The Science of Changing Climates
Impact on Agriculture, Forestry and Wetlands

The Canadian Society of Agronomy, Canadian Society of Animal Science, and the Canadian Society of Soil Science organized "The Science of Changing Climates- Impact on Agriculture, Forestry and Wetlands" July 20-23 2004 at the University of Alberta in Edmonton ,Alberta The following is a summary of some of the main invited speakers.

Overall Summary

Henry Hengeveld
Emeritus Associate
Meteorological Service of Canada,
Toronto, Ontario, Canada

Local climate is a major determinant of both the composition and behaviour of a region's ecosystems and of the infrastructure and culture of human society residing within the region. Hence, climatic statistics are an important factor in ecosystem management and planning for socio-economic development. Although decision makers often treat these statistics as a constant, there is clear evidence that climate has, is and will change. Such changes occur naturally and have at times been quite large during the geologic past. However, global climates have been remarkably stable during the current interglacial, resulting in natural climate fluctuations during the past few millennia that have been relatively modest. On the other hand, human interference with the climate system, primarily through land use change and changes in atmospheric composition, is now adding an unprecedented and increasingly dominant force for change. There is convincing evidence that this interference has already caused a substantial increase in global mean temperatures over the past 50 years. Projected changes for the next century will likely exceed anything yet experienced in human history and could rival the magnitude of very large changes during the past million years, but at a much more rapid rate. Such rapid change will have dramatic implications for, *inter alia*, the global hydrological cycle, ecosystem composition and the frequency and severity of extreme weather events.

Ruminant contributions to methane and global warming
– a New Zealand perspective

G.C. Waghorn and S.L. Woodward
Dexcel Limited, Private Bag 3221, Hamilton, New Zealand

Methane accounts for 37% of New Zealand greenhouse (GHG) emissions and recent research has defined the national methane inventory as well as some options for mitigation. Methane inventory calculations are based on animal census, physiological status, feed intakes and methane production/kg dry matter intake (DMI). The New

Zealand farming community supports environmental sustainability and recognises both methane and nitrogen pollution, in part because of publicity surrounding an attempt to levy livestock farmers to fund GHG research.

Mitigation can be expressed in terms of total emissions, a proportion of gross energy intake or in relation to production. Reducing stock numbers to lower total emissions is rarely an acceptable option but improving feed quality can increase performance and profitability as well as reducing GHG emissions per unit of production. The proportion of GHG emissions associated with maintenance is reduced with animals having high intakes of high quality, rapidly digested diets. Diets containing condensed tannins further reduce emissions by about 15%/unit feed intake.

Principal opportunities for short-term methane mitigation include improved feed quality, animal performance and pasture management. Although CH_4/unit feed intake is lower with legume diets compared to grasses, an analysis of data sets from sheep and cattle fed fresh forages showed a poor relationship between CH_4 emissions and chemical composition of the diets. Selection of animals having a high genetic merit, including reproductive performance will minimise CH_4 emissions/ unit of production but an improved understanding of rumen digestive physiology should complement mitigation strategies.

Long-term mitigation strategies include selection of animals with a low CH_4 production/kg DMI, vaccination or use of slow release non-toxic methanogen inhibitors. For example, in a group of 20 animals one is likely to produce about 30% less methane /kg DMI than the group mean, but it is not known if this trait is heritable. Vaccination has reduced CH_4/DMI by 8%, with good potential for greater reductions. Vaccination has wide applicability to animals raised under both intensive and extensive systems. Chemical inhibition with halogenated compounds has reduced methanogenesis by 90% without reducing animal growth rates, and slow release formulations offer good potential for mitigation providing they are non toxic to humans and animals.

Nitrous oxide emissions are dependent on nitrogen inputs from urine, feces and fertiliser and are exacerbated by soil moisture content. Strategic placement of appropriate fertilisers and matching ruminant requirements to feed composition will lessen nitrogen use and nitrous oxide losses.

