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气候变化
CLIMATE CHANGE

适应能力建设
Building the Adaptive Capacity

AN INTERNATIONAL CONFERENCE ON ADAPTATION SCIENCE, MANAGEMENT AND POLICY OPTIONS

MAY 17-19, 2004

LIJIANG, YUNNAN, CHINA

Edited by:
Adam Fenech, Don MacIver
Heather Auld, Robin Bing Rong
and Yongyuan Yin

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PREFACE

An international group of more than 100 invited people gathered in Lijiang, China in May of 2004 to discuss what may be the most ongoing threat to humanity over the next 40 years – climate change. The international body of thousands of scientists known as the Intergovernmental Panel on Climate Change has concluded that climate change is occurring, and results in a set of diverse and regionally-specific impacts on natural ecosystems and human societies. The Panel says that while climate mitigation strategies are necessary to reduce greenhouse gas emissions from anthropogenic sources, those alone are unlikely to be sufficient to eliminate the negative impacts of climate change. The impacts of climate change from emissions of greenhouse gases over the past 150 years will have to be confronted by all countries now. Therefore, pursuing a complementary strategy of enabling countries to adapt to climate change and negate many of the expected adverse impacts is equally, if not more, urgent.

The international conference, and this collection of peer-reviewed papers from that conference, is one step in addressing that urgency to build our adaptive capacity, that is, our ability to respond to changes in climate and reduce our vulnerability to the negative consequences.

The conference assisted in:

- showcasing the most recent science, management and policy options available in the climate change adaptation community;

- strengthening the capacity of key Chinese institutions, and sectors such as agriculture, to identify and assess the sensitivities and vulnerabilities associated with climate change;

- promoting the integration of adaptation strategies into Chinese government development and planning initiatives; and

- enhancing the adaptive capacity of Chinese agencies to employ techniques, tools and approaches to climate change adaptation.

We hope that you enjoy this collection of peer-reviewed papers. The papers are organized in this book around the themes of the conference including the keynote paper on the adaptation deficit; Canada-China Collaboration in Adaptation to Climate Change Research; Climate Change Impacts, Indicators and Assessments; Agriculture; Energy, Infrastructure and Growth; and Ecosystems and Biodiversity.

As the head organizers of this conference, we wish to thank the attendees, our kind hosts and the wonderful administrators who handled all of the logistics. And finally, thanks to the editors of this book, who quickly published these papers so that they may stand as a continuing contribution to our attempts collectively to build our adaptive capacity.

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chapter I

CLIMATE CHANGE:
BUILDING THE ADAPTIVE CAPACITY

paper 1

CLIMATE CHANGE:
BUILDING THE ADAPTIVE CAPACITY

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ABSTRACT: Canada and China co-hosted an international conference titled *Climate Change: Building the Adaptive Capacity* in Lijiang, Yunnan, China from 17-19 May 2004 on climate change adaptation science, management and policy options. This paper outlines the objectives of the conference, and provides brief introductions to each of the papers found in this peer-reviewed book. Each paper falls under one of the six themes: the keynote paper by Burton (2004) on the concept of an adaptation deficit; Canada-China Collaboration in Adaptation to Climate Change Research; Climate Change Impacts, Indicators and Assessments; Agriculture; Energy, Infrastructure and Growth; and Ecosystems and Biodiversity.

Keywords: climate change, adaptation, Canada, China, adaptive capacity

1. Introduction

Canada and China co-hosted an international conference titled *Climate Change: Building the Adaptive Capacity* in Lijiang, Yunnan, China from 17-19 May 2004 on climate change adaptation science, management and policy options. About 100 people met to hear experts share their global knowledge about adaptation to climate change with representatives from key international, Canadian and Chinese institutions, agencies and sectors. The conference assisted in:

- showcasing the most recent science, management and policy options available in the climate change adaptation community;
- strengthening the capacity of key Chinese institutions, and sectors such as agriculture, to identify and assess the sensitivities and vulnerabilities associated with climate change;

- promoting the integration of adaptation strategies into Chinese government development and planning initiatives; and
- enhancing the adaptive capacity of Chinese agencies to employ techniques, tools and approaches to climate change adaptation.

The conference program included keynote addresses from invited speakers such as Ian Noble, advisor on climate change adaptation to the World Bank; Richard Moss, director of the US Global Change Research Program; Ian Burton, president of the International Society of Biometeorology; Lin Erda, the Chinese Academy of Agricultural Sciences; Yongyuan Yin, researcher with the Meteorological Service of Canada; David Warrilow, UK Department of Environment, Gerry Metcalf, UKCIP, and Don MacIver, director of the Adaptation and Impacts Research Group, Meteorological Service of Canada. Sessions were held on developing and applying climate scenarios for adaptation science; adaptation science assessments; vulnerability and adaptation to climate change in socio-economic sectors; synergies and integration; integrated assessments and policy; and case studies on the Canada-China Cooperation in Climate Change (C5) Project; and the Integrated Assessment of Vulnerabilities and Adaptation to Climate Variability and Change in the Western Region of China (AS25) Project.

The conference marked the final reports from the adaptation science section of the CIDA-funded project titled *Canada-China Cooperation in Climate Change (C5),* as described in a subsequent paper of this book from the Conference, whose overall goal is to contribute to Canada's international climate change objectives, help China better address the issue of climate change while at the same time contributing to sustainable development and poverty reduction within the country.

The co-sponsors of the conference were many, and include: Assessments of Impacts and Adaptations to Climate Change (AIACC); United Nations Environment Program (UNEP); System for Analysis, Research and Training (START); Third World Academy of Sciences (TWAS); Canadian International Development Agency (CIDA); Chinese Meteorological Administration; China State Development and Reform Commission; Chinese Academy of Agricultural Sciences; International Society of Biometeorology; The Canada-China Cooperation in Climate Change (C5) Project; the Integrated Assessments of Vulnerabilities and Adaptation to Climate Variability and

Change in the Western Region of China (AS25) Project; Natural Resources Canada and the Meteorological Service of Canada, Environment Canada.

2. Building Adaptive Capacity to Climate Change

Climate change will result in a set of diverse and regionally-specific impacts on natural ecosystems and human societies. A growing literature suggests that while climate mitigation strategies are necessary to reduce greenhouse gas emissions from anthropogenic sources, those alone are unlikely to be sufficient. As studies have shown, the impacts of climate change from previous emissions of greenhouse gases over the past 150 years will have to be confronted by all countries. Therefore, pursuing a complementary strategy of enabling countries to adapt to climate change and negate many of the expected adverse impacts is equally, if not more, urgent (Adger and Kelly, 1999; Burton et al., 2002). To determine how countries are equipped to deal with the inevitable impacts of climate change requires an understanding of each country's adaptive capacity. A country's adaptive capacity is its talent and willingness to take the initiative in making adjustments to reduce the negative impacts of climate change. Fundamentally, adaptive capacity is the ability to respond to climate changes and then to initiate responses to these climate changes.

Adaptive capacity in ecological systems is related to genetic diversity, biological diversity, and the heterogeneity of landscape mosaics (Carpenter et al., 2001; Peterson et al., 1998; Bengtsson et al., 2002). In social systems, the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem-solving and balance power among interest groups play an important role in adaptive capacity (Scheffer et al., 2000; Berkes et al., 2002). Systems with high adaptive capacity are able to re-configure themselves without significant declines in crucial functions in relation to primary productivity, hydrological cycles, social relations and economic prosperity.

Adaptive capacity can be best understood with reference to vulnerability and resilience (Dayton-Johnson, 2004). Vulnerability is the tendency for people, ecosystems, communities, etc. to be damaged; while resilience is the opposite of vulnerability, and refers to the ability of people, ecosystems, communities, etc. to resist or recover from damage. Vulnerability and resilience are two sides of the same coin (SOPAC, 2004). Something is vulnerable to the extent that it is not resilient.

This international conference examined the building of adaptive capacity in China. One important aspect of that capacity is the information provided in the book from the Conference.

3. The Collection of Peer-Reviewed Papers

The primary role of this conference, and the title of the conference itself, refer to building the adaptive capacity to climate change. One major initiative to build capacity is in providing knowledge. This peer-reviewed collection of papers from the conference presents concepts, ideas, tools and other resources for assisting China, and in fact all countries, in adapting to the impacts of climate change.

The papers are organized in this book around the themes of the conference including the keynote paper on the adaptation deficit; Canada-China Collaboration in Adaptation to Climate Change Research; Climate Change Impacts, Indicators and Assessments; Agriculture; Energy, Infrastructure and Growth; and Ecosystems and Biodiversity.

3.1 The Keynote Paper – The Adaptation Deficit

The keynote paper is provided by Burton (2004). Burton introduces the concept of an adaptation deficit. Two types of adaptation are identified in the paper - Type I Adaptation, the everyday adaptation to weather and climate that has always been a feature of human life; and Type II Adaptation, the adaptation mandated under the UN Framework Convention on Climate Change (UNFCCC). Type I Adaptation is promoted as part of sustainable development, while Type II Adaptation relates to anthropogenic climate change and is subject to the rules and practices under the Convention. The two types of adaptation are similar but not identical. Type I Adaptation has traditionally assumed a stationary climate, and in Type II Adaptation, the climate is changing and the international community has a cost-sharing responsibility under the UNFCCC.

Burton suggests that there is a need to bring about a single seamless process of adaptation as Type I Adaptation has not been working very successfully considering that the losses from extreme weather and climate-related events are rising rapidly. This failure of current adaptation to keep pace with development is what Burton calls the adaptation deficit. Type II Adaptation could be developed under the Convention to help eradicate the adaptation deficit. This would require the development of a more formal adaptation regime under the Convention similar to the mitigation (Kyoto) regime that already exists. The paper concludes that, one, there is an unacceptably large and growing adaptation deficit; two, the adaptation deficit can be more effectively addressed by combining the UNFCCC work with the development process and mainstreaming climate risk; and three, by developing a more coherent and operational adaptation regime, there will be more confidence that the efforts to adapt to a changing climate will be rewarded with success.

Burton's keynote paper is followed by four short discussions that further the adaptation concept including Bass (2004) on measuring the adaptation deficit; Etkin (2004) on natural disasters and the growing gap of vulnerability; Fenech (2004) on natural capital and the adaptation deficit; and Mirza (2004) on addressing the adaptation deficit through funding.

3.2 Canada-China Collaboration in Adaptation to Climate Change

The second theme of Canada-China Collaboration in Adaptation to Climate Change begins with a linkage paper by MacIver (2004) on mainstreaming adaptation and impacts science into solutions. MacIver identifies the scientifically-sound knowledge, information, data, models, maps and policy strategies that have been used by the Adaptation and Impacts Research Group (AIR Group) of the Meteorological Service of Canada, Environment Canada over the past decade. MacIver views the adaptation process as an iterative, non-linear cycle that involves multi-disciplines, multi-agencies and all Canadians. MacIver presents the stages leading to adaptation outcomes including the knowledge creation and sharing process that involves scientific, technological, institutional, behavioral, political, financial, regulatory, and/or individual adjustments to the changing climate.

Jasmin et al. (2004) present a description of the successes of the Canada-China Cooperation in Climate Change (C5) Project funded under the Canada Climate Change Development Fund (CCCDF) of the Canadian International Development Agency (CIDA). C5 is organized around four components: awareness and outreach, national communication, adaptation and impacts and clean development mechanism. Jasmin details the most significant benefits of the C5 Project as an increased ability for China to address the issue of climate change (from emissions reductions through to adaptation), and the improved abilities for Chinese organizations and individuals to make decisions and take action that include climate change considerations.

Yin (2004) presents the integrated assessment approach designed for the project titled Integrated Assessment of Vulnerabilities and Adaptation to Climate Variability and Change in the Western Region of China, known as the AS25 project, a sub-project of the Assessments of Impacts of and Adaptation to Climate Change in Multiple Regions and Sectors (AIACC). The case study is the Heihe River Basin of China that provides an example of the integrated approach as an effective means for climate vulnerability assessment and the synthetic evaluation of the general desirability levels of a set of adaptation options through a multi-criteria and multi-stakeholder decision making process.

3.3 Climate Change Impacts, Indicators and Assessments

The third theme of Climate Change Impacts, Indicators and Assessments begins with a paper by Clinton et al. (2004) that provides an approach for quantitatively synthesizing the concepts of risk, impact, sensitivity and vulnerability with regard to climate change. Clinton et al. review approaches for the formulation of indicators for agricultural, water resources and socioeconomic vulnerability to climate change in the Heihe River Basin, an arid region of North West China. Quantitative issues involved with indicator formulation, computation and geographic allocation are discussed in this paper, with methods of fuzzy set construction finally proposed for continuous, categorical, and qualitative indicators.

Cohen (2004) presents work on a collaborative study of climate change and water management in the Okanogan region of British Columbia, Canada. An interdisciplinary approach is used, incorporating participatory processes as part of the research on regional adaptation experiences and consideration of future responses. Results of the hydrologic and water demand research efforts indicate that future climate changes are likely to result in reduced water supply, increased water demand, and an increased frequency of high risk years in which high demand and low supply occur concurrently. The Okanogan region has experienced droughts in recent years, and several communities and water purveyors have initiated measures to manage water demand. Cohen suggests that future climate change will require a portfolio of supply and demand measures, and needs to be considered as part of a basin-wide strategy that integrates with regional development plans.

Zhang et al. (2004) explores the relationship between climate change and war in China, by comparing high-resolution paleoclimatic reconstructions with the known incidence of war in China over the past millennium. The authors demonstrate a remarkable correlation between climate change and the incidence of war. Zhang et al. shows that wars broke out more frequently during cold phases, and suggest that the reduction of the thermal energy input during cold phases resulted in the shrinking of livelihood resources in the traditional agrarian society, which in turn led to armed conflicts or wars between states, tribes and peoples on the lands with different carrying capacity.

Bass and Etkin (2004) discuss whether climate change adaptation should focus on the use of existing, and the development of new, technologies or whether it should focus on the root causes of vulnerability - behavioural change and risk perception. The technological fix arguments are that resources should be put into promoting existing technologies that have been shown to be effective but underutilized, and the development of new technologies. The behavioural technique argues that behavioural change is essential, and the notion that one must choose either a technological or a behavioural solution is a false dichotomy. The paper concludes that technology will undoubtedly play a large and important role in climate change adaptation, but by itself is not sufficient to solve the adaptation problem. Behavioural changes are necessary as well - indeed they are likely to be the more crucial factor.

Bass (2004a) presents an interesting paper using an agent-based simulation model to conduct a large number of experiments, underlying the research into artificial life simulations and Holland's work with genetic algorithms and classifier systems. The research is based on the simulation platform, Complex Organization and Bifurcation Within Environmental Bounds, or COBWEB. COBWEB simulates how a system of autonomous agents adapts to variation and sudden changes in the resource base. COBWEB was set up as a generic system of agents in an environment, but can be configured to represent an ecosystem or a social system. In COBWEB, when the population is well adapted to its environment, an increase in resources is followed by an increase in population, which in turn is followed by decreasing resources, that is, the predator-prey pattern in ecology.

