Part V

Summary and Recommendations

20 Impacts of Climate Change on Agriculture, Forest, and Wetland Ecosystems: Synthesis and Summary

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20.1 INTRODUCTION

Two important issues are facing humanity at the dawn of the 21st century: (1) human-induced increases in atmospheric concentration of greenhouse gases (GHGs) with anticipated impacts on the climate (increase in the severity and frequency of extreme events, sea level rise, and changes in terrestrial and aquatic biodiversity), and (2) associated impacts on global food security due, among other reasons, to socioeconomic development goals, new technologies, and rapid changes in population and living standards in the developing countries where populations are already under great stress. Both of these issues are interlinked and governed by our management of the Earth's natural resources.

20.2 CLIMATE CHANGE IS REAL

In discussing the anticipated impacts of climate change on agriculture, forestry, and wetlands management it is first useful to describe the global context in which the climate is changing (Chapter 2). Scientists have drawn attention to the significant increase in the atmospheric concentrations of carbon dioxide and other GHGs as a result of the burning of fossil fuels and land-use changes. The threat of anthropogenic climate change has become an issue for governments and the general public at large. As a measure of Canada's fossil fuel emissions, these are equivalent to burning all of Canada's forests every 2 years (Chapter 9). The increases in atmospheric concentrations of GHGs are outside levels seen over the past 400,000 years. They can be expected to alter the climate to a degree that the past will no longer be a useful guide to the future. Indeed, the Intergovernmental Panel on Climate Change (IPCC) in its 3rd Assessment Report (TAR) concluded, "an increasing body of observations gives a collective picture of a warming world."[1]

There is already strong evidence of changes in biological and physical systems. The IPCC concluded in the TAR that "there have been discernible impacts of regional climate change, particularly in temperature, on biological systems in the 20th century."[1] Changes include many that are important for agriculture such as higher minimum temperatures at night, the earlier onset of spring and plant flowering, the lengthening of the growing season, shifts in bird, insect, and other populations, as well as the decline of mountain glaciers with the concomitant decline in runoff.[2] Similar changes have been described in the recent report of the Canadian Council of Ministers of the Environment (CCME) — Climate, Nature, and People: Indicators of Canada's Changing Climate (Chapter 3). As examples, frost-free periods have declined significantly and the blossoming time for trees such as aspen now occurs some 28 days earlier.[3]

Although the IPCC in the TAR concluded that: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities," it is important to be somewhat cautious in attributing all observed changes entirely to anthropogenic climate change since there are other stresses involved. Changes in some weather variables such as extreme events — heat-waves, droughts, and floods, for example — are very difficult to detect at the present time, and yet have an important impact on the climate.[4]

Humans have already made a commitment to the future climate because the GHGs emitted into the atmosphere are expected to remain there for many decades. In addition, it will take many years to turn around the development pathways being followed at present. Consequently, humans may be powerless to alter the impacts that are anticipated to occur over the next 30 years. Some adaptation will be essential and this will require significant investments and changes in behavior.[5] Most scientists are convinced that action to reduce emissions is necessary and that there is an urgency to act in order to avoid even worse impacts.

Looking to the future, continental summer droughts, disease, and insect infestations as well as forest fires are all projected to increase; animal and plant productivity are also expected to decline.[4] The actual impact of these changes on agriculture will vary depending on factors such as precipitation changes and other stresses associated with different land-use practices.

However, not all of the impacts of projected climate change will necessarily be negative. Indeed, there have been some recent studies that suggest that mid-latitude agriculture, such as in North America, may benefit from temperature increases of up to 1 to 2°C, although it is still unclear what the attendant moisture stresses may be.[6] On the other hand, forestry is expected to be impacted negatively and may not be able to adapt quite so readily. As an example of what has already occurred, prior to about 1980 the Canadian boreal forest was a net sink for carbon but estimates indicate that since then it has become a small source, due to increases in natural disturbances, which may have been caused by climate change[7] (Chapter 9). At the global scale, research suggests that since the industrial revolution, after which the use of fossil fuels has increased dramatically, the terrestrial biosphere has been a net source. This is something of a surprise and may represent an important finding.