Practical solutions for GHG mitigation require an integrated assessment of methane, nitrous oxides and carbon dioxide emissions and costs of implementation must not penalise producers. A systems approach is essential to achieve an overall reduction in GHG emissions. One limitation to dietary mitigation is the release of soil carbon with cultivation, so long term GHG mitigation may favor animal selection, management, vaccination, rumen modifiers and appropriate fertiliser use, to balance GHG emissions associated with cropping.

Climate Change and Forest Ecosystems

M. J. Apps[1],P. Bernier[2] and J. Bhatti[3]

1. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Center
2. Natural Resources Canada, Canadian Forest Service, Quebec Forestry Center
3. Natural Resources Canada, Canadian Forest Service, Northern Forestry Center

Earth's climate has changed during the past century and will continue to change significantly over the next few centuries. Despite relatively modest changes of + 0.6 ± 0.2 ^{o}C in global mean temperature so far, ecological impacts and disruptions to human infrastructure are already evident. The Intergovernmental Panel on Climate Change, in its 2001 assessment, concluded that the predicted changes for the next 50 to 100 years are larger and faster than previously thought. The projections are also more certain. Without purposeful mitigation, changes in global mean temperature over the next 100 years will be at the high end of, or even exceed the IPCC 2001 predictions of + 1.4 to 5.8 ^{o}C above the temperatures of the 1990s – itself a decade of record-breaking temperature.

Change, however, has not been, and will not be, evenly distributed over the planet. Climate changes are greatest at mid- to high latitudes and over continental landmasses, where large human populations dwell and rely on ecosystem services for their sustenance. Nor are the changes expected to be simple linear increases in temperature or other climatic variables: abrupt and inherently unpredictable changes (surprises) similar to those seen in the geological record must be expected in the future. The impacts that have already been recorded over the twentieth century will likely intensify over the twenty-first, profoundly affecting natural ecosystems and the services that society has come to depend on.

Thus climate change is arguably the most important environmental issue of the twenty-first century. It will have significant implications for resource management strategies. Are forests and forestry part of the problem or part of the solution? This paper examines the contribution of the forest ecosystems of Canada, and their management to the Earth's climate system.

Human induced climate change is but one component of a larger suite of global change stressors (including pollution, land-use change, and loss of biodiversity) that we have imposed the earth's ecosystems on which we depend. Many indicators can be cited to show the nature of this problem, but perhaps the most telling is the observation by Vitousek and co-workers that humans now control more than 50% of the primary productivity of the planet. There is not much room for further expansion, and small local perturbations can have a global ripple effect. When these local perturbations are mutually reinforcing, as in our individual modifications to the carbon cycle, they can have globally significant impacts. Human induced climate change is the aggregate impact on the climate system by the actions of individuals.

Nowhere are the global change impacts felt more acutely than in northern forests, and the Canadian forest ecosystems are particularly vulnerable – as are the goods and services they supply and on which we have come to take for granted. At first sight this vulnerability is paradoxical since northern forests appear to be well adapted to rapid and large seasonal changes in climatic variables. Indeed, boreal forests have evolved so as to thrive on annual swings between extreme cold winters and often hot summers. In fact, many northern species expect this annual change and use the pronounced seasonality to schedule physiological processes and therein lies at least one source of vulnerability: when this external clock is altered by climate change, the organisms ability to compete for the environmental resources that sustain their growth is affected. The entire ecosystem is effected by the sequence of cascading effects that stem from such disruption of synchrony.

Although the climate change issue is global in both extent and cause, it has components that play through all scales of observation and activity – from the very small and fast, to the global and slow. But *are* the imposed changes slow at the global scale? The unprecedented high rate of global change is a significant part of the problem. Understanding this scaling problem – how small scale changes percolate through to the larger scale, and how large scale changes are expressed at the smaller scale – is a part of the challenge to both science and policy aimed at dealing with the problem, as will be reviewed in this paper and a subsequent one by Bernier and Apps.

One of the most significant notions of the last few decades has been the growing awareness that global change is an earth *systems* problem. Understanding its mechanisms, designing migitigation options and developing adaptation strategies requires looking at the system as a whole. It cannot be understood by focusing on forests, or energy, or human activities, or oceans etc, in isolation, but rather requires the focus to shift to the interactions between these elements. In this paper a few of the mitigation and adaptation options that can be part of the Canadian resource manager's toolbox will be briefly sketched.