In environmental change experiments conducted for this paper, the system was most sensitive to changes in the energy cost of activities, particularly movement, and the amount of energy available from resources. This was highlighted in two sets of experiments designed to mimic invasive species and the response of the system to climate change, expressed as a change in the length of seasons. COBWEB also allows for experiments with communication and memory. A series of experiments was conducted with very low rates of resource production, in other words, a resource scarcity. Without communication, all of the agents died out. With communication, the probability of survival for the whole population increased by 50 percent. The simulations highlighted the characteristics of a well-adapted system and the importance of threshold values, energy, communication and memory in adapting to variability and change. A system that is well-adapted to its current environmental variability is characterized by a balance between population and resources that is quite resilient to minor changes in various parameters that define its environment. However, at the margins, there are threshold values which, when crossed, produce more significant changes. This paper demonstrates that adaptation to change was far more likely to be successful if the available energy was increased or remained constant although the impact could be somewhat mitigated throuh inceasing the level of communication. More importantly, these experiments raise the question as to the speed of innovation required to develop new strategies to adapt to change.

3.4 Agriculture

The fourth theme on agriculture has three papers, the first of which is Rong et al. (2004) selecting socio-economic indicators to examine the adaptive capacity of Northeastern China to the impacts of climate change on agriculture. The approach is focused directly on the underlying determinants of adaptive capacity. The analytic hierarchy process (AHP) method is used to prioritize indicators to assess the potential contributions of various aspects to the systems coping capacities. Indicators are compared and analyzed. Web-mapping technology is introduced to visualize and disseminate the results.

Fang et al. (2004) study the impact of past climate warming to crop yield to understand how climate change is impacting agriculture. However, it is difficult to separate the contribution of climate change and human activities because of the traditional means of calculating real yield, trend yield and fluctuant yield of rice crops. The main disadvantage of the traditional method is that it could not show the contribution of a climatic trend to the yield trend. In this paper, a new method is put forward to calculate a yield with a climate trend. In the new method, a reference period that satisfies the hypothesis of the traditional method is selected to construct a function on the dominant meteorological factor and climate influence coefficient by regression. The function can be used to calculate the climate's influence coefficient of other years. A case study on the contribution of climate change to rice yield change from 1952 to 2000 is made for this region. The results show that, although non-climatic forces have likely dominated the trends in rice per unit area yield in Heilongjiang province, the impact of climate warming on rice production becomes more and more prominent during the past 20 years. The real rice yield per unit area in the 1980s is 30.6 percent higher than that in the 1970s. The increased yield due to a warming climate was from about 12.8 to 16.1 percent of the real increased yield. The real rice yield per unit area in the 1990s is 42.7 percent higher than that in the 1980s. The increased yield due to warming climate was about 23.2 to 28.8 percent of the real increased yield.

Wang et al. (2004) calculate the average and standard deviation of the accumulated temperature from May to September for the period 1960-1999 in Northeast China. The result shows that the heat resource in almost all of Northeast China increased during this time period. According to the quantitative relation between the heat resource and rice yield per-unit-area of different rice varieties, a model is established to calculate the expected rice yield per-unit-area. The authors found that climate warming increased rice production in the Heilongjiang and Jilin provinces of China, and reduced rice production in most areas of Liaoning Province, China. So the impact of climate warming on crop yield and structure in China should not be ignored, though it is often credited to technology and economic benefit.

3.5 Energy, Infrastructure and Growth

In the fifth theme on Energy, Infrastructure and Growth, Auld and MacIver (2004a) provide evidence from around the world indicating that the costs of weather related disasters are increasing over time. In many cases, these weather-related disasters have resulted from the failure of our infrastructure and built environment to cope with extreme weather events, environmental degradation and the location of infrastructure in high risk locations. While debate still continues on whether or not climate variability and weather extremes have increased, other evidence suggests that vulnerabilities to climate events likely have increased. Auld and MacIver suggest that reducing societal vulnerability to weather related disasters under current and changing climate conditions will require a diverse and interconnected range of adaptive actions. These actions include hazard identification and risk assessment, comprehensive disaster management, improved predictions of high impact weather, better land use planning, strategic environmental and ecosystem protection, continuously updated and improved climatic design values for disaster resistant infrastructure codes and standards, more enforcement of building codes and improved structural design methods and materials. Steps taken today to reduce the impacts of weather hazards will provide new opportunities to learn how to better face the challenges of the future. The authors conclude that while several adaptation steps, both structural and non-structural, can be undertaken today to ensure that communities can withstand the climate of the future, other adaptation actions will be limited by considerable uncertainty in projections on future extremes and by the difficulties of retrofitting or changing the existing built environment.

Mirza (2004) focuses on the impacts of climate change on the Canadian energy sector, specifically the vulnerability of the power generation, transmission and distribution components to extreme weather events. Power output loss due to low lake levels on the Great Lakes in 1964 was estimated at 4.4 million Megawatt hours. During the ice storm of 1998 in eastern Canada, power transmission and distribution suffered a total insured loss estimated at CAN$3 billion. The damage to high voltage transmission towers, distribution systems and transformers raised serious questions about the robustness of the power distribution systems in Ontario and Québec. In general, the measures to cope with the situations were found to be inadequate. The author points to the future possibilities of more heat waves, ice storms and drought conditions in Canada due to climate change. Therefore, the energy sector may become more vulnerable unless adequate adaptation measures are designed and implemented.

Chiotti et al. (2004) explore the important role that the production and use of energy in a more sustainable manner can serve as an effective integrated response to climate change, specifically the role of energy efficiency and energy from renewables. The paper draws upon secondary and primary research and highlights similarities and differences in Canada and China. The authors focus on three policy priority areas if progress is to be made on accelerating the development of renewable energy and energy efficiency. First, it is necessary to level the playing field, which currently favours the conventional centralized energy systems for electricity generation, and invest in renewable energy sources in the same way. Second, it is necessary to invest in innovative technologies for renewable energy and energy efficiency to ensure future market readiness for emerging technologies. And thirdly, it is necessary to engage a wide range of decision-makers and the public in achieving this vision, particularly at the community level. In the case of China, the authors suggest that the solution may be to build on the trend of decoupling economic growth from energy consumption and adopt a normative approach to energy production and use that accepts economic growth as a necessary but not a sufficient condition.

Auld and MacIver (2004b) focus on the vulnerability of infrastructure to climate change through gradual changes in weather patterns and through increasing variability and potential increases in extremes. Climate change will affect the safety of existing structures, potential for weather disasters, design criteria and engineering of future structures and potential for premature weathering of all structures. Because infrastructure built in current times is intended to survive for decades to come, it is critically important that adaptation options to climate change be developed today and implemented as soon as possible. The climate change adaptation actions that will likely be required in future will be significant and numerous. At the same time, infrastructure will also be required to contribute to climate change mitigation actions.

The first step will be to identify gaps in current capacity for addressing climate variability and extremes. Such "no regrets" adaptation actions are available today and include measures such as enforcement of engineering codes and standards, efforts to reduce uncertainties in climatic design values and to update calculations, maintenance of the quality and length of climate data records and networks, consistent forensic analyses of infrastructure failures, regular maintenance of existing infrastructure and community disaster management planning. Where updated information is not available, the implementation of a Climate Change Adaptation Factor may provide an option to address deficiencies in existing design criteria conditions and to allow for projected trends in future climate conditions. Where the impacts of the future climate lie outside of existing experience and the coping ranges of infrastructure, adaptation options will need to be developed over time through "adaptation learning", along with better pre-disaster planning. Climate change adaptation will require that planners, their agencies, the engineering community and community decision-makers consider timeframes beyond statutory requirements and even beyond the lifetime of most individuals. Improved understanding of climate change impacts and the need for adaptation must be combined with "tough" actions that include better risk assessment of community climate change impacts and vulnerability, the identification and avoidance of development in vulnerable areas and ongoing incorporation of adaptation strategies into land use planning and community disaster management planning. The authors conclude that such actions will entail significant costs, disruptions to communities and require political commitment and cooperation between all levels of government.

Bass (2004b) examines the recent focus of efforts for future land-use planning in Ontario on the concept of Smart Growth. Smart Growth delimits areas where cities can expand and encourages higher densities of commercial and residential land use. Bass examines how Smart Growth strategies in Ontario, Canada influence the vulnerability of Ontario's urban environments to climate change through two specific impacts – increased storm water runoff and warmer summers. The paper concludes that Ontario's Smart Growth strategies both increase and decrease the vulnerability of Ontario urban environments to climate change. It is shown that Ontario Smart Growth strategies can be modified by increasing the vegetative components of the urban environment using approaches such as green roofs that ensure a decrease in the vulnerability of urban environments to climate change.

3.6 Ecosystems and Biodiversity

The sixth and final theme of the book is Ecosystems and Biodiversity and begins with a paper by MacIver and Wheaton (2004) that provides a look at forest biodiversity and its adaptation to climate change. Adaptation of forest biodiversity means taking into account a changing climate; improving the understanding of forest landscapes, ecosystems, species and genetics under climate change; adjusting the planning, planting, tending, protecting and harvesting of our future forests; and conserving native forest biodiversity. Not all forests are alike, nor do they share the same multi-taxa, adaptive life-cycles, feedbacks and threats. Given the life cycle of most forest species, the authors suggest that forest management systems will need to adjust their limits of knowledge and adaptive strategies radically to initiate, plan and enhance forest biodiversity in relative harmony with the future climate. Protected Areas (IUCN), Global Biosphere Reserves (UNESCO), Model Forests and Smithsonian Institution sites provide an effective community-based platform to monitor changes in forest species, ecosystems and biodiversity under changing climatic conditions.

Riedel (2004) provides an examination of the potentially significant impacts of climate change on human health and well-being in Canada. Some key concerns include an increase in illness and premature deaths from temperature stress, air pollution, and increases in the emergence and persistence of infectious diseases. The effects of climate-related natural hazards and extreme events on both physical safety and mental health are another concern. Although there will likely be some benefits to climate change, such as a decrease in cold-weather mortality, negative impacts are expected to prevail. Adaptation will be necessary to reduce health-related vulnerabilities to climate change. Some adaptation initiatives include the development of vaccines for emerging diseases, public education programs aimed at reducing disease exposure and transmission, and improved disaster management plans. The implementation of early warning systems for extreme heat is another effective adaptation strategy. The author concludes that successful adaptation to climate change will require coordinated efforts among different groups and the consideration of climate change in health care decision-making.

Taylor (2004) examines the impacts of climate change on the coastal zones around Canada's Great Lakes, the largest bodies of fresh water in the world. The majority of Canadians live within the Great Lakes drainage basins and many of the larger cities and industries are located along the shores of these lakes. The coastal zone is sensitive to climate change and all the global climate models indicate a lowering of lake levels, an increase in air and water temperatures, a change in the snow and rainfall and an increase in the severity and frequency of storm events. The paper describes examples of recent efforts to restore degraded habitats in places such as Hamilton Harbour, the Toronto Waterfront and the Bay of Quinte. Major adaptation options to climate change include changes to fisheries, modification to marinas, harbours and canals, changes in power output in hydroelectric dams, changes in property boundaries and access to water are a stress on coastal wetlands that serve as habitat for a wide variety of fish and wildlife. The author concludes that the involvement of local municipalities, conservation authorities, industry and farmers is essential in planning for a future sustainable environment in a changing environment.

He et al. (2004) provide results from investigations of the glacial system at Mt. Yulong, Lijiang, China since 1999. The paper shows that glaciers have greatly retreated after the Little Ice Age because of climate warming. The recent 50-year climate data at Lijiang, the closest meteorological station to Mt.Yulong, indicate that there are 2 to 3 year periodic changes for the local temperature and apparent 11 to 12 year periodic cycles for precipitation, showing a corresponding pattern with that in the northeastern part of India. During the most recent half-century, glaciers in Mt. Yulong have alternately retreated and advanced, with smaller amplitudes. Those glaciers on Mt. Yulong with the lowest latitude and smallest area have reduced in size by 60 percent from the Little Ice Age to the present. It is evident that there is a close relation between the atmospheric temperature and glacier retreat at Mt. Yulong. The authors conclude that global warming is the major and most important reason for glacier retreat in the Lijiang-Mt. Yulong region.

Roots (2004) provides a look at the impacts of climate on tourism and recreation at protected area and biosphere reserves. Tourism, in its many forms, has been stated by the United Nations to be the world's largest industry. It is a world-wide activity, important in both developing and industrialized countries. It provides a significant part of the economy of many countries and is an important educational, physical and psychological element in the life of millions of people. A large portion of tourist activities is oriented toward experiencing nature, and the phenomena that are attractive to tourists are commonly sensitive to climate change. Many popular outdoor recreation activities depend upon environmental conditions remaining within a fairly narrow range of those prevalent at present. Any significant change of climate could have serious consequences for tourism and outdoor recreation. Roots concludes that adaptation of the tourist and recreation industry to climate change will require increased knowledge of climatic, hydrological, and ecosystem dynamics at appropriate scales to identify and appraise the sensitivity of tourist destinations and outdoor recreation sites.

Yu and Saprunoff (2004) examine plant species richness (spermatophyte) patterns along an elevation gradient in Hubei province of China using published elevation range data. The result shows a hump-shaped distribution, with high species richness in the middle elevation range from 800 to 1400 meters. The maximum value of species richness was observed at 1000 meters, and this is accounted for about 52 percent of the total number found in Hubei province. The observed pattern in the Hubei province is compared with reports from other regions, and is related to hypotheses published in the literature. Possible factors, such as resource availability, overlap of habitats, the total land area at each elevation band, hard boundary, and human activities, may underlie the patterns. The authors conclude that there is a need for greater efforts in conserving biodiversity in the high species richness areas of Hubei province.

The final paper of the book by Beaubien and Chen (2004) looks at what can be considered to be the most sensitive and easily-observed indicator of the biotic response to climate change - the timing of spring plant development. Spring bloom and leafing dates for perennial plants are largely controlled by heat accumulation, and trends in these dates can help reveal the rate of climate warming. These phenology data have been recorded in Canada for over a century, while the record in China goes back 3000 years. Analyses of phenology data show trends to an earlier onset of spring development in many temperate areas of the world, particularly over the last three decades. This trend has been detected also by remote sensing. Impacted sectors of society and the environment could include agriculture, forestry (including carbon sequestration), human health (for example, allergy seasonality), and biodiversity. The ecological implications include impacts at the level of species, populations, communities and ecosystems. The authors conclude that future cooperation to establish observation of key indicator plant species on a wide geographic basis could greatly enhance our understanding and monitoring of the effects of climate change.

4. Acknowledgements

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paper 2

OPENING STATEMENT TO THE CONFERENCE

LEIGH SARTY[1]

[1] *Counsellor, Canadian Embassy in China*

Let me begin by thanking the conference organizers for their invitation to His Excellency Joseph Caron, Canada's Ambassador to China, to address this conference, and by expressing his regret at not being able to be here in person. It is my privilege and pleasure to be here to represent the Embassy of Canada on his behalf.

As Embassy Counsellor and Head of its political section, I am part of the Canadian Government team that manages our bilateral relations with the People's Republic of China, and it is in that context – that is, the Canada-China bilateral relationship – that I offer the following brief remarks.

The fact that we are gathered here in Lijiang, China reflects the predominant truism of contemporary international relations: on climate change, as on virtually every other item on the global agenda, China is a player of central importance.

This in turn reflects the transformation underway here over the past quarter-century of reform and opening, a transformation with profound and growing consequences for China's role in the world.