Wetlands have been the forgotten ecosystems. They are very sensitive to climate change and can respond rapidly. Wetlands are estimated to contain about a third of the world's carbon; if this were released, the atmospheric concentration of CO_2 would be at least 50% higher (see Chapter 10). Wetlands are already threatened by human disturbances, for example, through drainage for agriculture, and may become more so due to expected increases in evaporation, although the effects of melting permafrost may confound the final outcome of this complex process.

Changes in agriculture, forestry, and wetland ecosystems will also be affected by the interactions between the climate and the carbon cycle (Table 20.1). There is much that is not understood about the biological processes that govern carbon-stock changes. This was discussed in a report on the scientific basis for separating out the natural and human contributions to carbon-stock changes that the IPCC undertook for the U.N. climate change convention process.[8] Increasing carbon dioxide in the atmosphere is expected to enhance plant growth in some crops, but studies suggest

TABLE 20.1
Atmospheric Concentration of GHGs and the Factors Affecting Them

	CO_2	CH_4	N_2O
Pre-industrial concentration	280 ppmv	0.80 ppmv	288 ppbv
Present-day level (2004)	378 ppmv	1.78 ppmv	310 ppbv
Current annual increase (%) (between 1990 and 1999)	50	90	25
Factors causing increase in emissions			
Agriculture	Deforestation Biomass burning Soil degradation Soil erosion Soil tillage	Rice cultivation Ruminants	Synthetic N fertilizers Animal soil excreta Biological N fixation
Forestry	Fire Biomass burning Land-use change Site preparations	Fire	Synthetic N fertilizers Biological N fixation Fire
Wetlands	Fire Drainage Peat mining Land-use change	Permafrost melting Reservoir creation	Biological N fixation

that this effect declines with increasing concentrations. In addition, while higher levels of carbon dioxide may increase plant mass, there may be a displacement of nitrogen take up which is essential for protein synthesis. The CO_2 fertilization effect is limited by the lack of water and essential elements (e.g., N, P, S, and some micronutrients).[9] Finally, increased temperatures associated with climate change are expected to enhance soil respiration, particularly in boreal soils.

In addition to climate change, other human activities are also exerting an influence on the environment such that they are now overwhelming many of the natural forcing on the ecosystems upon which humans rely for products and services. Such activities include land-use changes and the addition of nitrogen as fertilizer. Humans now control more than 50% of the primary productivity of the planet. These factors are working together and influencing the planet in ways that are not fully understood. Small local perturbations can sometimes have global consequences. As long ago as 1985, a conference in Villach, Austria, concluded, "Many important economic and social decisions are being made today on long-term projects … based on the assumption that past climate data … are a reliable guide to the future. This is no longer a good assumption."[10] It is not just the magnitude of the changes that is of concern, but also the rate of change, which is likely to be too fast for many ecosystems and socioeconomic systems to adapt. Some of the changes may be irreversible within several generations and others, such as the loss of species, irretrievable.

The scientific knowledge of the climate system is still not complete and this will remain a challenge for scientists for many generations to come. Earth's climate system is complex, involving many nonlinear components, both natural and human, and we are forcing the system at rates that are likely to produce surprises. Further monitoring and research is needed particularly to strengthen knowledge at the local and regional level knowledge of climatic processes on such indicators as precipitation and extreme events. Despite these continuing challenges, considerable progress has been made in the last few years through concentrated efforts such as the biological carbon program (BIOCAP) initiative.