STATE OF KNOWLEDGE ON CLIMATE CHANGE AND WETLAND ECOSYSTEMS

Dale H. Vitt, Department of Plant Biology, Southern Illinois University,
Carbondale, Illinois, 62901, U.S.A. e-mail: dvitt@plant.siu.edu

Globally, wetlands represent a large Carbon stock, estimated at 397-455 Pg of Carbon. In boreal and subarctic Canada wetlands form an important component of the landscape and in western Canada store about 48 Pg of Carbon. A large percentage of these wetlands, especially the peatlands of the boreal forest, form deep, extensive deposits of peat and store relatively large amounts of Carbon. These peatlands may be influenced by water that has been in contact with the surrounding upland soils (fens) or may be somewhat raised above the immediate upland soils and receive their water and minerals solely from the atmosphere (bogs). Whereas fens are in general relatively wet, have a shallow acrotelm, and are open or have scattered trees, bogs are comparatively dry, have a deeper acrotelm, and in continental areas always have a well-developed layer of trees. *Sphagnum* mosses dominate bogs and the more acidic fens. Permafrost is traditionally thought to be restricted to high and low arctic climatic zones where it dominates both upland and wetland soils, forming a continuous layer of frozen soil. Farther south, under subarctic climates, permafrost becomes discontinuous and in these climates is largely restricted to organic soil deposits forming continuous permafrost within peat plateau landforms. Boreal peatlands have isolated ice lenses that may or not coalesce. These peat-forming ecosystems have accumulated Carbon since the mid-Holocene at an estimated rate of 24.5 g C/m^2/yr; however, the natural fire regime reduces the actual Carbon accumulation rate to about 19.4 g C/m^2/yr. Additionally, Turetsky et al. (2002) estimated that under the present disturbance regime 13% of the boreal peatlands are affected by recent disturbance and that Carbon uptake in continental peatlands is reduced by 85% when compared to a non-disturbance scenario. Contemporary levels of disturbance and development across the boreal region have reduced the Carbon accumulation rates to 3.6 g C m^2/yr. Thus, these estimates reveal that present day peatlands are minimally Carbon sinks.

Since the Little Ice Time that ended in the late 1800's, temperatures have gradually increased. There is increasing evidence that this natural warming pattern is exacerbated by Global Warming. Additionally, precipitation over the past 50 years has decreased across the southern boreal (Fig. 1). Warming coupled to drought will affect permafrost, water levels, and nitrogen availability. Thus the high landscape cover of peatlands, the large amount of Carbon contained in organic soil, the strong effects of warming on nitrogen and water cycles, and the extreme sensitivity of NPP and NEE to small additional changes in climate make these key ecosystems. Organic matter stored in these long term sinks, if released through additional warming and drought could add up to 200 ppm CO_2 to the atmosphere. Thus stability of this large Carbon reservoir should be a priority.

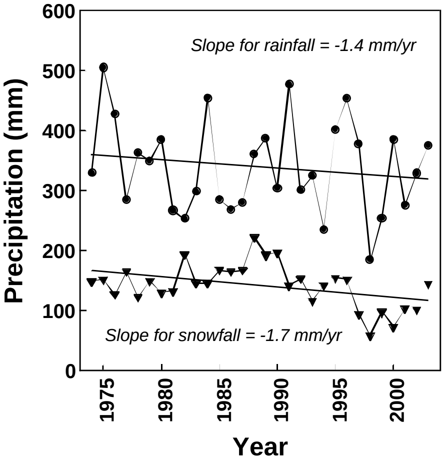

Figure 1. Thirty year directional decreases in rainfall and snowfall at Ft. McMurray, Alberta

This presentation will examine four potential effects of warming and associated drought using a variety of approaches. 1) Current permafrost melting across the boreal and its affects on Carbon accumulation -- an empirical approach (Halsey et al. 2000, Turetsky et al. 2000). 2) Current displacement of peatland species -- a response surface modeling approach (Gignac et al. 1991; Gignac & Vitt 1994; Gignac et al. 2000). 3) Past ecosystem sensitivity to climate and global interaction of peatlands and Carbon (Yu et al. 2003). 4) Current observations and research -- dead fens, stagnant bogs, wild fire, and plant succession (B. Benscoter, R. K. Wieder, D. H. Vitt, pers. comm.).