Last year, enjoying annual economic growth that topped 9 percent, China's GDP reached USD 1.4 trillion, making China the globe's sixth largest economy. The Chinese leadership has matched impressive growth with more active international engagement, evident in China's entry into the WTO and recent actions such as addressing the North Korean nuclear crisis. The social and environmental dimensions of China's growth command global attention. The prosperity and security of countries around the world are increasingly bound up with the directions in which it develops over the next years and decades.

As Canada's Minister of Foreign Affairs, the Honourable Bill Graham noted, these are the factors that help to explain why expanding our relationship with China is fundamentally important for Canada.

That relationship is growing and multifaceted. Trade and investment links are on the rise; China is now Canada's fourth most important export destination and our third most important import source. Political ties are strong; our two Prime Ministers have exchanged visits. People-to-people contacts make ours a special bond, reinforced by the fact that over one million Canadians – one in thirty – are of Chinese origin.

In sum, from Canada's perspective – and, I suspect, from that of our Chinese friends as well — our partnership counts among our most significant. And nowhere is this more easily apparent, I would argue, than with respect to our cooperation on climate change.

This audience does not need reminding of the challenges we face in this regard. In Canada we see the commitment to action on climate change as an opportunity to create the climate-friendly economy of tomorrow – helping to unleash the economic power of innovation and new ways of achieving sustainable growth.

Our Chinese friends share our desire to see sustainable development that protects the global commons. We both recognize that without significant investments and technological changes, China's stated goal of quadrupling GDP by 2020 could come at the expense of the Chinese environment and hurt the quality of life of both the Chinese and Canadian people.

Canada is pleased to be working together with China toward achieving the goal of successful, sustainable development. In this regard, Canada and China can be said to have formed a strategic partnership in the fight against global climate change.

The Government of Canada, through the Canadian International Development Agency, provides funding for seven bilateral cooperation projects in China in the area of climate change, with a total Canadian contribution of approximately 20 million Canadian dollars. They cover the areas of policy dialogue, awareness and outreach, national communications, clean development mechanism, solar energy, small hydro, boilers, coal bed methane and carbon sequestration. These projects are producing significant results in building China's policy and technological capacity.

Canada is therefore pleased to be among the sponsors of this conference on "Climate Change: Building the Adaptive Capacity." To quote Don MacIver of the Meteorological Service of Canada, responses to the threats to sustainable development posed by climate change "must include adaptation actions that will reduce vulnerabilities to climate variability and extremes and minimize negative impacts, maximize positive impacts, and allow both Canada and China to take advantage of opportunities that arise as a result of these climate changes."

In conclusion, I would like to return to the broader bilateral context within which our important cooperation on climate change takes place. Intensive expert-level exchanges such as this are key to the progress we all wish to see made toward truly sustainable development. Yet sustained engagement at the political level is important in facilitating such exchanges, and our two countries have enjoyed a favourable climate in that regard.

In October 2003, during the visit to China of Prime Minister Chrétien, Canada and China issued a Joint Statement on Strengthened Dialogue and Cooperation on Climate Change, which expresses the desire of both governments to expand and intensify bilateral efforts on climate change, including the development of new policies and technologies in a wide range of sectors including energy, transportation, agriculture, forestry and environment. The Statement mandated the formation of a bilateral Climate Change Working Group to identify opportunities for cooperation and develop a program of work.

Climate change will continue to figure prominently as we move forward on our active bilateral agenda. It is a key component of the broader Canada-China dialogue that is central to Canada's efforts both to seize the opportunities and overcome the unique challenges of the 21st century. In that spirit, I wish you every success in your work here in Lijiang and in the months and years ahead.

chapter II

Keynote Paper

3 paper

CLIMATE CHANGE AND THE ADAPTION DEFICIT

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ABSTRACT: Two types of adaptation are identified. Type I Adaptation is the everyday adaptation to weather and climate that has always been a feature of human life. Type II Adaptation is the adaptation mandated under the UN Framework Convention on Climate Change. Type I Adaptation is promoted as part of sustainable development. Type II Adaptation relates to anthropogenic climate change and is subject to the rules and practices under the Convention. The two types of adaptation are similar but not identical. Type I Adaptation has traditionally assumed a stationary climate. In Type II Adaptation the climate is changing and the international community has a cost-sharing responsibility under the UNFCCC. There is a need to bring about a single seamless process of adaptation. Type I Adaptation has not been working very successfully. Losses from extreme weather and climate-related events are rising rapidly. This failure of current adaptation to keep pace with development is called the adaptation deficit. Type II Adaptation could be developed under the Convention to help eradicate the adaptation deficit. This would require the development of a more formal adaptation regime under the Convention similar to the mitigation (Kyoto) regime that already exists. The paper concludes that: 1. There is an unacceptably large and growing adaptation deficit; 2. The deficit can be more effectively addressed by combining the Climate Convention work with the development process and mainstreaming climate risk; and 3. By developing a more coherent and operational adaptation regime we can have more confidence that the efforts we collectively make will be rewarded with success.

Keywords: climate change, adaptation, deficit, risk

1. Two Perspectives on Adaptation

Adaptation is by no means a new concept or practice. Adaptation, including adaptation to climate, is as old as our species. Human beings have adapted successfully to all except the most extreme climates on the planet. People make a living and a livelihood in the sub-Arctic tundra of Canada, and in the steppes of Mongolia as well as in tropical rainforests, in small islands, and in mountain regions, and the Sahel. On this planet, climate varies as much or more over space than in time. Now however, we are concerned with something different from the age-old human practice of human adjustment to environmental circumstances, including adaptation to a climate that for practical purposes can be considered as stationary. We are concerned with adaptation to a climate which is changing at a fast rate due to anthropogenic interference.

The United Nations Framework Convention on Climate Change (UNFCCC) was negotiated and agreed to deal with the new threat of anthropogenic climate change. The ultimate objective of the Convention as stated in Article 2 is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". Adaptation comes into this equation because the more that adaptation can be used to reduce impacts that might be considered dangerous, the higher the threshold of concentrations that can be accepted. Thus adaptation is important in the decision about how much and how rapidly greenhouse gas emissions need to be reduced. I call this the "pollutionist" view of adaptation, because it is important in deciding what level of greenhouse gas pollution can be tolerated in the atmosphere. It seems that the "pollutionist" view was what was uppermost in the minds of those who drafted the UNFCCC.

There is, however, a second view of adaptation that I will call the development view. This view recognizes that climate variability and extremes, even without climate change, can inflict significant damage on human lives and activities, and that this damage can be a significant impediment to development. Climate-related extreme weather events and climate variability help to cause poverty, and to keep poor and vulnerable people, poor and vulnerable. If we are to reduce climate-related disasters, eliminate extreme poverty, and attain the Millennium Development Goals we must incorporate adaptation to climate into development planning and implementation. We must begin adapting to climate change now. You might wish to argue that the two views are really the same. In both cases adaptation is needed. One difference however, is that the development perspective clearly implies adaptation now regardless of climate change, whereas the pollutionist view requires adaptation to be factored into decisions according to a schedule that involves the projection and observation of climate change and efforts at mitigation.

2. Two Categories of Adaptation

We can therefore think of two categories of adaptation. They might be called Type I and Type II Adaptation. Adaptation Type I refers to past and current adaptation strategy, policy, and measures without considering climate change. Most of the adaptation that we do is still Type I. Type II Adaptation is adaptation to climate change. Because climate change risks have still not been factored into many development decisions, and because awareness of the need for adaptation has still not been well incorporated into the work of development agencies, or Ministries of Finance and Development, not much Type II adaptation has taken place. This may also be partly explained by uncertainty about the amount and rate of future climate change, and to the lack of development assistance specifically earmarked for climate change adaptation. There is also a limited capacity to deal with adaptation in many countries in the face of a host of other urgent problems. It is also due to the adoption of short-term perspectives. Climate change is often seen as a slow process and the idea that adaptation can be left to a later date is commonplace. Type II Adaptation is therefore seen as not urgent, and also is often related to climate averages rather than variability or extremes. This is the case not only in developing countries, but even more so in the most highly developed and richest countries.

There is nevertheless a demand for attention to adaptation at the meetings of the UNFCCC, especially from those developing countries considered to be most vulnerable such as the Least Developed Countries (LDCs), and the Association of Small Island States (AOSIS). Article 4.4 of the Convention states, " the developed country Parties and other developed Parties included in Annex II shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects". A number of funds which can be used to support adaptation have been established including the Least Developed Countries Fund (LDC Fund), the Special Climate Change Fund (SCCF), and the Adaptation Fund established under the Kyoto Protocol. The Global Environment Facility (GEF) is now proposing a Strategic Programme on Adaptation (SPA) that will be a pilot exercise in the implementation of adaptation. The strategic priority was adopted by the GEF council meeting in November 2003, as part of the 2005-2007 GEF business plan, which allocates US $50 million to it.

How are these funds for adaptation to be used? It is proposed that their use be limited to the incremental costs of adaptation, that is the adaptation that is necessary because of climate change (Type II Adaptation) and not the costs of adapting to current climate or Type I Adaptation. From a development perspective it makes sense to graft adaptation to climate change onto existing adaptation strategies, policies and measures. Adaptation to climate change makes no sense unless it starts from present day adaptation. In other words Type II Adaptation should be built upon and strengthen Type I Adaptation. Type II Adaptation is what we need to do differently, both more and better, if we are to adapt to climate change. Unfortunately the science of climate change does not allow the theoretical distinction between climate and climate change to be measured. It is impossible to state how much of a tropical cyclone, or a heat wave or a flood can be attributed to climate change. Type I and Type II Adaptation therefore have to be considered as part of a seamless process of adaptation. There are however, two important differences between Type I and Type II Adaptation. Type I Adaptation has always been the responsibility of sovereign states. Type II Adaptation involves anthropogenic climate change, and therefore some degree of globally shared responsibities. Further Type I Adaptation has been and is to a climate considered as stationery. Type II Adaptation recognizes tat the assumption of a stationery climate is no longer valid.

3. The Adaptation Deficit

What is the status of Type I Adaptation and how successful is it? Unfortunately the story is not encouraging. An examination of losses from extreme weather events, or what might be called climate-related disasters, shows that they have been rising (Figure 1). Data from the Munich Reinsurance Company show that both insured and economic (non-insured) losses have been rising at what looks like an exponential rate. Those curves if extended on the same trajectory look very ominous indeed. The losses do not yet reflect much climate change. If we add some of the projected rates of climate change into this graph the levels of loss are likely to become catastrophically high.

The high level of current losses results from what I will call the adaptation deficit. Why are weather related losses growing so rapidly? There are a number of possible explanations. (White et al., 2001). Could it be that we have insufficient knowledge of the behaviour of the climate system and that the management of weather hazards continues to be flawed by significant areas of ignorance? Scientific understanding of the processes generating natural extremes has expanded considerably in recent decades, and in many cases of atmospheric hazards, forecasting and warning capacity has improved dramatically. This accounts in large part for the reduction in the level of mortality from extreme climate-related events. Knowledge of the probability and potential magnitude of hazard events has also increased. White and his colleagues conclude that lack of scientific knowledge is not a major cause for the rise in losses.

Perhaps then the available knowledge is not used or not used effectively? There is more evidence to support this explanation. In developing countries especially, weather-related disasters continue to take people by surprise. Emergency responses are apparently improving, but longer-term programmes to reduce vulnerability through poverty reduction and related measures are slow to take off. There also might be a time lag. The initial expectations of the UN International Decade for Natural Disaster Reduction

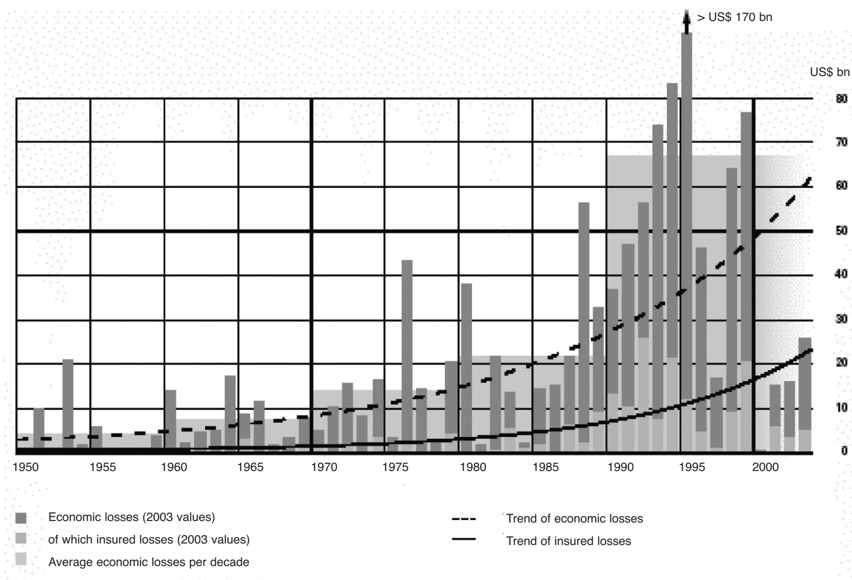

FIGURE 1

Economic and insured losses during 1950-2003 with trends. The chart presents the economic losses and insured losses – adjusted to present values. The trend curves verify the increase in catastrophe losses since 1950. *Source: Munich Re (2004)*

(1990-1999) were that damage could be reduced by 50% by the effective use of knowledge and forecasting. Unfortunately these predictions proved to be far too optimistic. There is no doubt that more scientific knowledge would be helpful, especially the designation of hazards zones as a basis for the deployment of adaptation measures. There is no doubt that the knowledge that exists could be used more effectively, and that more timely action could bring more rapid results. While more and better knowledge, more effectively used could help, it has not so far proved sufficient to offset the growth in vulnerability and damage potential resulting from the growth of population, the increase of material wealth in some places, and the persistence of poverty elsewhere, and the expansion of human settlements and populations into high hazard zones. The adaptation deficit is increasing and is set to get larger with climate change. What seems to be needed is a much more effective process of adaptation (both Type I and Type II) that uses both structural and non-structural measures, and includes land-use planning, building codes are standards, insurance and where necessary policy innovations to bring losses under control.

4. The Role of the Climate Convention (UNFCCC)

Can the Climate Convention bring success where the UN Decade for Natural Disaster Reduction, and the efforts of many governments, development assistance agencies and humanitarian relief organizations have so far failed? If the Climate Convention is to help, the concentration on the "pollutionst" perspective and on Type II Adaptation will have to be augmented by the development view and take into consideration the need for Type I adaptation to address the current adaptation deficit.

There are indeed indications that this process is already underway, for example, as noted previously, in the creation of funds to assist in meeting the costs of adaptation. While these funds are directed at anthropogenic climate change or Type II Adaptation and not specifically at the current adaptation deficit, the operational guidelines being developed for the funds make it clear that their use is to be country driven, and "mainstreamed" or integrated into the national development process. Clearly Type I and Type II Adaptation need to be brought together. But as we have seen Type I Adaptation is not working very well. This is leading some to suggest that adaptation promoted and supported through the Convention must be something new, and stronger, and better. Perhaps this could be facilitated by the development of a new legal instrument for adaptation which might become an Adaptation Protocol? My view of this is that before serious discussions or negotiations on such a topic are started it would be good to hear from the science and expert communities about the potential role of such a Protocol in promoting the adaptation that is needed. At the moment we have little idea of how the objective of an Adaptation Protocol might be specified, and what it might contain.