20.3 IMPACTS OF CLIMATE CHANGE ON AGRICULTURE, FOREST, AND WETLAND ECOSYSTEMS

There are optimum temperatures for plant growth and there is already some evidence that rice crops in the tropics are suffering (see Chapter 5). Crop yields in mid- and high-latitude regions may be less adversely affected by higher temperatures. Farm-level adaptation, including new crop strains, can generally offset the detrimental effects of climate change but poor soil conditions will be a major factor limiting the northward expansion of agricultural crops. The positive impacts of warmer temperature and enhanced CO_2 on the rates of crop maturation and production are expected to mitigate the impact of moisture limitation, so that increased growth rates in grasslands and pastures are generally expected[11] (Chapters 7 and 8). With a doubling of CO_2 concentrations an average increase of about 17% in grassland productivity is anticipated with greater increases in the northern regions. However, some studies

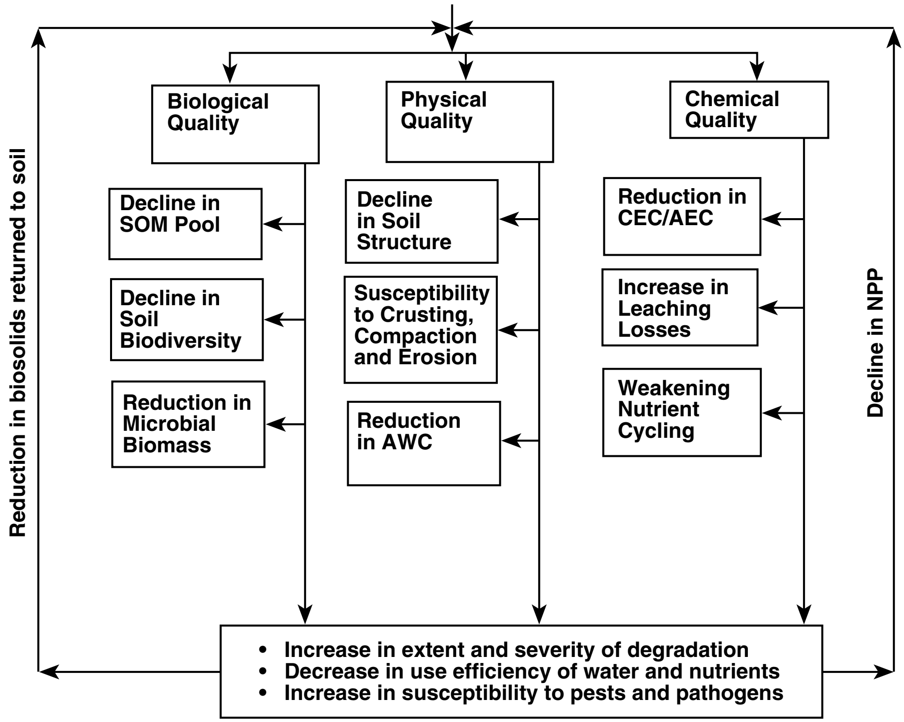

FIGURE 20.1 Some probable adverse effects of projected climate change on world soils.

suggest that under climate change, particularly with extreme weather events, the invasion of alien species into grasslands could reduce the nutritional quality of the grass.[12]

The projected changes in climate are expected to have some adverse impacts on the world's soils (Figure 20.1). Increases in soil temperatures will enhance the rate of decomposition of soil organic matter. Consequently, the soil organic matter pool will decline with adverse impacts on soil structure, plant-available water retention capacity, and cycling of nutrients. All other factors remaining the same, soils with less organic matter content are more susceptible to crusting, compaction, and erosion. However, the impact of projected climate change on soil quality will differ among regions, with more adverse impacts on soils of higher latitudes than in the tropical ecosystems. Agronomic/biomass productivity is also likely to decline because of increased intensity and frequency of drought, reduced nutrient use efficiency, and increased incidence of pests and diseases.

Climate change is expected to present both benefits and challenges to livestock operations. Increases in temperature during winter will reduce the feed requirements, increase survival rate for the young, and reduce energy cost for the farmers (Chapter 12). However, the heat waves during summers could kill the animals and adversely affect the milk production, meat quality, and dairy cow fecundity (Chapters 12, 13, 14, and 15).