These studies, both past and present, clearly indicate that peatlands are among the most sensitive boreal ecosystems, and of great concern is the loss to the atmosphere of their large Carbon pool if drought, disturbance, and warming continue to accumulate and to increase. In particular, the net ecosystem exchange of Carbon is the balance between

Carbon uptake by plants (photosynthesis) and the release of Carbon by plants and microbes (respiration). On an annual basis the rates of these two processes determines whether a peatland is a source or a sink of Carbon to the atmosphere. It is possible that little can be done to protect this large old Carbon pool from being lost as a source of CO_2 to the atmosphere; however, the following may provide some guidance to mitigation. The first order priority should be the protection of the large Carbon pool by attempts in maintenance of high water tables and reduction of nutrient influxes through:
--reducing disturbance to bogs.
--protecting bogs from wildfire.
--not draining or reducing water tables for areas rich in fens.
--retention of boreal peatlands in their natural state.
--allowing adequate buffer zones around large complex peatland areas when uplands are disturbed.

Knowledge gaps and challenges involving the mitigation of greenhouse gases emissions from agriculture systems under climate change.

Jilene Sauvé, Alberta Agriculture, Food and Rural Development and David Burton, Nova Scotia Agriculture College.

The Agriculture and Agri-Food Table of the National Climate Change Process identified current knowledge gaps as one of the significant impediments for developing an action plan in response to Kyoto. Since that time there have been several programs undertaken to identify and address these research gaps. These include the Climate Change Funding Initiative in Agriculture, the Alberta Greenhouse Gas Science Plan and the Biological Greenhouse Gas Sources and Sinks Program. This presentation we will identify the research efforts undertaken as part of these programs and the remaining knowledge gaps they have identified.

Climate Change Funding Initiative in Agriculture – This program focused on human resource development and the funding of projects targeted at knowledge gaps identified in the Agriculture and Agri-Food Table Options Report. The program funded 12 research programs and 60 graduate students wholly or in part. The major findings of the program, as summarized in a recent wrap up workshop in Winnipeg, will be summarized.

Development of the Alberta GHG Science Plan – Alberta Agriculture, Food and Rural Development and Alberta Agricultural Research Institute jointly funded this project. This process started in March 2000 when the agriculture community determined the need for an On-Farm GHG Assessment Tool because “you can’t manage what you can’t measure”. Over 2 600 scientific papers and publications were examined, organized into a bibliographic database and summarized into a preliminary “State of Knowledge” report on agriculture GHG research. This report identified gaps in current GHG research and was the basis for an Agriculture GHG Science Planning Workshop in June 2003 (Canmore I). The gaps identified were confirmed and prioritized by scientific experts from across Canada and were included in a report titled "*Development of a Farm-Level Greenhouse Gas Assessment: Identification of Knowledge Gaps and Development of a Science Plan*". Progress since the publication and distribution of the report and results from a follow up workshop (Canmore II) will be presented.

Biological Greenhouse Gas Sources and Sinks – Agriculture and Agri-Food Canada funded this collaborative program targeted at fundamental knowledge gaps in our understanding of GHG production and carbon sequestration in agroecosystems. In total 20 graduate students, co-supervised by Agriculture and Agri-Food Canada scientists and university scientist have been supported.

Knowledge gaps and challenges in forest ecosystems under climate change

P.Y. Bernier and M.G. Apps
Natural Resources Canada, Canadian Forest Service

A strong consensus has emerged from the Third Assessment Report from the IPCC that anthropogenic green house gas emissions are affecting the earth's climate. Atmospheric CO_2 will likely double from present within the next century, and global temperatures will increase by at least 1 to 2ºC or even more. Models predict that these effects will be least in tropical latitudes and greatest in northern latitudes. This last point is particularly important because the boreal forests are thought to hold 30-50% of the world's forest carbon. Direct and indirect effects of climate change are likely to modify the dynamics of carbon uptake and release from these ecosystems. Also, as a more short-term concern, these forest are a source of wealth to many national economies. However, mitigation and adaptation options to climate change can be developed only when climate-forests interactions are quantified with enough certainty for risk assessment.