How might the international science and expert communities be asked to contribute? Some appropriate process has to be developed and put into operation. It is easier to suggest what is not likely to work. The organization of workshops under the Convention process has been one much used method of getting expert input. In my view this rarely works well because the time is too short and the workshop syntheses and reports have rarely produced truly helpful results. Another route is to use the IPCC, either the periodic Assessments or in the preparation of a Special Report. The deficiencies of this approach include the great length of time between IPCC Assessments, (the Fourth Assessment is not due till 2007), and the restriction that the IPCC limits its Assessments to the peer reviewed scientific literature, perhaps extended to include some informal folk or traditional knowledge. Whereas what is needed is creativity to develop new ideas and new options for the way in which adaptation might be facilitated. In the final section of the paper I have a few questions that could be directed to a group of scientists and experts especially selected to work for the necessary period of time on the idea of the potential contents of an Adaptation Protocol. Only when we have a better sense of what a Protocol might achieve does it make sense to start serious discussions within the established institutions of the Convention process.

5. Mitigation and Adaptation Compared

The reduction of greenhouse gas emissions has been the focus of attention in the Convention Process, and a coherent regime has been created for mitigation. There is a clear objective in Article 2 which calls for the stabilization of greenhouse gas concentrations. There is no similar stated objective for adaptation. What is meant by mitigation is clearly understood. By contrast adaptation means too many unclear things. There is no formal definition of adaptation in the Convention. There is a mitigation baseline. The year 1990 has been chosen as the point in time against which to measure changes. There is no adaptation baseline or discussion on what it might be and how it might be measured. There are agreed targets and schedules for emission reductions. There are no targets and schedules for adaptation. Mitigation has a clear funding regime in the Clean Development Mechanism. Adaptation can be supported from several funds in principle, but these are funds based on voluntary contributions, and are not linked to any measure of progress on adaptation. Mitigation has a legal instrument in the form of the Kyoto Protocol which clearly establishes a mitigation regime and points the way forward. We are far from having a clear adaptation regime.

6. Towards an Adaptation Regime

It is not yet clear that an Adaptation Protocol could deliver the more effective adaptation that is required. (After all the Kyoto Protocol is not yet delivering mitigation). But it is clear that more needs to be done to create a more coherent and effective adaptation regime. Perhaps the need that is most recognized now is captured in the word "mainstreaming". This means that ways must be found to integrate climate change risks into development activities. National governments, planning and development agencies, ministries charged with management tasks in agriculture, water, forests, environment, physical planning, coastal development, health and others, should to begin to consider how climate change risks will affect their policies, plans, and projects, and programmes. Bilateral and multilateral development assistance agencies and banks should be prepared to help in this process. Whatever is done under the convention should be integrated into present efforts, or in other words Type I and Type II adaptation need to be brought together. The ideas under development at the World Bank for the application of a climate change screening tool and climate risk assessment are examples of what might be done (Burton and van Aalst, 2004).

As part of the "mainstreaming" process, some serious thought should be given to the development of a more practical and operational view of adaptation. How is it to be defined and measured? Can the objectives of adaptation be specified in such a way that progress can be assessed? Does it make sense to formulate targets for adaptation? The International Decade for Natural Disaster Reduction (1990-1999) wanted to reduce the costs of natural disasters by 50%. But they have continued to increase. Can linking climate change risks and the Climate Convention process with disaster mitigation help development and reduce poverty?

Most climate-related losses are not insured. People and nations suffer the losses and have to rely on their own resources and humanitarian assistance to attempt to recover. They can also borrow money for reconstruction. The private insurance industry is generally not expanding its services in this area and reinsurance companies are concerned about increased exposure to catastrophic losses. Could some new provision be made for insurance under the Climate Convention that would help to spread losses, ensure a safer economic climate for investment, and at the same time promote effective adaptation policies? Could such a plan, organized at an international level, and involving public-private partnerships be an attractive way of addressing the need for more adaptation? Some experiments that are being tried in the areas of earthquake insurance and weather derivatives show that some people and agencies at least are awake to the possibilities.

Let us determine that the work of this conference, and the messages we send out from Yunnan, will say clearly to people at least four things:

- That there is an unacceptably large and growing adaptation deficit.
- That we can get on the right track and begin to address the deficit more effectively by combining the Climate Convention work with development process and mainstreaming climate risk.
- That by developing a more coherent and operational adaptation regime we can have more confidence that the efforts we collectively make will be rewarded with success.
- That future work on adaptation should be done in the context of applications, which include climate risk assessment. This experience should be monitored and evaluated so that a library of knowledge base of best or good practice can be built up.

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4 paper

DISCUSSIONS ON KEYNOTE PAPER: CLIMATE CHANGE AND THE ADAPTATION DEFICIT

1. MEASURING THE ADAPTATION DEFICIT

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How do we move adaptation into the mainstream? It has been proposed that quantifying adaptation is a necessary measurement to begin mainstreaming adaptation into decision making. The suggested approach, based on losses, is not an index of adaptation, but an indication of the outcome. A loss index, such as rising insurance claims, indicates the degree to which we have not yet adapted, or the adaptation deficit. It may gain favour as it is an easily understood measure, and it suggests a target that is isomorphic to the mitigation of greenhouse gases (reduce losses by a fixed percentage). Interestingly enough, the UN set a target of a 50% reduction in losses to natural hazards during its Disaster Reduction Decade, only to witness an increase in the amount of destruction due to hazards.

A true index of adaptability would have to encompass a property of the system that leads to increasing vulnerability to weather hazards. From a systems perspective there are probably several measures (diversity, redundancy, connectedness and resource potential). This would build on the work of Holling (1986) in developing the adaptive cycle and its application in both an ecological and social context. Although this is the best measure from a strictly scientific perspective, these indices are not as well understood by the public or policy makers, may be difficult to quantify and agreement on a single index of a system measure is extremely difficult.

A third alternative is to base a measure on the degree of innovation for coping with variability and change. Innovation refers to developing new strategies or technologies or reviving old ones and using them in a novel fashion. Green roof technology represents one example of using an old strategy to cope with new environmental issues. Nanotechnology represents a totally new innovation that can be used in the development of new technologies to mitigate the damage associated with extreme weather events. Measuring innovation is extremely difficult, but it may be possible to develop a measure of the capacity to innovate. The proposed method is based on the COBWEB simulation model, developed to explore how systems respond to environmental variability and change.

A simple simulation model has been constructed to illustrate how strategies evolve in a system of autonomous agents. In the program Complex Organization and Bifurcation Within Environmental Bounds (COBWEB) each agent's strategy is a vector of 8 dimensions, consisting of only 1's and 0's. Any particular combination will determine a few simple actions (movement, consumption and reproduction). Those strategies that are best suited for the environment will survive and reproduce, the others will die out. Depending on the environment, it is expected that a different combination of 1's and 0's would allow for varying degrees of success. Once the system has selected those strategies that work, it is possible to change the environment and observe if these strategies are effective at adapting to change.

A strategy is considered to be successful if it can stay in the environment through reproducing itself. However, for the system to survive, it has to allow for innovation in order to cope with changes in the environment. In COBWEB, innovation occurs when strategies can change. Change can occur via mutation at reproduction, either asexual or sexual, or through sexual reproduction by combining half of its string of 1's and 0's with half the string from another agent. Both of these methods allow for innovation to occur.

Innovation can also occur by expanding the dimensions of the strategy. The program allows for the strategies to be augmented at every time step through new information that is gathered from the environment, i.e. through observation, or from communicating with other agents. Both of these activities expand the dimensionality of the vector. COBWEB has been used to conduct experiments with and without communication and new environmental information. The probability of survival and reproduction favoured new information by a very small margin. However, with new information, the agent was able to survive much longer and produce many more offspring.

Innovation has been recognized as an important aspect of adaptation, and this has been illustrated with the COBWEB simulation model. The COBWEB simulation also indicates how the capacity for innovation can be measured.

COBWEB has various quantitative parameters that allow for more change or less change to occur in an agent's strategy. These include the rate of mutation, the probability of communication, the size of the memory for new information and/or communication and the probability of sexual reproduction. Both probabilities and binary strings lend themselves to measurement in an information-theoretic context. Information theory can provide a measure of uncertainty in terms of the number of choices available in a situation, the larger the measure, the more choice available.

Translating this measure into something that is as clear as loss remains a challenge. If we conduct an inventory of what is required to expand our range of choices it will include income, education, experience, ability for communication and observation and other aspects of society that will overlap with various systems-theoretic measures such as diversity and redundancy. The key difference is that this measure of adaptability, i.e. the capacity to innovate, has to be expressed in terms of our ability to choose. It may reduce to a few simple proxy measures, such as the average levels of education, income and funding for research in all disciplines, or it may be expressed as a new index, such as our ability to choose.

This measure of adaptability can complement an outcome, such as insurance losses. However, an outcome does not represent our ability to adapt rather it represents our failure to use our capacity for innovation to adapt to climate change. Insurance loss reduction may be a target to aim for, but just as an archer requires a bow and arrow and practice to hit a target, reducing insurance losses will also require various strategies and perhaps experiments with different technologies.

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2. NATURAL DISASTERS AND THE GROWING GAP OF VULNERABILITY

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Natural disasters occur when a natural event triggers some vulnerability within the socio-economic fabric of our society, and results in damage exceeding the ability of the affected community to recover without outside assistance. These sorts of events have been affecting humankind throughout our history and have become part of our myth, legend and religions.

In recent decades data on the number and costs of natural disasters (see Figure 1) have shown increasing trends (Munich Re, 2003; Etkin et al, 2004). There has been a good deal of discussion regarding the reasons for this. Population growth and increases in wealth account for part of it, but case studies have shown that many disasters have occurred because of increases in social vulnerability, and this is thought to lie at the root of the problem. In spite of increases in knowledge and technology, they have not been able to solve the disaster problem.

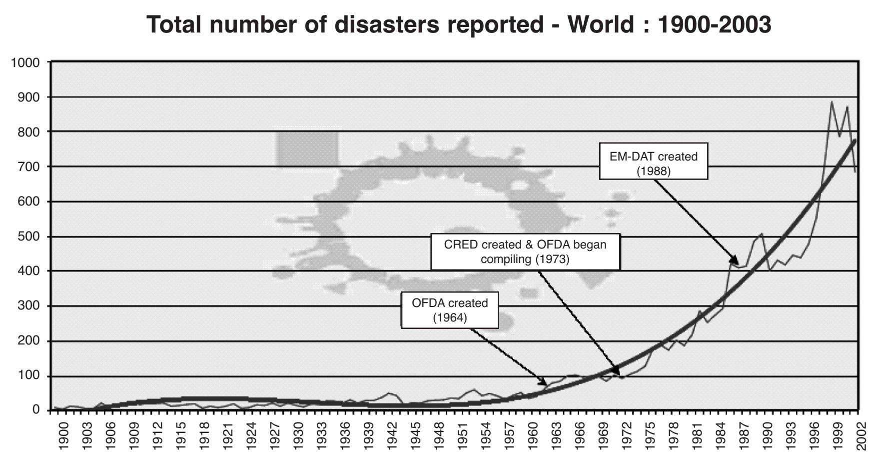

FIGURE 1

Number of disasters in the world from 1900-2003. *Source: Centre for Research on the Epidemiology of Disasters (CRED), 2004.*

Various authors have discussed the issue of how trends in modern society can increase vulnerability to extremes.

In 'The Labyrinth of Technology' Willem H. Vanderburg notes "The fundamental contradiction in technological and economic growth... At the micro level, we find technical and economic rationality; at the macro level, technical and economic irrationality". In 'The Perception of Risk' Paul Slovic states that "We live in a world in which information … has reduced our susceptibility to accidents and diseases at the cost of increasing our vulnerability to massive social and economic catastrophes". In 'Normal Accidents' Charles Perrow argues in complex & tightly coupled systems, accidents are a fundamental property of the system, and all of them cannot be prevented. Thus - catastrophes are therefore unavoidable. In 'Risk Society: Towards a New Modernity' Ulrich Beck suggests that society is undergoing a transition, from one based upon capital and production, to one mainly concerned with risks associated with a technological society. He argues that "A risk society is a catastrophic society, where exceptional conditions threaten to become the norm." 'Disasters by Design' by Dennis Mileti overviews the second U.S. national assessment of natural hazards. He concludes that "Too many of the accepted methods of coping with hazards have been shortsighted, postponing losses into the future rather than eliminating them". In part, this is because "People have sought to control nature and to realize the fantasy of using technology to make themselves totally safe". 'The Ingenuity Gap' by Thomas Homer-Dixon is explicit about our adaptation deficit, arguing as follows – "I'm convinced that if we … allow the complexity and turbulence of the systems we've created to go on increasing, unchecked – these systems will sometimes fail catastrophically…. I believe this will be the central challenge – as ingenuity gaps widen the gulfs of wealth and power among us, we need imagination, metaphor and empathy more than ever, to help us remember each other's essential humanity".

Essentially, these insights argue that many strategies used to mitigate risk only transfer it to the future (Etkin et al., 2004). In part, the argument for this is that many mitigative strategies have the unintended result of people and communities engaging in excessive risk taking behavior, such that their risks to extremes beyond the design standards of their infrastructure or land use planning become so large that the risk reductions achieved to more commonplace events is overwhelmed in comparison (Etkin, 1999). This transfer of risk is illustrated in Figure 2.

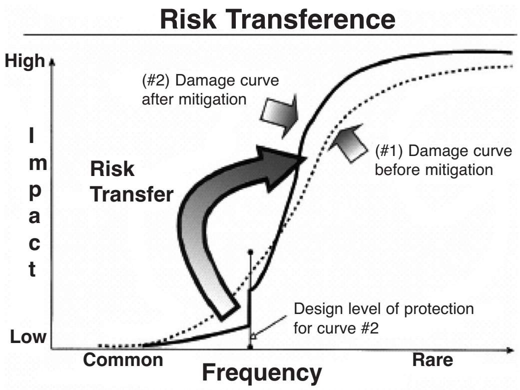

FIGURE 2

Risk transference.

The result of environmental degradation, excessive risk taking and short term values is a widening adaptation deficit – a gap between our ability to address the problems we face as a civilization and species and the risks those problems generate.

When development or mitigation improperly assesses the risk of rare high-consequence events, risk is transferred from the more common hazards to extreme events that exceed design criteria. Long-term vulnerability can thereby be increased.

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3. NATURAL CAPITAL AND THE ADAPTATION DEFICIT

by ADAM FENECH, *Meteorological Service of Canada, Environment Canada, email: adam.fenech@ec.gc.ca*

To calculate the adaptation deficit in many areas of the human economy, it becomes a matter of gains or losses, or costs or benefits. These gains or losses are calculated using traditional economic theories that fail to recognize the real or "true" costs of adaptation measures as they affect the value of ecosystems and biodiversity – what is often referred to as natural capital. The gains or losses in the value of natural capital as affected by adaptation measures need to be captured in the accounting of the adaptation deficit.

In traditional economics, capital is a manufactured (human-made) means of production, that is, the tools, machinery, buildings and so on to generate profits. However, this approach also views land and nature as a source of materials and a source of services that are provided as "free" goods. Natural capital is the living and active ecosystems that yield a steady flow of useful goods and services. It is not necessarily the use of the Earth's natural capital that is troublesome, but the failure to understand what its use means, to account properly for it and to invest in it.