The dominant factor to decision making in agricultural ecosystems is the economic net return to the farmer (see Chapter 5). Farmers, as guardians of the land, have experience in adapting to the variability of weather and the climate. Agricultural planners will need to identify options that have benefits not only in moderating the impacts of changes in the climate but that will also benefit farmers' bottom line and, indeed, that for any natural resource manager. Land management practices based on sound scientific recommendations are essential to minimize the adverse effect of climate change and for soil conservation. These arguments have been used in persuading farmers to adopt low or no-till farming since this not only can lead to increases in take-up of soil carbon, and so reducing the atmospheric build-up of CO_2, but can also improve the water-holding capacity of soils, as well as render the soil better able to cope with future climatic change.

Methane emissions from agriculture account for 38% of total greenhouse gas emissions in New Zealand (Chapter 12). Resources diverted by ruminants in producing methane are not being used for growth. Therefore, diets and feed quality are very important factors affecting methane emissions. Furthermore, it has been found that, when looking at total greenhouse gas emissions, cattle raised on pasture produce less than a third as much emissions as those raised in feedlots (see Chapters 13 and 15). Similarly, taking cattle off waterlogged pastures can lead to less nitrogen emissions and reduces damage to the land.

There are already notable climate-related changes in forest growth as a result of different drivers such as increased CO_2, higher temperatures, more water stress, changing nutrient loading and permafrost melting (Chapter 9). The scientific knowledge of the effects of these drivers is limited. With climate warming, it has been suggested that trees will migrate northward and to higher altitudes. However, temperature is not the sole control on species distribution as other factors including moisture conditions, soil characteristics, and nutrient availability may be more important in forest dynamics.[13] Moisture conditions are the most important factor governing the growth of trembling aspen in western Canada.[14] There are also changes in community structure and ecosystem functioning as a result of climate change and other stresses. In addition, changes in disturbance regimes from pests and fires resulting directly and indirectly from human activities are expected to be significant. As an example of the challenges facing the forestry sector, the population of the mountain pine beetle now devastating western Canadian forests currently occupies only a fraction of its potential range.

Yet, there are many uncertainties related to the influence of these drivers on forest ecosystems. For example, although elevated CO_2 concentrations can benefit tree growth, other anthropogenic emissions may complicate this effect. Human-induced increases in ambient concentrations of ground-level ozone (O_3) may lower tree productivity while N_2O may enhance growth in nitrogen-limited boreal forest ecosystems. Furthermore, the positive effects of CO_2 fertilization and nitrogen deposition may be minimal relative to other factors, particularly land-use change.[15] These contrasting results of many studies may be complicated by other factors such as the species studied, age of the tree stand, the length of the study period, and the methodology used.

There are numerous challenges facing the forestry sector (Chapter 16). Among the key needs is the development of tools for the verifiable measurement of carbon stock changes. For a country with as vast a forest area as Canada, this is obviously no simple matter. There are some encouraging techniques now being developed using remote sensing. It is not known whether carbon stocks in Canadian forests are at present increasing or decreasing. Making useful forecasts of future carbon stocks requires an understanding of the cause and effects of fast and slow processes and understanding disturbance regimes (fire and insects). This is a significant modeling challenge. It will also be important to consider the belowground carbon stocks — for example, the change of root respiration with temperature — as well as other processes in the soil and scaling them up. The FLUXNET initiative will provide much of the data required and will examine how climate variability, management practices, and natural disturbance influence carbon cycling in forest and peatland ecosystems. We will also examine how changes in the carbon pools in living biomass and soils might help in the management of GHGs through the short-term sequestration of atmospheric CO_2.