The present review looks at current uncertainties in our knowledge concerning forest vulnerability to climate change by asking three critical questions: How are current and projected changes in climate and atmospheric composition affecting growth and ecosystem processes? Are forest ecosystems presently responding to current changes? What changes can we expect in our forests in the future? The first question deals with process studies on the direct effects of increases in atmospheric CO2 and temperature, as well as changes in precipitation regime. The second question deals with monitoring of on-going changes, trying to see the "invisible present" and using modelling studies to factor out the effect of individual forcing factor. The last question deals with forecasting change in the state of the forest. The review shows that significant progress has been made on the understanding of environmental regulation of photosynthesis, of factors controlling the carbon dynamics of forest stands, and of linkages between the inter-annual variability of climate and of disturbances. At the forefront of current research are scaling methods and procedures that can account either implicitly of explicitly for the spatial or temporal variability of forests and processes. The larger challenge ahead is to develop methods that integrate information at all scales, and to derive methodologies for quantifying errors in predictions and large scale assessments.

Over the past decade or so, major research projects have been undertaken at local, regional, national and global scales to study specific aspects of forest dynamics as they relate to direct or indirect consequences of climate change, and to provide partial answers to the questions raised above. Examples are the BOREAS and LBA projects in the Canadian boreal forest and in the Amazon, FACE projects in the US and elsewhere, Canada's Large Fire Database, ecosystem research stations such as Sweden's Flakaliden, flux tower networks in many countries around the world, and satellite programs for global monitoring of key vegetation attributes. At the forefront of current research are scaling methods and procedures that can account either implicitly of explicitly for the spatial or temporal variability of forests and processes. Inverse modelling of CO_2 sinks and sources at continental scales, stable isotope research and satellite-driven estimates of productivity are examples of such fields.

Linking biosphere carbon management to biomass energy.

David Layzell and Jamie Stephen, BIOCAP Canada Foundation

Plants have been in the business of managing greenhouse gases and solar energy for hundreds of millions of years. Therefore, it is not surprising that concerns about climate change and energy security have greatly increased the interest of industry, government and researchers in the possible role that Canada's vast forests and farmlands could play in reducing both greenhouse gas emissions and fossil fuel demand.

A major science-policy focus in recent years has been on how to enhance and quantify carbon stocks in agricultural and forest ecosystems to provide an 'offset' sink for fossil fuel emissions. The biomass created through this process provides only a temporary sink since it will eventually return to the atmosphere through metabolism, decomposition or combustion. At such a time, it will need to be replaced with other emission reductions or carbon sinks.

This paper will explore the potential of coupling increases in biomass carbon stocks and new biomass production to the use of biomass as a renewable and sustainable source of energy. What are the conversion factors? How many MW of electrical power or millions of litres of fuel ethanol could be obtained from a biomass resource that is equivalent to that which Canada hopes to sequester in the first Kyoto commitment period? What is the potential for biomass energy production using existing waste carbon streams, through

more intensive forest management practices or through the use of biomass crops on unused farmlands?
An attempt will be made to develop a model for a multi-decadal strategy that links biosphere carbon management to the sustainable production and use of biomass as a renewable energy resource.
The paper will end with a summary of some of the challenges associated with realizing these biomass energy opportunities, and suggestions regarding the role that research can play in helping to develop biosphere solutions to the challenges of climate change.