Decisions about the exploitation of natural capital are evaluated ordinarily according to criteria that take for granted that all economic values of natural capital are known and reflected in the prices the resources bring to the open market. These decisions also assume that markets are undistorted by subsidies and externalities; and that the proceeds from the extraction and sale of resources are actually reinvested in other productive capital, not just squandered.

The national accounts of nations fail to accurately describe changes in the quality and quantity of natural capital stocks, in contrast to the way stocks of manufactured capital are treated. Three changes have been proposed to address the shortcomings of national accounts:

1. expanding the asset boundary to include the now uncounted environmental and natural resources;
2. redefining national income to include the value of recreation, aesthetics, biodiversity and non-use benefits; and
3. recognizing the contribution process of environmental services such as waste absorption.

However, no national accounting system anywhere is yet fully adequate to the task. Traditionally, the Gross National Product (GNP) is the market value for all goods and services produced within a nation in a given time period – the accounting measure that is used when quantifying the adaptation deficit. GNP is supposed to gauge human welfare but there are major perversions such as when a major oil spill that damages the ecology of a coastal zone increases a country's GNP because the clean-up efforts are calculated in the accounting while the ecological damage is not. There have been some attempts to address the problem with the GNP such as the Index of Sustainable Economic Welfare (Daly and Cobb, 1989) that incorporates income distribution, net capital growth, natural resource depletion and environmental damage, unpaid household labour, streets and highways, health care, education, and national advertising in national accounting measures. And the Human Development Index (HDI) developed by the UN Human Development Program goes beyond per capita wealth to life expectancy, quality of nutrition, education, access to water and sanitation, distribution of wealth, freedom index, etc.

Some suggest that pricing the world cannot be done on a moral basis. Species have a right to exist, period, and attempting to assign values to them is meaningless. Markets clearly ignore certain important values of our society, and no market value can be given to a species' role as a component of an ecosystem. This view ignores the fact that dollar values are a useful if incomplete measuring stick for decision-making. It permits reasonable comparisons. Economists say that it yields a quantified measure of peoples' preferences.

Attempts have been made to put a market value on natural capital and its goods and services. This is done through what economists call contingent valuation, or what is known as the "willingness to pay" approach. Contingent valuation simply asks people what they are willing to pay to forgo a benefit or tolerate a loss. There are many problems inherent in this approach, but it manages to place a market value on things that we humans traditionally take for granted and do not account for. Costanza et al (1997) estimated that the total value of all the Earth's ecosystem services stemming from natural capital totaled $33 trillion per year, a figure that exceeds the sum of the world's gross national products. Others have called the $33 trillion per year a "serious underestimate of infinity", as without the services from natural capital, humans would not exist.

An effective adaptation deficit will be difficult to calculate because of the inherent difficulties now of accounting for environmental sustainability and the earth's natural capital.

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4. ADDRESSING THE ADAPTATION DEFICIT THROUGH FUNDING

By **MONIRUL MIRZA**, ***Meteorological Service of Canada, Environment Canada, email: monirul.mirza@ec.gc.ca***

The UNFCCC calls on developed country Parties to assist developing country Parties that are vulnerable to the adverse effects of climate change in meeting costs of adaptation. At the third conference of the parties (COP) meeting adaptation as an expenditure goal was first cited. At that meeting, the UNFCCC Parties agreed to the Kyoto Protocol, which defined the Clean Development Mechanism (CDM). Article 12 of the Kyoto Protocol defines the CDM and it performs a three-fold function to:

- Assist non Annex-I countries in achieving sustainable development;
- Contribute to the ultimate goal of the convention i.e., stabilization of greenhouse gas concentrations in the atmosphere; and
- Help Annex I countries comply with their emission reduction commitments.

Within the provisions of the CDM, financial resources are to be made available to assist developing countries that are particularly vulnerable to the adverse effects of climate change and associated sea level rise to meet the costs of adaptation. At the COP 4 held in Buenos Aires in 1998, a decision was adopted that funding could be made available to developing countries for the preparation of adaptation activities.

As a result of the broad political compromise reached in July 2001, Governments decided to establish three new funds to assist developing countries with adaptation activities at UNFCCC COP 7. The following three funds are part of the Marrakech Accord.

The Special Climate Change Fund is operated by the GEF with guidance to the convention, to finance adaptation, technology transfer, energy, transport, industry, agriculture, forestry and waste management and activities to assist oil-exporting countries diversify their economies. Dessai and EURONATURA (2002) argue that ultimately, the prioritization of activities under this fund will be based on politics because of the nature of the Convention process.

The Least Developed Countries Fund is operated by the Global Envionmental Facility with guidance to the Convention, to support National Adaptation Programmes of Action (NAPA). The NAPA established a set of guidelines for communicating urgent and immediate needs of the Least Developed Countries (LDCs) to adapt to climate change. It identified a set of criteria for selecting priority activities such as: life and livelihood, human health, food security and agriculture, water availability, quality and accessibility, essential infrastructure, cultural heritage, biological diversity, land management, other environmental amenities and other socio-economic factors, especially poverty. The Marakesh Accords of COP 7 launched an LDC Expert Group to support them in their preparation and implementation of the NAPAs.

The Kyoto Protocol Adaptation Fund is resourced by the share of the proceeds on CDM project activities, to finance concrete adaptation projects and programs.

All of these funds will be necessary to help less developed countries meet their adaptation deficits.

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chapter III

Canada-China Collaboration in Adaptation to Climate Change Research

5 paper

MAINSTREAMING ADAPTATION AND IMPACTS SCIENCE INTO SOLUTIONS

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ABSTRACT: Over the past decade the Adaptation and Impacts Research Group (AIR Group) of the Meteorological Service of Canada, Environment Canada, has developed scientifically sound knowledge, information, data, models, maps and policy strategies from the global to the community levels. The adaptation process is best viewed as an iterative, non-linear cycle that involves multi-disciplines, multi-agencies and all Canadians. The adaptation outcomes may occur at any stage in this knowledge creation and sharing process and may involve scientific, technological, institutional, behavioral, political, financial, regulatory, and/or individual adjustments to the changing climate.

Keywords: climate change, adaptation

1. Introduction

Over the past decade, the Adaptation and Impacts Research Group (AIRG) of the Meteorological Service of Canada, Environment Canada, has developed scientifically sound knowledge, information, data, models, maps and policy strategies ranging from the global to the community levels. The adaptation process is best viewed as an iterative, non-linear cycle that involves multi-disciplines, multi-agencies and all Canadians. The adaptation outcomes may occur at any stage in this knowledge creation and sharing process and may involve scientific, technological, institutional, behavioral, political, financial, regulatory, and/or individual adjustments to the changing climate.

Climate change, based on past and current observed data and scenarios of the future climates, creates a picture of a warming climate along with other changes in variability and extremes. The concern facing the impacts and adaptation science community is the determination of the frequency and magnitude of extreme events in the future. The associated mitigation actions to reduce greenhouse gases will have a minimal effect on the global mean temperature change and hence a much greater acceleration and commitment to adaptation solutions is needed now. Within this context, the

AIRG has evolved significantly from its early focus on the science of impacts to that of adaptation options. Today, the AIRG has refined its concepts, methodologies, partnering and delivery of adaptation science (AIRG Newsletter, 2004) to help Canadians prosper by making adjustments in their social, environmental and economic activities. This includes the co-development of solutions in partnership with more than 200 clients and partners across Canada and worldwide.

Generally, the thematic areas of study include climate change and socio-economic scenarios; climate variability and change; natural and human-induced hazards; water resources; adaptation modeling; human health and biodiversity. Specific topics include, for example, regional climates and adaptation baselines; climate change scenarios and downscaling

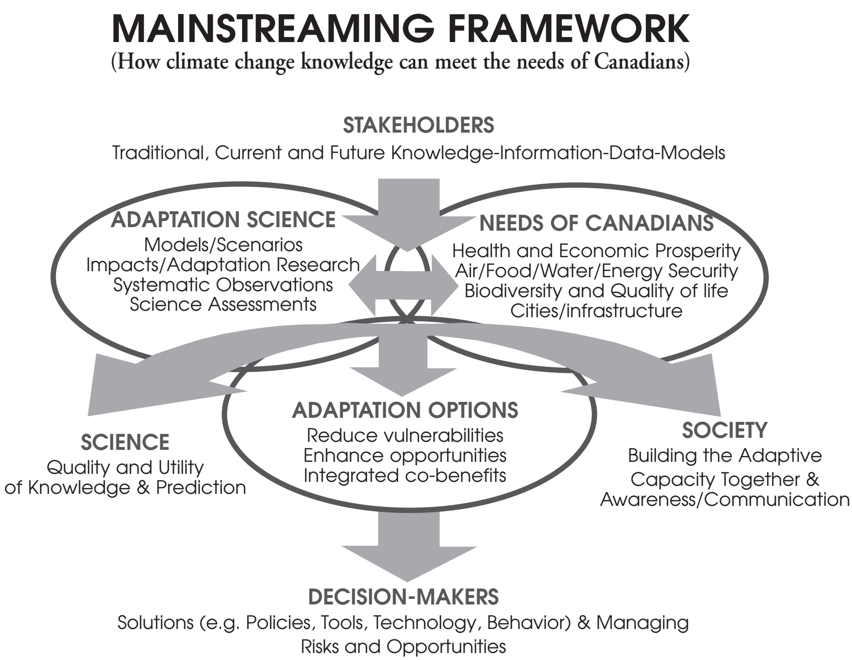

FIGURE 1

The Mainstreaming Framework where the upper left circle represents the top-down approach, the upper right circle represents the bottom-up approach and the lower circle represents the unified solutions (adapted from Wheaton and MacIver, 1999).

methodologies; high impact weather and hazards; weather warnings for behavioral adaptations; water resources and participatory impact assessments; climate change and energy modeling; transportation and weather extremes; safety and security; human health (e.g., water-borne diseases, infectious diseases) and biodiversity conservation (e.g., forestry, agriculture, parks).

The Mainstreaming Framework, utilized by the AIRG in many projects, is illustrated in Figure 1, where the top-left circle represents the top-down approach and the top-right circle represents the bottom-up approach and the bottom circle yields unified solutions.

2. The AIR Group Adaptation Vision and Mission Statement

2.1 Vision

Canadians become well-adapted to current and future changes in the climate and weather systems and prosper by making adjustments in their social, economic and environmental activities.

2.2 Mission Statement

To provide scientific expertise and leadership to Canadians on the environmental, social and economic risks, vulnerabilities, impacts and adaptations associated with climate variability, extremes and change.

3. Adaptation Science Capacity (The Where)

The location of adaptation scientists is fundamental to the successful development and delivery of their science into solutions. Building the adaptive capacity of Canadians begins with developing sound science, increasing confidence in the certainty and resolution of climate change scenarios, understanding adaptation lessons and trends from the past, integrating adaptation into decision-making models and participatory dialogue with partners/stakeholders to effectively implement adaptation solutions.

The AIRG scientists, a core group of twelve plus many project-based researchers, are distributed and embedded in Universities across Canada to help increase the intellectual collaboration and to provide a portal for the transfer of new scientific developments into policy and practice. The benefits to both participating agencies are significant. The University community gains

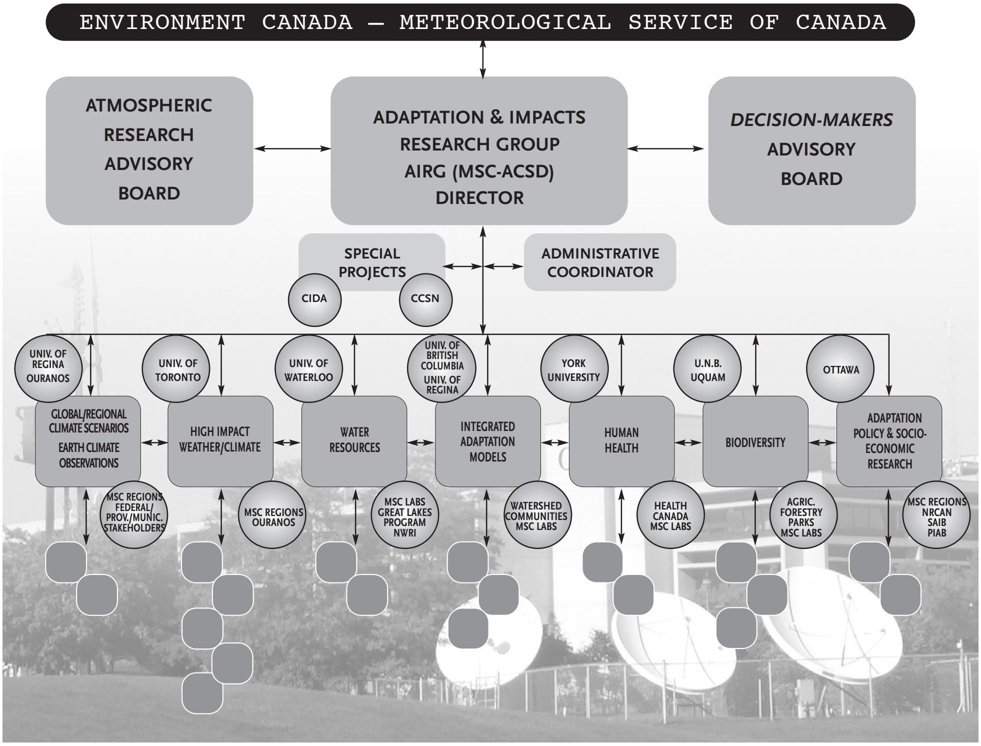

FIGURE 2

Organizational Structure of the AIR Group at various Universities across Canada (top circles) with direct interlinkages to the applied science and forecasting parts of the Meteorological Service of Canada (MSC) regions, economic sectors, and other agencies (the bottom circles) and the various adaptation issues are illustrated in the square boxes.

from greater scientific collaboration, intellectual advances, teaching and graduate student supervision and employment opportunities for students, post-doctoral fellows and staff. On the other hand, government scientists lead and/or participate in the development of new science, new research partnerships, new funding opportunities and the effective transfer of knowledge from many regions across Canada and worldwide into policies and solutions for decision-makers.

Building the adaptive capacity in Canada has been a long-term investment strategy to strengthen science and technology, education, training and communication. Adaptation solutions can take many forms ranging from pro-active and preventive changes to reactive and responsive changes.

The organizational structure of the AIRG is illustrated in Figure 2:

4. Adaptation Science (The How)

Enhancing the well-being of Canadians, preserving our natural environment and advancing our long-term competitiveness will require environmental predictions at ever-increasing resolutions and certainties. To achieve these goals, impacts and adaptation research needs better regional climate models and downscaling methodologies, improved earth observing systems information, strengthened electronic infrastructure, greater participatory engagement by the public and private sectors and dynamic modeling capabilities for the timely dissemination of knowledge into policy and adaptive management decisions. Climate change and associated sea level rise; frequent extreme weather events and increasing losses from them; pollution of land, water and air; threats to freshwater and groundwater resources availability; increasing energy demand; rapid urbanization and pressures on natural capital have become the most pressing environmental and economic problems facing Canada in the 21st century. These problems are further compounded due to increased human interventions on the natural systems and by changes in natural and human-induced climate variability and extremes. Collectively, these impacts have already become a major challenge to human health, safety and security, well-being and quality of life, long-term competitiveness and the protection of our ecosystem and planetary health.