Canada has the second largest area of wetlands and peatlands in the world (Chapters 10 and 17). These wetlands/peatlands were created over the last 8000 years.[16] In terms of GHGs, wetlands could be either a source or sink of CO_2, CH_4, and N_2O. Some of the time, these wetlands may be a sink for one gas and a source for others (Table 20.2). The ability of wetland ecosystems to act as sinks (or sources) of carbon is a delicate and complex balance of ecosystem processes – most largely controlled by climate. On a global scale, wetlands are today a minor source of CO_2 and N_2O while a major source of CH_4 (Table 20.2). Wetlands are subject to change from sink to source due to non-climatic factors such as mining, reservoir creation, agriculture, fire and permafrost melting[17] (Chapter 10). Carbon is sequestered when plant production is greater than decomposition and the export of dissolved organic carbon through stream flow is low. At present, the accumulation of carbon in wetlands is about 13% of their full potential. The worry is that future climate change could convert these stores of carbon into net sources. It is important to recognize that wetlands provide many ecosystem services. Wetlands need to be managed for the benefit of society as a whole — they are a valuable natural resource (Chapter 17).

These examples illustrate the need to take a holistic and integrated approach to addressing climate change. Decisions regarding GHG abatement must be broad in scope and not focus on individual factors in isolation. Reduction in one GHG should not be undertaken at the expense of another. Scientific knowledge must be expanded

TABLE 20.2
Wetland Contribution to Global Annual GHGs Emissions ($Tg\ yr^{-1}$)

GHGs	Wetland Emission	Global Emissions	% Contribution
Carbon dioxide	8.5[19]	7000[1]	0.12
Nitrous oxide	0.133[20]	7.1–12.7[21]	0.8–1.4
Methane[22]	113	540	21

and coupled to include the climate system, the carbon and nitrogen cycles, the hydrological cycle, and ecosystem functioning. Each of these components, which do not operate independently, is important and each is crucial to the proper functioning of agriculture and forestry.

It is important to involve not only the natural science community — biologists, physicists, and chemists — but also experts from the social and economic science disciplines. Furthermore, it is also important to bring in the users and producers in order that the scientific knowledge is transferred and behavior is changed (this is a steep learning curve). There is a strong need to build on current best practices, for example, those used in adapting to today's climate variability as was demonstrated by the experience in Alberta with its GHG science planning process. It is essential to look for win–win options where farmers and forestry managers see an economic advantage for themselves as well as contributing to addressing the global issue of climate change. It is equally important to take advantage of synergies between actions to reduce emissions and those to adapt to the impacts of climate change. Finally, significant investment monitoring and research is required.

One area that illustrates the challenge and could have significant potential in agricultural and forestry management is that of biofuels and bioproducts (Chapter 11). Biological systems have been in the business of managing GHGs and solar energy for more than 400 million years and offer the opportunity to be part of the solution to climate change. The carbon cycle is a natural process that has operated for millennia to maintain the atmosphere at levels that have kept the climate within a habitable range. At present, agriculture and forestry produce an annual harvest of some 143 Mt C/yr which is equivalent to 50% of the biomass needed to meet the nation's current fossil fuel energy demand[18] (Chapter 11). It is important to assess how much of this can be diverted to bioenergy. The biotic carbon is now a tradable commodity, and any forest or agricultural residue should not be considered a waste. Currently, in Canada biomass converted into energy products amounts to only 10 Mt C/year,[18] and this could be increased by utilizing residues from harvest and natural disturbances, which are not currently being used, and by increasing carbon stocks, especially in forests. Such an approach would significantly replace fossil fuel emissions. Canada may need to choose between forest carbon credits and large-scale bioenergy.

20.4 WHAT IS NEXT UNDER CHANGING CLIMATE?

Future climate change and environmental issues need a careful assessment. There are several important issues that need to be addressed. It is necessary to recognize the real threat of climate change and prepare for it. The challenge for scientists is to do good, solid science. But this is not enough; scientists must also be deeply involved in communicating this science and stimulating an informed scientific debate, not one based on narrow vested interests. It is important to communicate the robust findings as well as provide valid estimates of the uncertainties and to be able to communicate the limits of our scientific understanding to decision makers. Determining and communicating uncertainty is essential for policy makers and something that scientists have to learn to do better.

In addition to providing scientific information, it is equally relevant to develop the tools (for example, for measurement), technologies (for mitigation and adaptation), and advice on management practices to farmers and forestry managers. It is time to shift from working mostly to better define the problem of climate change to helping to find solutions to address the problem. There is still much that is to be understood about the functioning of the ecosystems on which our agriculture, forestry, and wetland management relies, and this certainly requires more research.