KNOWLEDGE GAPS AND CHALLENGES IN WETLANDS AND OTHER AQUATIC ECOSYSTEMS UNDER CLIMATE CHANGE

Barry G. Warner and Taro Asada,
Wetlands Research Centre,
University of Waterloo,
Waterloo, Ontario N2L 3G1
Email: bwarner@uwaterloo.ca

There have been many major environmental disasters in recent years in Canada known to be the direct consequence of human activities. Many of these issues have revolved around water, which in turn, can be linked to wetlands. Canada continues to be challenged in developing adequate management and conservation strategies around water and wetlands despite decades of significant progress. We have a common and accepted definition for wetlands and a recognition of them as discreet units in the landscape mosaic. A classification system provides the basis of a common taxonomy for describing wetlands, yet despite 20 years in the making, the system requires refinement and expansion to include all wetlands in the country. Our inventories on the extent and distribution of wetlands are incomplete. The new remote imagery being collected provides a starting point for checking and modifying old inventories, but it is not a substitute for the necessary work needed in the field for a complete and useful inventory of our wetland resource. There needs to be a greater appreciation of the direct linkages between wetlands and water, and the role of wetlands in preserving water quantities and qualities. More focus is needed on how and why wetlands fit into the complex landscape mosaic, both with respect to their immediate adjacent landscape units and the whole landscape within watersheds. We have not adequately identified what the wetland management problems are and that many wetland management problems are water management problems. Only having done so will it then be possible to identify the probable causes and the necessary solutions. Wetland ecotechnology, the restoration and creation of wetlands, offers great potential yet we have only a rudimentary appreciation of the relationships between design, wetland process, and the longer-term viability of the technology. Human-induced changes to climate will continue to exacerbate extremes that will lead to more environmental disasters in the future unless we gain a better awareness and appreciation of wetlands in the landscape and of the wetland and water relationship.

CLIMATE CHANGE AND TERRESTRIAL CARBON SINKS: ECONOMIC AND POLICY ISSUES

by
Richard M. Adams
(Oregon State University)
and
G. Cornelis van Kooten
(University of Victoria)

Climate change and mechanisms to mitigate its potential effects have attracted considerable economic and policy attention. The purpose of this paper is to provide an overview of economic reasoning and options that may be applied to the issue of climate change. Attention is focused on the economic consequences of climate change and the feasibility of terrestrial carbon sinks to slow the rate of CO_2 buildup in the atmosphere. Specifically, the first part of this presentation reviews previous economic estimates of the impacts of climate change, including effects on agriculture and forestry. The second part addresses the economic potential for these two sectors to sequester atmospheric carbon and thus reduce the economic effects of the buildup of CO2 in the atmosphere.
 Economists favor a tax on greenhouse gas emissions if little is known about the marginal costs of mitigating climate change, and a quantity instrument (maximum emissions) if marginal costs are well known. While the tax may be preferred, some policy options, such as the Kyoto process, employ a quantity instrument. Two such quantity instruments are available: permit (allowance) trading that relies on the authority to establish an international or national cap on emissions, and credit trading. We review the merits of each and discuss their implications with respect to carbon sinks.

We also examine the results of several empirical studies into the costs of carbon uptake – by agricultural ecosystems and by forestry. For example, Manley et al. (2004) examined the costs of creating soil carbon sinks by switching from conventional to zero tillage. The viability of agricultural carbon sinks was found to vary by region and crop, with no-till representing a low-cost option in some regions (costs of less than $10/tC), but a high-cost option in others (costs of $100-$400/tC). A particularly relevant finding is that no-till cultivation may store no carbon at all if measurements are taken at sufficient depth. In some circumstances no-till cultivation may yield a “triple dividend” of carbon storage, increased returns and reduced soil erosion, but in many others creating carbon offset credits in agricultural soils is not cost effective because reduced tillage practices store little or no carbon. This is particularly the case in the Great Plains. In another study Van Kooten et al. (2004) reviews estimates from 55 studies of the costs of creating carbon offsets using forestry. Lowest costs of sequestering carbon are through forest conservation, while tree planting and agroforestry activities increase costs by more than 200%. The use of marginal cost estimates instead of average cost results in much higher costs for carbon sequestration, in the range of thousands of dollars per tC, although few studies used this more-appropriate method of cost assessment.

We conclude by making the case that there remains a great potential for carbon sinks. In particular, more attention needs to be paid to post-harvest. In the above research, post harvest storage of carbon in wood products yielded much lower cost estimates. Further, it is important to investigate the economics of bio-oils from wood fiber and biomass electricity generation, particularly in the context of fire control.