The adaptation science analytical approach begins with either a science, policy or private sector need expressed in the form of a question or a problem worthy of further scientific investigation. In some cases, proxy and current climate models, based on systematic observations of the earth's climate system, can provide answers. In other cases, both historical data and future climate model scenarios at the global and regional scales are needed to help answer the problems. This type of analytical framework is illustrated in Figure 3:

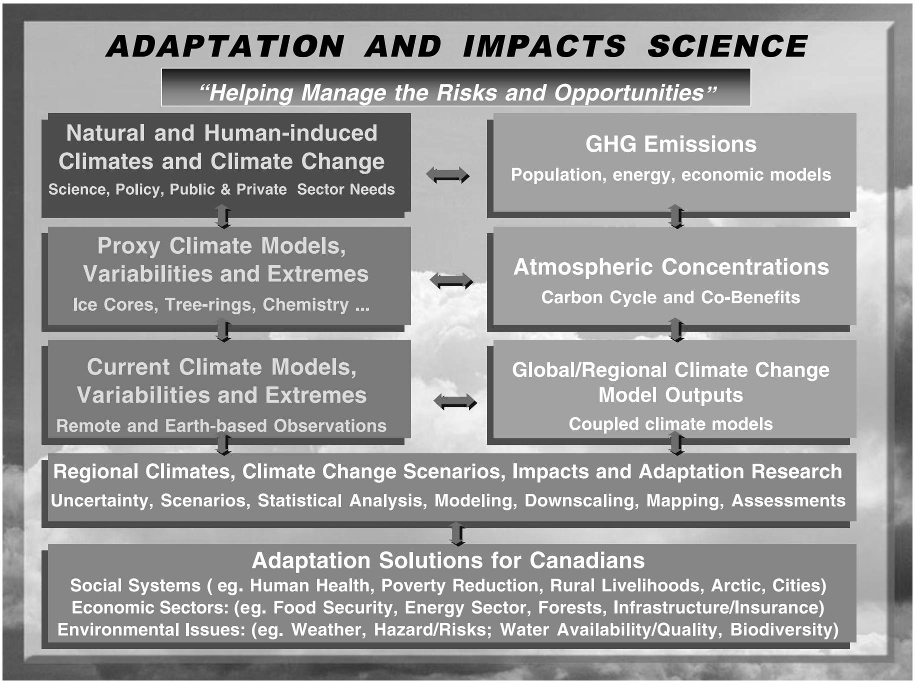

FIGURE 3

This analytical framework illustrates the adaptation science approach leading to solutions that are embedded within the social, economic and environmental framework of sustainable development.

5. The Outcomes (The Why)

The outcomes or solutions are further defined beyond the sustainable development framework of social, economic and environmental issues into specific outcomes. This table is illustrated in Figure 4, where the first level matrix recognizes the following four outcome levels:

- Improving Human Health, Safety and Security: This section focuses on near-term Environmental Prediction, indices and warnings to reduce the vulnerability of Canadians.
- Enhancing Well-Being and Quality of Life: This section focuses on enhancing Environmental Quality, especially from 2010 and beyond (e.g., climate change).

- Strengthening Long-Term Competitiveness: This section focuses on *Sustainable Use* in order to strengthen our long-term competitiveness.
- Protecting Ecosystem and Planetary Health: This section focuses on *Environmental Conservation* in order to help protect ecosystem health and planetary health.

OUTCOMES (THE WHY)

A&I Research (The How)	SECTION 1	SECTION 2	SECTION 3	SECTION 4
	Improving Human Health, Safety & Security	Enhancing Well Being & Quality of Life	Strengthening Long-term Competitiveness	Protecting Ecosystem & Planetary Health
International				
National				
Communities and People				

The left column of the matrix recognizes the scale-dependency of adaptation solutions. Specific adaptation projects form the body of the matrix with considerable interlinkages between projects, outcomes and spatial/time scales. For example, projects that address adaptation solutions for coastal zone management will have international, national and community applications as well as human health, well-being, economic competitiveness and ecosystem health interconnections.

Internally, the second level of stratification focuses on the individual projects that are then further clustered into five adaptation pillars – science and technology; information, prediction and reporting; performance policies and tools; governance; and education. This helps considerably in further identifying the partners, clients and outcomes of each project and the efficient development of solutions. In order to attain the objectives of numerous adaptation and impacts research projects, the formation of multi-disciplinary and multi-agency teams has long been an effective mechanism to deliver results in a timely manner. Since its establishment, the Adaptation and Impacts Research Group has been working very closely with the relevant government agencies, non-government organizations and citizens groups and aboriginal people. Our activities have expanded beyond Canada and the

AIRG is providing scientific and technical support to many regions of the world to share our adaptation science and knowledge (eg. UNFCCC, IPCC, CBD, UNESCO, WMO, IJC, FAO, ISB, World bank, UNEP, UNDP, Smithsonian Institution, Canada-China, Canada-Caribbean, Canada-Africa, Canada-SE Asia).

Without a highly organized Mainstreaming Framework of this type, there would be little hope of integrating adaptation science into the decision-making processes. Within the overall matrix approach, this internal assessment of projects is further illustrated in Table 1.

TABLE 1 Internal identification of projects by who, scale, adaptation pillars, timing and engagement with partners, clients and decision-makers, internationally, nationally and locally.

WHO	SCALE	ADAPTATION PILLARS	TIMING	ENGAGEMENT
Scientists Canadians Communities Governments Private Sector	Site Local Regional National International	Science and Technology Information Governance Performance Education	Anticipatory (pro-active) Responsive (reactive)	Forecast and Preventative Natural and Autonomous

6. Summary Comments

The challenge facing many countries will be the identification of their international/national/community adaptation priorities and managing the risks and opportunities. The Mainstreaming Framework identified in this paper has been effective at bringing together the adaptation science communities; the communities that need to adapt and decision-makers. In other words, the definition of the problem, the effective creation of knowledge, the mobilization of the adaptation science capacity; the translation of knowledge into solutions, all requires an enabling Mainstreaming Framework that interlinks the science, policy, public and private sectors.

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6 paper

CANADA-CHINA COOPERATION IN CLIMATE CHANGE: THE C5 PROJECT

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ABSTRACT: China is responsible for 14 per cent of the world's energy-related carbon emissions, making if the second largest emitter after the United States. China has recognized the effects of climate change and is taking steps to mitigate and adapt to climate change. China became one of the first ten countries to sign and ratify the United Nations Framework Convention on Climate Change (UNFCCC). In early 2001, the Canadian International Development Agency (CIDA) approved funding for the "Canada-China Cooperation in Climate Change (C5)" Project under the Canada Climate Change Development Fund (CCCDF). C5 was organized around four components: Awareness and Outreach, National Communications, Adaptation and Impacts and Clean Development Mechanism (CDM). The most significant benefits of C5 are an increased ability for China to address the issue of climate change (from emissions reductions through to adaptation), and improved abilities for Chinese organizations and individuals to make decisions and take action that include climate change considerations.

Keywords: Canada; China; climate change, adaptation, awareness, communication

1. Environment and China's Development

Outstanding economic growth in China has produced the second largest economy in the world, with predictions it will be the world's largest by 2025. In addition, China has 25 per cent of the world's population, and according to the latest United Nations' statistics, about 20 per cent of the world's poor live in China.

As other industrialized countries have also experienced, China's rapid economic development has had a significant negative impact on the environment. China's push to urbanize, raise the living standards of its people and become a global player have all increased industrialization and energy consumption. To meet the needs of its population, China has found itself in a climate change circle where more fossil fuels have been burned to produce energy for a country en route to becoming a developed nation. In fact, 70 per cent of China's energy needs are being supplied by coal-fired stations. However, per capita energy consumption in China remains very low.

To address its environmental problems, China's State Council approved the *National Tenth Five-Year Plan for Environmental Protection* in December 2001. As part of this plan (2001-2005), the government has pledged to improve environmental conditions through a combination of legislation and increased investment. Great progress has been achieved in the energy field that is favorable to environmental protection, including energy conservation, energy efficiency improvement, legislation and standards. Most recently, in November 2004, China submitted its initial National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) and issued the first Medium and Long-term National Plan for Energy Conservation where strategies, goals and key areas for energy conservation, policies and measures are addressed. Meanwhile, China's Renewable Energy Law is under the process of legislation and will be issued in 2005.

2. China and Climate Change

According to the International Energy Agency's estimates, China is responsible for about 14 per cent of the world's energy-related carbon emissions, making it the second largest emitter after the United States. By 2015, China will take first place in carbon emissions. Understanding the relationship between its rapid economic development and increasing strain on natural resources and the environment, China has identified sustainable development as the pathway for its development and as a key element in all decision-making processes. China has also recognized the effects of climate change and is taking steps to mitigate and adapt to climate change.

2.1 China's Climate Change Commitments and Interests

China became one of the first ten countries to sign and ratify the United Nations Framework Convention on Climate Change (UNFCCC). It then established the National Climate Change Coordination Panel (NCCCP) to implement the UNFCCC and Agenda 21 (Delphi Group, 2001), and to provide guidance on international negotiations and domestic implementation. The Committee is led by the National Development and Reform Commission (NDRC) and is composed of 15 government departments and institutions, including the State Environmental Protection Administration.

Based on its challenges, China's climate change interests are:

- To understand more about the causes and impacts of climate change, related sensitivities and vulnerabilities of different regions, and ways to adapt that also meet sustainable development goals;
- To increase technology transfer and the flow of investment from both domestic and international sources towards sustainable solutions for environmental and climate change problems; and
- To increase awareness and understanding of key decision-makers, industrial leaders, researchers, and the general public of the current problems, causes and impacts and the actions they can take to mitigate climate change issues.

3. C5: China as a Partner of Choice for Environment Canada

In early 2001, the Canadian International Development Agency (CIDA) approved funding for the "Canada-China Cooperation in Climate Change (C5)" Project under the Canada Climate Change Development Fund (CCCDF).

Environment Canada's role in C5 was a natural one, based on existing bilateral cooperation. China ranks as one of Canada's most important partners in environmental cooperation and sustainable development. Since 1986, a number of agreements have been signed such as the *Memorandum of Understanding on Cooperation in Meteorology, the Memorandum of Understanding on Environmental Cooperation, and the Framework Statement on Cooperation on Environment into the 21st Century.*

The two Canadian Executing Agencies for C5 were the Environment Technology Advancement Directorate of Environment Canada and Resource Futures International for the Clean Development Mechanism. The total budget was $4.9 million.

The overall C5 goal was to contribute to Canada's international climate change objectives through activities that address the causes and effects of climate change while contributing to sustainable development and poverty reduction. To meet this goal, C5 was organized around four components: Awareness and Outreach, National Communications, Adaptation and Impacts and Clean Development Mechanism (CDM). General objectives for C5 were:

- Stronger institutional capacity for awareness and outreach strategies and programs around climate change;

- Higher awareness by the general public and key stakeholders about climate change, its causes, impacts and potential methods to adapt to and mitigate the problems;
- Expanded knowledge and skills for key researchers to employ greenhouse gas inventory and forecasting methodologies;
- Enhanced capacity within Chinese research institutions to identify and assess the sensitivities and vulnerabilities of key sectors/regions to changing climatic conditions;
- Stronger ability of research institutions and key decision and policy makers to develop adaptation strategies that incorporate the principles of sustainable development;
- Increased ability to identify, assess and undertake technology transfer projects under the Clean Development Mechanism;
- Enhanced bilateral linkages and dialogue between Chinese and Canadian government agencies, institutions and the private sector.

With the three year mandate for C5 at an end, this report is designed to provide details on the success of the three year effort on climate change between Canada and China. This Executive Summary presents highlights of the various components. There are full details in the body of the report that show the several different layers of success, intangible achievements and above all the strong commitment by both countries to ensure the highest levels of cooperation and long-lasting results.

4. Results

4.1 Awareness and Outreach

Under the Awareness and Outreach component, one of the key activities was the development of climate change training materials by the Centre for Environmental Education and Communications (CEEC), in conjunction with Nanjing University. The documents were to be used by government officials, educators, journalists, and enterprises. With input from a broader group of experts, shorter versions were developed to target four key audiences: teachers, journalists, environmental protection officials, and enterprises. A final version was printed in June 2004.

The Journalists' Capacity Building Workshop was held in March 2004, with a lead-up session in November 2003, in Beijing. The earlier session allowed for journalists to provide input into the design of the formal workshop. The main objective was to build Chinese media understanding of the issue of climate change and help journalists develop storylines that would be relevant for their audiences. A number of presentations and site visits were arranged during the week-long event, and participants were more than satisfied with their experience. By working together during the workshop, they indicated that they would team up in the future to strengthen their outreach work in China. The media then covered the Adaptation and Impacts international conference in May 2004. As a result of the workshop and the conference, media coverage on climate change has increased significantly in China.

The Youth Focused Campaign included many different sub-activities, such as China Youth Daily articles, Friends of Nature on Wheels, a Climate Change Poster contest, and the School Twinning Project, which was added to the program. The China Youth Daily produced 28 articles on climate change, providing readers with a wide perspective of climate change and its impacts. Friends of Nature on Wheels, a mobile environmental education program developed by a non-governmental organization, delivered climate change messages to school children. The Climate Change Poster contest encouraged creative talents and targeted university students, publishing a collection of selected posters with three chosen to create an outdoor bus shelter advertisement. The School Twinning Project was introduced to build a strong and sustainable capacity at a local level to deliver climate change education. One school in Guiyang and another in Vancouver were chosen to participate. Because of the dedication of the teachers and students from both schools, this activity was a great success. Students exchanged perspectives, stories and experiences related to local climate change issues and there was ongoing cultural exchange.

4.1.1 ***Success Factors and Results***

Open lines of communication were essential for effective project implementation, especially face-to-face interaction. Trust and respect were also very important, and strong relationships were developed with the CEEC team. Necessary flexibility in design and implementation was a key factor because although a plan was developed in the beginning, partners were able to find new opportunities and introduce new and extended activities.

The ongoing commitment and creativity of the CEEC team was key to the success of the component. Superior climate change information products and tools were produced in short periods of time, and the right people were engaged to ensure that project activities could occur. The Canadian partner credits the China team for their dedication and motivation, making the component a great success.

The Chinese partners agree with these observations and add that the component reached its objectives and expectations. China indicated that although C5 is concluding, climate change awareness and dissemination has just started and will continue beyond the project. In this way, C5 has created a sustained capacity in China. The cooperation has opened new fields for the CEEC, such as renewable energy, and will provide opportunities to address local issues such as water, health and agriculture.

4.2 National Communications

Under the National Communications component, three key activities were held to assist the Energy Research Institute (ERI). The first was a study tour, held in October 2002 in Canada, during which Chinese experts learned about the Canadian experience with data collection, inventory systems and processes, and data and information handling. The knowledge gained by the Chinese experts was demonstrated in the development of an inventory framework report.

The second key activity for this component involved two methodologies training workshops, held in November 2003 and April 2004. The first was in Beijing, successfully transferring Canadian knowledge and experience with inventory methodologies and problem solving approaches. Experts continued their training with the fugitive emissions from the oil and gas sector workshop, held in Calgary. Canadian experts provided training to the Chinese participants in the area of fugitive emission methodology and inventory. Participants were pleased with the training, having gained a more detailed understanding of the methodology employed in Canada.