While good solid science is essential, it must be done in social and economic contexts. There is a need to have much better understanding of the cost and benefit curves. This is not a trivial undertaking. Estimating the costs of addressing climate change requires having a baseline of how the economy would evolve in the absence of action. Estimating the benefits of taking action by avoiding the impacts requires having a good understanding of the regional or local impacts of climate change, other stresses that might be experienced, and the current adaptive capacity. There is a need for a much more complete examination of the economics of using biological carbon sinks — some analyses suggest that conservation tillage has no real gains for the Prairies (Chapter 18).

However, not everything can be expressed in monetary terms. Sound land management practices are essential for soil conservation, an important goal in itself. Similarly, climate change in some parts of the world, such as the Canadian Arctic, is very likely to threaten the very existence of a people and their culture. Ethical considerations, because of the intergenerational and intercultural aspects, will inevitably feature in any consideration of how best to address climate change.

Some argue that enough is known about the threat of climate change to begin to take action to address it. Indeed, the threat may be graver and the need to take action more urgent that previously thought. It is important to recognize that not all impacts will be negative and there will be opportunities. We need to take a balanced approach. Alarmist comments are not an appropriate response but neither is waiting for all the uncertainties to be resolved before acting.

For agriculture, forestry, and wetlands management, the first stage is to consider how to adapt to the anticipated impacts of climate change, while recognizing that these sectors also make contributions to the emissions of GHGs — they are part of the problem (Chapters 11, 15, 16, and 17). Being prepared will mean in part the development of new technologies and the efficient use of existing and new technologies — technologies for adaptation and for mitigation. These would include new cultivars more suited to the changed climate, techniques to enhance carbon sequestration and reduce disturbances, technologies to take greater advantage of the biosphere, and more energy efficient practices. Adopting these new technologies will position Canada better not only to cope with the change in climate but also to remain competitive in international markets for our crops and products. It is essential to get ahead of the curve.

It is important in tackling climate change to recognize the interactions with human activities. This is more than accepting that most of the observed changes in the climate are a result of human actions, such as fossil fuel burning and land-use changes, and exploring deliberate societal and economic options to lessen this perturbation. It is crucial to understand that there is an inescapable interaction between development and climate change. Similar emissions scenarios can be arrived at through different choices of socioeconomic pathways.[1] Choices include population growth, technology development, and addressing equity differences.

Our present development plans may not only be affected by climate change in the future, but there is also the opportunity to modify these development plans in ways that can also address climate change. Our development choices may exert many pressures on environmental, social, and economic systems in agriculture, forestry, and wetland management. Wetlands are being drained, forests being removed, chemicals being added, new species being introduced and, at the same time, being eliminated. Because of the intricate link between climate and development, it may be difficult to tackle climate change as a single silo issue as has been attempted up to now. Rather, it may be necessary to consider the implications of climate change in every development decision and implementation. This may be the lesson of the Kyoto Protocol.

REFERENCES

1. IPCC, *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.
2. Brklacich, M. et al., Implications of global climatic change for Canadian agriculture: a review and appraisal of research from 1984 to 1997; in *Responding to Global Climate Change: National Sectoral Issue*, Koshida, G. and Avis, W., Eds. Environment Canada, Canada Country Study: Climate Impacts and Adaptation, v. VII, 1219, 1998.
3. Barr, A.G., Black, T.A., Hogg, E.H., Kljun, N., Morgenstern, K., and Nesic, Z., Interannual variability in the leaf area index of a boreal aspen — hazelnut forest in relation to net ecosystem production, *Agric. For. Meteorol.*, 126, 237, 2004.
4. 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 University Press, New York, 2001, chap. 15.
5. Smithers, J. and Smit, B., Human adaptation to climatic variability and change, *Global Environ. Change,* 73, 129, 1997.
6. Reich, P.B. et al., Ecosystem impacts of elevated CO_2, nitrogen deposition, and plant diversity, *Nature*, 410, 809, 2001.
7. 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.
8. IPCC, Report of Experts Meeting on Current Scientific Understanding of the Processes Affecting Terrestrial Carbon Stocks and Human Influences upon Them, July 21–23, Schimel, D. and Manning, M., Eds., IPCC, 2003.
9. Oren, R. et al., Soil fertility limits carbon sequestration by forest ecosystems in a CO_2-enriched atmosphere, *Nature*, 411, 469, 2001.
10. IPCC, *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.

