget, *Environ. Int*., 29, 437, 2003.
13. Kimmins, J.P., Importance of soil and role of ecosystem disturbance for sustained productivity of cool temperate and boreal forest, *Soil Sci. Soc. Am. J.* 60, 1643–1654, 1996.
14. Environment Canada, Wetlands in Canada: A Valuable Resource. Fact Sheet 86-4. Lands Directorate, Ottawa, Ontario, 1986.
15. Moore, T.R., Roulet, N.T., and Waddington, J.M., Uncertainty in predicting the effect of climatic change on the carbon cycle of Canadian peatlands, *Climatic Change* 40, 229–245, 1998.
16. Turetsky, M.R., Weider, R.K., Halsey, L.A., and Vitt, D.H., Current disturbance and the diminishing peatland C sink, *Geophys. Res. Lett.* 29(11)**,** 1526–1526, 2002.
17. Turetsky, M.R., Wieder, R.K., Williams, C.J., and Vitt, D.H., Organic matter accumulation, peat chemistry, and permafrost melting in peatlands of boreal Alberta, *Ecoscience* 7, 379–392, 2000.
18. Intergovernmental Panel on Climate Change (IPCC), 2000. *Land Use, Land-Use Change, and Forestry,* Watson, R.T., Novel, I.R., Bolin, N.H., Ravindranath, N.H., Verardo, D.J., and Dokken, D.J., Eds., Cambridge University Press, New York, 2000.
19. Saugier, B., Roy, J., and Mooney, H., Estimations of global terrestrial productivity: converging towards a single number? In *Terrestrial Global Productivity*, Roy, J., Saugier, B., and Mooney, H.A., Eds., Academic Press, New York, 2001.

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