The third event was a methods and models workshop, held in Beijing in November 2003. The objective of this workshop was to share Canadian greenhouse gas forecasting models, tools and techniques. It is evident by the development of an emission forecasting methodology report that the training built the Chinese experts' knowledge and capacity.

4.2.1 Success Factors and Results

The ability to communicate openly was a key element in ensuring success for the transfer of knowledge and experiences between both Chinese and

Canadian experts. The engagement of appropriate experts was also very important to the success of the component.

The time allotted for the workshops session was a main point as key materials were successfully covered, but additional time would have allowed for more questions, clarifications and discussions of methodological options. Further, success of this component was assured by the interest of the ERI experts in improving the quality of their inventory estimates and their greenhouse gas forecast to better assist with China's first National Communication. The interest of Canadian experts in sharing their experience and knowledge with the Chinese delegates was essential and greatly appreciated by China. It is also important to note that the participants adapted well to changes with the format of the training sessions.

The Chinese partner agreed with the Canadian point of view, and added that they are confident that all activities will continue, and that there will be ongoing cooperation among the partners. China understands that Canada is a leader in the areas covered under this component, and although it does not have the information required for replicating the same level of detail, it recognizes the benefit in continuing a learning relationship with Canada.

The Chinese team gained knowledge from Canada on the preparation of an inventory system, and when comparing Canada's system to other countries', decided that the Canadian system is where they obtained more detailed information. The discussions on emissions forecast modeling were also useful, to both Canada and China, and there are plans to continue a dialogue.

4.3 Adaptation and Impacts

Key activities under the Adaptation and Impacts component include an extremes workshop and a practical attachment, under the *Identify Nature and Characteristics of Climate Extremes* sub-component.

In January 2003, scientists from the China Meteorological Administration (CMA) participated in the workshop, held in Canada. The purpose of the workshop was to strengthen the research capacity in China for understanding the links between climate change and climate extremes. Participants indicated that the Canadian experience and expertise in data analysis and extremes research are valuable for building and enhancing research capacity in China in related fields. Following the workshop, one expert stayed for the practical attachment, which concentrated on analysis of extreme precipitation. The CMA was very pleased with the success of both these activities.

In September 2003, two back-to-back workshops were held in China. The first, a climate scenarios training workshop, was aimed at developing and enhancing the scientific and technical capacity of the Chinese scientists working in the area of climate scenario development and climate change impact, vulnerability and adaptation assessment. The workshop included lectures, interactive discussions and hands-on exercises. The second workshop focused on six themes, namely climate change policy issues; adaptation and impact assessment approach; methodologies/techniques; case studies; scenarios; and dialogues with decision and policy-makers. Researchers felt that both workshops enabled the participation of all involved.

A third highlight is the redesigned adaptive capacity training initiative, that evolved into an international scientific conference entitled *Climate Change: Building the Adaptive Capacity*, held in China in May 2004 that led to this book of papers. This conference provided an opportunity to include international researchers in dialogue and to provide input to the case studies and other component results. Experts shared their knowledge about adaptation to climate change. The conference was an excellent example of the international leadership role that Canadian scientists play in climate change adaptation science.

4.3.1 ***Success Factors and Results***

The Canadian partner identified partnership as an important factor in the success of this component. Effective working relationships have been established and will extend beyond the end of the C5. The Canadian partner added that informed and timely action was also key, and that most researchers agreed that the adaptation policy development provided under C5 was very useful. As in all components of the C5, good communication was extremely important to achieve success.

Another success factor was the coordinated approach taken by both countries. This component has managed to stake out a unique role for Canadian experience and expertise. The selection of Chinese partners for this component also contributed extensively to its success. As well, a dynamic and flexible approach to project implementation was necessary to achieve outputs, especially due to the SARS delay, as well as changes to the program to avoid duplication with other funding agencies.

Adaptation and Impacts team members from China agree with the Canadian team's observations, and added that key success factors included bilateral government support from NDRC, Environment Canada and CIDA. Canadian and Chinese scientists all worked together effectively to make the component successful.

The work achieved in this component strengthened the research capacity to understand Canadian and international tools, methodologies and techniques on climate change studies. The C5 provided opportunities for state and provincial policy makers to understand the impacts of climate change and appropriate policy responses, increased the participation of women in adaptation and impacts activities, and contributed to the adaptation section of the first Chinese National Communication. The C5 will provide an opportunity for policy makers and will open a window to the public on what climate change will do to China's key economic sectors. China's future work will focus on climate change and drought, socio-economic studies, and climate scenarios, as well as continued research on adaptation techniques in a wider number of sectors and regions, and further analysis of the impacts of climate extremes and their variability.

4.4 Clean Development Mechanism (CDM)

The Clean Development Mechanism (CDM) component was aimed at enhancing capacities to initiate and undertake Clean Development Mechanism projects. Activities were the creation of an operational model for the Clean Development Mechanism, outreach and networking, and a transportation case study.

The first activity, the creation of an operational model for the CDM, created an authoritative guide for those involved in the Clean Development Mechanism project cycle, including government and business. The operational model evolved into a guidance document over the life of the project. The work of this activity enhanced the knowledge and experience of the Chinese in undertaking collaborative research, and resulted in useful products that were disseminated to government policy and decision makers in China and Canada. The guidance documents were released during a Canada-China workshop on the Clean Development Mechanism, held in China in September 2003.

The second activity was the development of a Clean Development Mechanism Enterprise Network (CEN), a bilingual web site to facilitate Clean Development Mechanism project collaboration between China and Canada. This activity was redesigned at the request of the Chinese, and allowed the partners to use innovative, and originally planned, activities to ensure the results of the project were widely disseminated. While the CEN was not created, the project team identified a series of activities to participate in to raise awareness of the project. The participation in regional workshops in China allowed the project to extend its reach beyond Beijing.

The last activity under the Clean Development Mechanism component is a transportation case study, intended to test the Clean Development Mechanism operational model in the transportation sector. The activity included two study tours to Canada for Tsinghua University researchers. An official from the Beijing Public Transport Corporation also participated in one of the tours. Capacity was developed in survey methodologies, research methods, and identification and evaluation of potential Clean Development Mechanism projects. Partners developed an improved understanding of the Clean Development Mechanism and its applicability in the transportation sector.

*4.4.1 **Success Factors and Results***

The Canadian partner identified open lines of communication as an important issue. Face-to-face meetings were crucial and therefore more frequent in the second year of the project. Trust and respect were also key in this component as well, ensuring collaboration and innovation and allowing the project to attain and exceed expected results.

The engagement of appropriate experts was a successful factor for the Clean Development Mechanism component. A number of Canadian and Chinese experts were involved in the delivery of this component and proved essential to its success. High level support from both countries contributed, as did a dynamic and flexible approach that helped achieve outputs. Private-public sector partnerships were effective in project implementation, and Resource Futures International worked closely with Environment Canada throughout the project.

The Chinese partner agreed with the factors outlined by the Canadian partner, but indicated that problems occurred because of distance. He added, however, that trust and respect were a positive experience and that responsible government agencies provided a high level of support. China indicated that the training materials were used to raise capacity in both central and regional levels and that the work helped remove confusion about Clean Development Mechanism-related issues. The documents produced are now "road maps" for Chinese Clean Development Mechanism project developers. Experts also gained experience in developing project development documents.

The Clean Development Mechanism component has laid the foundation for developing Clean Development Mechanism projects and other technology-related initiatives and potential technology transfer under the Clean Development Mechanism in two key areas – transportation and renewable energy. The Chinese team learned from Canadian experiences and examined institutional structures applicable.

5. General Success, Factors and Considerations

Canada and China agree that the service provided by the Local Project Manager (LPM) was key to the success of the C5. The office ensured that the relationships between technical leads were built and sustained, and that the team was motivated. The Local Project Manager was essential to ensuring that information was transmitted and that appropriate tasks were completed.

The Director of NDRC, Ms. Sun Cuihua, indicated that it would have been better if there had been just one Canadian Executing Agency for C5 instead of two. Working with two separate agencies was sometimes difficult for the Chinese side.

It was indicated that China was pleased with the achievements of the C5 and the way in which the results had been brought together at the closing seminar. A strong foundation has been laid for future work on climate change in China and the Canada-China working group on climate change will provide an excellent vehicle to discuss future cooperative activities between the two countries.

6. Benefits to China and Canada

The most significant benefits of C5 are an increased ability for China to address the issue of climate change (from emissions reductions through to adaptation), and improved abilities for Chinese organizations and individuals to make decisions and take action that include climate change considerations.

C5 has enabled China to be at the forefront of public awareness and adaptation. Stronger foundations have been laid on which climate change can be addressed more effectively, while gaining positive environmental, social and economic benefits.

New partnerships were developed, such as with the National Development and Reform Commission, which led to the signing of the *Canada-China Joint Statement on Strengthened Dialogue and Cooperation on Climate Change*. Existing agreements were reinforced such as those with State Environmental Protection Agency of China and the Chinese Meteorological Administration.

In addition, China has strengthened its knowledge in policy building and linkages to climate change and sustainable development, which greatly assisted in the development of the national strategy.

The C5 project also resulted in numerous benefits for Canada. For example, Environment Canada already had a well-established relationship with China, but the project has helped to foster trust and build on the department's relationship with the National Development and Reform Commission. The project has assisted Canada in meeting its UNFCCC objectives and improving its international position with respect to the major issues surrounding climate change and China. The *Canada-China Joint Statement* will continue to build on the foundation established by C5. Clean Development Mechanism projects can now be executed, and the training delivered on scenarios development will facilitate the transfer of Canadian climate-friendly technology and know-how to China.

Canadians have also gained experience in applying the regional climate modelling for impact studies, which in turn greatly promote the development of Canadian regional models, especially at Environment Canada's Meteorological Service of Canada. In addition, the creation of potential future commercial opportunities for Canadian business, while at the same time facilitating future Clean Development Mechanism activities (and thus the generation of carbon credits), will make it easier for Canadian business to interact with China.

The gender equity issue was also an important factor as it has helped Canada progress towards its goals of gender equality and sustainable development. Lastly, the C5 project has assisted Canada in becoming a global beneficiary resulting from China's increased effectiveness in addressing their greenhouse gas emissions.

These benefits will likely impact numerous Canadians directly such as researchers (better understanding of developing country considerations), businesses serving climate change needs (better able to market their products in China), and indirectly, such as Canadian citizens who will benefit from fewer climatic disruptions than would otherwise be the case.

7. Recommendations for the future

In its evaluation report, the Pembina Institute suggested the transfer of capacity building to the Chinese provinces should continue, specifically through the components of Awareness and Outreach and Adaptation and Impacts.

In the short-term, Canadian International Development Agency has agreed to Environment Canada's request to extend C5 until the end of March 2005, with no additional budget. Two main activities will be delivered: an Awareness and Outreach workshop entitled *Building Regional Capacity for Climate Change A&O*, and an Adaptation and Impacts workshop entitled *Adaptation to Climate Change in Agriculture – Evaluation of Options.* There will also be vulnerability mapping on agriculture for one province (Ningxia) in western China, combining both the sensitivity and the adaptive capacity information. The National Communications component will also be using the extension to facilitate a practical attachment at Simon Fraser University.

With C5 leading to the development of the *Canada-China Joint Statement on Strengthened Dialogue and Cooperation on Climate Change*, Environment Canada's internal cooperation with China is assured. All C5 components were invited to participate in the development of its workplan. While all components will be important to the future activities of this agreement, the Awareness and Outreach component will be present throughout the work program. The next meeting of the working group of the Joint Statement will be held in China in the spring of 2005.

For the Clean Development Mechanism, future work will include the development of a Clean Development Mechanism policy framework for the Kyoto second commitment period, further assessment and case studies on carbon sinks Clean Development Mechanism project and other priority areas. Another important task will be finding an investor for the Beijing transport case study and taking the project to the Clean Development Mechanism Executive Board for approval.

8. Conclusion

China is now at the forefront of climate change adaptation because of C5. New domestic and international partnerships have been developed, and stronger foundations have been laid to address the issue of climate change more effectively, while gaining positive environmental, social and economic benefits. The success of the Awareness and Outreach Component is a prime example of how C5 helped build professional skills for women and men while getting the climate change message to the public, and youth in particular.

The C5 project also resulted in numerous benefits for Canada. Environment Canada's well-established relationship with China has been furthered with new trust and relationships. Canada's role in the project helps meet its UNFCCC objectives and improves its international position with respect to the major issues surrounding climate change and China.

These benefits will reach into the future as Canada's researchers have a better understanding of considerations for developing countries, as businesses serving climate change needs can better market their products, and indirectly as another country becomes more capable of addressing the global challenge of climate change.

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paper 7

THE AS25 PROJECT:
METHODOLOGIES AND RESEARCH ACTIVITIES

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ABSTRACT: This paper presents an integrated assessment (IA) approach that integrates climate change impact assessment/vulnerability identification, adaptation option evaluation, and multi-stakeholder participation. The integrated approach was designed for the project titled "Integrated Assessment of Vulnerabilities and Adaptation to Climate Variability and Change in the Western Region of China" (AS25 project) which is a sub-project of the Assessments of Impacts of and Adaptation to Climate Change in Multiple Regions and Sectors (AIACC). The IA approach has been applied in the Heihe River Basin of China for identifying desirable adaptation options to reduce climate change vulnerabilities. The case study provides some articulation on how the integrated approach can provide an effective means for climate vulnerability assessment and the synthetic evaluation of the general desirability levels of a set of adaptation options through a multi-criteria and multi-stakeholder decision making process. Thus, the case study contributes to the science on climate vulnerability assessment and adaptation option evaluation.

Key words: climate vulnerability, adaptation policy evaluation, integrated assessment, AS25 project, AIACC, Heihe River region, China

1. Introduction

The Assessments of Impacts of and Adaptation to Climate Change in multiple regions and sectors (AIACC) is a global project funded by the Global Environmental Facility (GEF) and implemented by the United Nations Environment Programme (UNEP), for enhancing the scientific and technical capacities in developing countries to assess the impacts of climate change, and to design cost-effective adaptation response options, which are needed to formulate national adaptation policy options and prepare national communications. The AIACC decided to fund a number of studies assessing the impacts of climate change on a range of socio-economic sectors and ecological systems at the regional and national scale and the development of a range of adaptation response options.

In response to a "Call for pre-proposals for Regional or National Assessment Projects" distributed by AIACC in early 2001, a pre-proposal was prepared by the author and submitted to AIACC. Approximately 50 out of 150 project teams whose pre-proposals best met the evaluation criteria were invited to submit full proposals. A full proposal entitled "Integrated Assessments of Vulnerabilities and Adaptation to Climate Variability and Change in the Western Region of China" (AS25 project) was submitted and was selected for an award by AIACC. After a long delay by the Chinese GEF Office, the AS25 project eventually received the Chinese government's endorsement and held its first team and Steering Committee meeting on 25 November 2003 in Beijing, China.