11. Campbell, B.D., Stafford Smith, D.M., and GCTE Pastures and Rangelands Network members, A synthesis of recent global change research on pasture and rangeland production: reduced uncertainties and their management implications, *Agric. Econ. Environ.*, 82, 39, 2000.
12. White, T.A. et al., Impacts of extreme climatic events on competition during grassland invasion, *Global Change Biol.*, 7, 1, 2001.
13. Kimmins, J.P., Importance of soil and role of ecosystem disturbance for sustainable productivity of cool temperate and boreal forest, *Soil Sci. Soc. Am. J.*, 60, 1643, 1996.
14. Hogg, E.H. et al., Factors affecting interannual variation in growth of western Canadian aspen forests during 1951–2000, *Can. J. For Res.*, 35, 610, 2005.
15. Caspersen, J.P. et al., Contributions of land-use history to carbon accumulation in U.S. forests, *Science*, 290, 1148, 2000.
16. Zoltai, S.C., Ecoclimatic provinces of Canada and man-induced climatic change, *Newsletter, Canadian Committee on Ecological Land Classification*. Canadian Forestry Service, Headquarters, Ottawa, 17, 12, 1988.
17. Turetsky, M.R. et al., Current disturbance and the diminishing peatland C sink, *Geophys. Res. Lett.*, 29, 1526, 2002.
18. Wood, S.M. and Layzell, D.B., A Canadian Biomass Inventory: Feedstocks for a Biobased Economy, Prepared for Industry Canada: Contract 5006125. BIOCAP Canada Foundation, 2003. Available online at http://www.biocap.ca/images/pdfs/BIOCAP_Biomass_Inventory.pdf.
19. Gorham, E., Northern peatlands: role in the carbon cycle and probable responses to climatic warming, *Ecol. Appl.*, 1, 182, 1991.
20. Freeman, C., Lock, M.A., and Reynolds, B., Fluxes of CO_2, CH_4, and N_2O from a Welsh peatland following simulation of water table draw-down: potential feedback to climate change, *Biogeochemistry*, 19, 51, 1993.
21. Davidson, E.A., Fluxes of nitrous oxide and nitric oxide from terrestrial ecosystems, in *Microbial Production and Consumption of Greenhouse Gases: Methane, Nitrogen Oxides, and Halomethanes*, Rogers, J.E. and Whitman, W.B. Eds., American Society for Microbiology, Washington, D.C., 1991, chap. 12.
22. Bartlett, K.B. and Harriss, R.C., Review and assessment of methane emissions from wetlands, *Chemosphere*, 26, 261, 1993.

Climate Change and Managed Ecosystems

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CRC Taylor & Francis
Taylor & Francis Group
Boca Raton London New York

A CRC title, part of the Taylor & Francis imprint, a member of the Taylor & Francis Group, the academic division of T&F Informa plc.

Published in 2006 by
CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-10: 0-8493-3097-1 (Hardcover)
International Standard Book Number-13: 978-0-8493-3097-1 (Hardcover)
Library of Congress Card Number 2005028910

Library of Congress Cataloging-in-Publication Data

Climate change and managed ecosystems / edited by J.S. Bhatti ... [et al.].
p. cm.
Includes bibliographical references and index.
ISBN-10: 0-8493-3097-1 (hardcover)
1. Climatic changes. 2. Ecosystem management. I. Bhatti, J. S. (Jagtar S.)

QC981.8.C5C5113823 2006
333.95--dc22 2005028910

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