2. Brief Description of the AS25 Project

The purpose of the project is to develop an integrated assessment (IA) approach for identifying regional vulnerabilities to climate variations and change, and for prioritizing adaptation options to deal with climate change vulnerability. The IA will be used to examine societal vulnerabilities to climate variations and change, and to evaluate alternative adaptation options for alleviating vulnerabilities in Western China. The IA can provide a research framework that integrates climate change scenarios, socio-economic scenarios, current climate vulnerability identification, climate change impact assessment, sustainability indicator specification, adaptation option evaluation, and multi-stakeholder participation. The IA can provide an effective means for the synthetic assessment of climate vulnerabilities and evaluation of the general performance levels of a set of adaptation options through a multi-criteria and multi-stakeholder decision-making process. Thus, the research will contribute to science on regional vulnerability assessment and adaptation evaluation. In particular, the study attempts to:

- design an integrated assessment (IA) approach to identify the societal vulnerabilities to climate change scenarios (focus will be on food supply, water shortage, land use conflicts, and ecosystem health);
- use the IA capacity to assess current and future climate vulnerability and risks, and to prioritize a number of adaptation options that could be undertaken to reduce vulnerabilities associated with climate variation and change in the Heihe River regions of China;
- facilitate the participation of regional stakeholders in climate change vulnerability and adaptation option studies;

- suggest desirable and practical adaptation options and/or policies to handle climate change impacts effectively and to ensure sustainable development;
- train and enable scientists in the region to design and apply IA methods in a real world context; and
- prepare a final report of the project and publish at least ten peer-reviewed journal articles to provide scientific information to other parts of the world.

Western China includes predominantly arid and semi-arid areas in the north and is dominated by mountains in the south. With barriers such as extremely fragile ecological conditions, fewer financial resources, poorer infrastructure, lower levels of education, and lesser access to technology and markets, the region has been suffering from climate variations and will experience severer impacts of climate change on food production, water resources, and ecosystem health. Moreover, the region's adaptive capacity is lower than in the coastal region of China. People in the Western region are facing substantial and multiple stresses, including rapidly growing demands for food and water, large populations at risk to poverty and infectious diseases, degradation of land and water quality, and other issues that may be amplified by climate change.

In Western China, the extremely limited water and land resources have to provide a number of competing users with a range of different and often conflicting functions to meet their demands. While the demands for water and land resources increase dramatically as population and economic grow, the availability and the inherent functions of water and land resources are being reduced by climate variation and change, water pollution, salinization, rapid urban expansion, and environmental degradation. Unsustainable resource uses have created a sharp decline in natural resource availability and increase in water and land use conflicts. Water shortage, already a problem in northern China, may be exacerbated by climate change.

Under climate change conditions, periods of drought are likely to become more frequent and severe, and water shortages may increase water use conflicts. Land degradation problems and limited water supplies restrict present agricultural production and threaten the food security of the region. Climate change may cause negative impacts on food and fibre production in the region. In addition, decreases in water availability and food production would lead to indirect impacts on human health.

The project will enhance the regional capacity of integrated assessment (IA). Science capacity building is a primary concern of the project. The regional climate change impact and adaptation study has been undertaken by local scientists in partnership with U.S.A. and Canadian experts. This can improve local scientific capacity and provide expertise available in Canada and the U.S.A. The expected study results will include a digital database containing better socio-economic and ecological data, capacity building training, information to improve decision making, publications and IA tools that can be used in other regions in China or elsewhere.

3. The Integrated Assessment (IA) Approach

The study is built on many years of research experience of the investigators in integrated climate change impact and adaptation studies in the Georgia Basin (Yin, 2001), the Mackenzie River Basin (Yin and Cohen, 1994; Yin et al, 2000), and Great Lakes Basin in Canada (Qi et al, 2000), the Western China region (Kang et al, 1999; Kang, 2000), Yangtze Delta (Yin et al, 1999; Yin et al, 2003; Yin, forthcoming) and other regions in China (Cheng, 1997; Shi, 1995; Yin and Wang, 2004).

The IA approach is consistent with the Intergovernmental Panel on Climate Change (IPCC) Technical Guidelines for Assessing Climate Impacts and Adaptations (Carter et al., 1994), and takes consideration of research directions suggested by the UNDP-GEF (2001) Adaptation Policy Framework. The IA approach combines computer modelling and non-model based methods including a series of training workshops, survey, expert judgement, community engagement, multi-stakeholder consultation, applications of ecological simulation modelling, geographical information system (GIS), remote sensing, multicriteria decision making (MCDM), as well as methods suggested by the Technical Committee of AIACC. In particular, the project will address the following questions:

1. How vulnerable is Western China to current climate variations and future climate change in some key sectors?
2. What can the vulnerabilities of these key sectors to present climate variations teach us about future vulnerability? and
3. What are the desirable adaptation options to deal effectively with future climate changes?

The IA framework facilitates the participation of regional stakeholders in the whole IA process. Workshops have been undertaken by as many local scientists as possible. In partnership with scientists from North American universities and institutions, the project can provide valuable assistance to enable local scientists to conduct high quality research in integrated assessment. Figure 1 shows the general approach of the study.

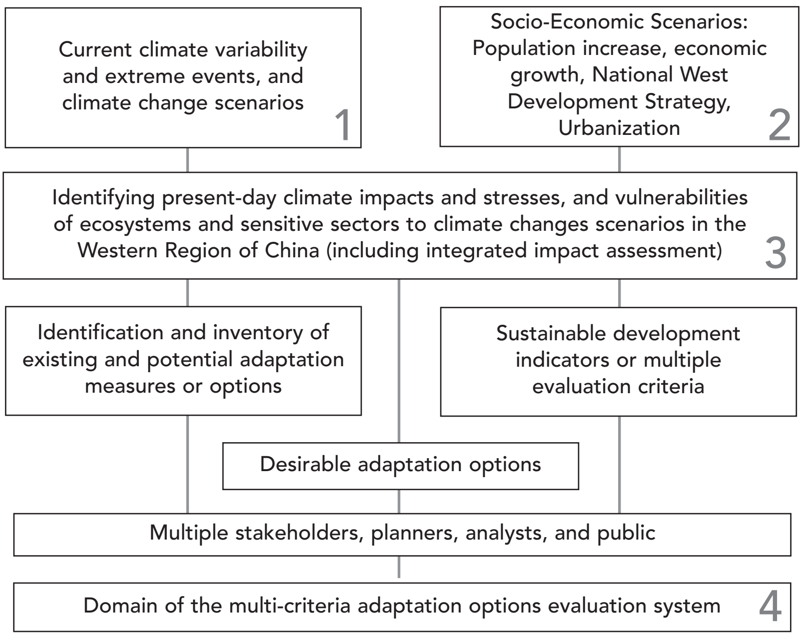

FIGURE 1

Flow-chart showing the research structure of the proposal

3.1 Climate Variation and Change Scenarios (STEP 1)

In identifying present-day climate risks, and conducting the climate change impact assessment and adaptation option evaluation study, existing climate variation patterns and future climate change scenarios need to be specified to examine their economic, social, and environmental impacts. In developing climate change scenarios, the study identifies a set of baseline assumptions and conditions. Thus, climate change scenario specification for this study represents the possible future climate conditions under various assumptions.

Ding (2001) and his research group have been developing a regional climate model (Ncc/RegCM2) nested with a coupled GCM (NCCT63L16/T63L30) and Hadley Center model (HadCM2). The research team is part of the AS25 project responsible for providing climate change scenarios.

3.2 Socio-Economic Scenarios (STEP 2)

Changes in socioeconomic conditions, such as population, income, technology, consumption rates, and China's new Western Region Development Strategy, have been taken into consideration in developing baseline socio-economic scenarios. Various methods have been used to set future population increase and economic growth scenarios. AIACC suggests that the IPCC Special Report of Emission Scenarios (SRES) scenarios be used as the basis for creating future socio-economic scenarios. Chinese government development strategies and plans will be reviewed to collect additional data for socio-economic scenario design. To improve quality of scenarios, workshops and community consultations with multi-stakeholders in the region have been held to identify regional concerns related to socio-economic scenarios. Those economic sectors (agriculture, water and land resources, and fragile ecological systems) sensitive to climate change in the region are included in the integrated assessment.

3.3 Identifying Present-day Climate Impacts and Vulnerabilities to Climate Change (STEP 3)

Step 3 can be further divided into two parts. While Part One examines present-day climate impacts or stresses of various key sectors in the region, Part Two identifies societal vulnerabilities to future climate change scenarios. In particular, the vulnerability assessment examines the effects of climate variations and change scenarios on food supply, water shortage, land use conflicts, and ecosystem health.

Results of Part One of Step 3 will establish a baseline set of measurements and observations that can be used to measure progress toward reducing vulnerability to future climate change. Once these vulnerability measures are identified for each economic, ecological, and social vulnerability indicator, they can be applied to project potential vulnerabilities of the sensitive sectors to future climate change scenarios. Thus, the research on present vulnerabilities and adaptive capacities of human and ecological systems will provide insights into potential impacts and vulnerabilities associated with future climate change. A set of existing adaptation options to deal with current vulnerabilities to climate variations and extremes will be identified for current adaptation capacity evaluation.

3.4 Domain of the Multi-criteria Adaptation Options Evaluation System (STEP 4)

There is an evident need for new research approaches and tools that are able to evaluate alternative adaptation strategies or policies, which many impact assessment methods are not appropriate to do. IPCC (2001b) suggests a list of high priorities for narrowing gaps in vulnerability and adaptation research. Among them is to integrate scientific information on impacts, vulnerability, and adaptation in decision making processes, risk management, and sustainable development initiatives. In this respect, Step 4 focuses on methodology development to link impact assessment with sustainability evaluation assisted by multi-criteria policy analysis and multi-stakeholder consultation in Western China. Main tasks of Step 4 include: 1) the sustainability indicators identification, 2) multi-stakeholder consultation, and 3) adaptation policy evaluation.

4. Implementation of the AS25 Project

4.1 The First Meeting of AS25 Project Committees and Research Team

The first meeting of the AS25 Project Steering Committee (SC), Expert Committee (EC) and research team was held on 25 November 2003 at the Chinese National Climate Center in Beijing, China. SC members were briefed about the project progress. After hearing reports of the status, work plans, and research activities for each research groups, SC and EC members made some constructive comments and suggestions to the project team. The meeting agreed that the AS25 project was an innovative and special project with clear thoughts of research. The expected research delivery may support Chinese government international activities in global climate changes and provide strong scientific support for the 4th IPCC Assessment Report.

4.2 Climate Change Scenario

The climate change scenario setting in 50 years over Western China has been conducted by the National Climate Center (NCC) of the Chinese Meteorological Administration (CMA) using the model simulation results provided by the IPCC data distribution center. Climate scenarios for this study focus on temperature and precipitation projection under various IPCC socio-economic scenarios (IS92a and SRES). Meanwhile, the simulation experiments have been conducted using the global atmospheric-oceanic coupled model of China National Climate Center (noted as NCC/IAPT63) under the SRES A2 and B2 scenarios. The purpose of the simulation is to analyze the climate change over Western China, especially in the Northwestern China and the Tibetan Plateau region. Some simulations have been conducted to provide a scientific base for estimating the melting of permafrost zone where the Qinghai-Tibetan railway will be constructed. The global climate model results have also been processed to provide the initial and boundary fields for climate prediction in Northwestern China with a regional climate model (RCM). Up to now, the ten-year control run and hindcast experiments have been completed with the regional climate model. The simulation of using variable vegetation and the study of vegetation change impact on the climate in Western China using the RCM are still under way. In addition, the study will combine dynamical downscaling results with a statistical downscaling strategy to get more reasonable results.

Based on results of seven GCMs used in the IPCC (2001a) Third Scientific Assessment Report and the NCC/IAPT63 model, the study estimates climate change over Western China during the 21st century. The results show that the temperature will increase continuously with the increase of atmospheric greenhouse gas (GHG) concentrations, but the magnitude of temperature increase is larger than that in Eastern China. The precipitation will have an increasing trend for the next 100 years, especially in Western and Northwestern China, while the increase is not so obvious in Southwestern China. The simulation results were used to set future climate change scenarios for the Qinghai-Tibet region in the next 100 years. Variation of the mean temperature, precipitation and maximum and minimum temperature at stations along the Qinghai-Tibetan railway line is of particular interest.

Considering the uncertainty of the GCM output, especially in precipitation projection, further scenarios study has been carried out using both GCM and RCM results. In particular, dynamical downscaling simulation using RCM with the boundary conditions provided by the global model will project various episodes in 21st Century. Downscaling results will be used as input for a hydrological model to simulate a future hydrological cycle over Western China. In addition, climate change scenarios from the RCM will be used for impacts and vulnerability assessment of the AS25 project.

4.3 Climate Vulnerability and Impact Assessment

Assessment of current resource system vulnerability and analyses of social, economic, and environmental impacts (negative and positive) of alternative climate change scenarios for different economic sectors have been undertaken for key sectors that are sensitive to climate change. In vulnerability and impact assessment, expert judgement, vulnerability indicators, and various crop models, ecological simulation or statistical models, GIS, developed for other climate impact studies and for studies in Western China have been employed to identify the impacts of climate change scenarios (Yin and Wang 2004; Yin et al., 2003; Yin et al., 2000; Yin et al., 1999; Kang et al., 1999; and Cheng, 1997).

The main goal of vulnerability assessment is to develop effective methods to measure vulnerability and to assess the environmental risks in dealing with climate stresses. In this study, several major factors that influence resource system vulnerability in the Heihe River region of China will be considered. In other words, resource vulnerability is a function of these factors including: climate, economic activities in the region, land users, size of resource use activities, resource use efficiency, the price elasticity of supply and demand, environmental protection, policy options (economical, technical, or policy), lifestyle associated with income increasing, and population growth.

The vulnerability assessment focuses on methodology development for estimating land and water system vulnerability. The study adopts approaches for the formulation of indicators for agricultural land and water resource system vulnerability to climate variation and change. Indicators are selected in relation to their specificity, descriptive power, thresholds, and capacity for geographic allocation using ancillary or modeled data. Each system is addressed individually, with a description of applicable indicators, literature references, and geo-spatial data requirements for the mapping of the indicators.

Data required include meteorological, hydrological, soil, prices of products, costs of production, average yields, areas of different types of land, water supply and demand, erosion, desertification and salinization rates, pollutant emission rates, and other impacts data. The data collected also have spatial and temporal dimensions. The model variables and parameters differ among sub-regions, and vary between the present and the future (changed climate condition). Thus, the database consists of information for each land unit under both current and future conditions. Remote sensing image processing technology will be used for collecting and updating land cover and land use information. Specific computer software technologies for satellite image processing will be employed to extract, enhance, and classify digital images (Gong et al., 1999; Qi et al., 2000; Gong, 2000).

One task of the study is to determine whether alternative adaptation options or policies can lead to a reduction in damages or taking advantage of opportunities associated with climate change. The adaptation evaluation in this study will apply two approaches. The first approach examines the effectiveness of alternative short term or autonomous adaptation options by using impact assessment modelling (Carter et al., 1994). Another approach deals with anticipatory or planned adaptation strategies and government policies. And thus the tools used for the second approach are related to policy evaluation or analysis (Stratus Consulting Inc. 1999). The first approach will be associated with impact assessment. Impact assessment models will be run with different climate change scenarios coupled with or without certain adaptation options. Results generated from climate impact assessment will be used for public consultation and adaptation evaluation processes.

The following sections present the importance of indicator setting in adaptation evaluation research and the approach to identify indicators. Then, the IA system assisted by analytic hierarchy process (AHP), a multi-criteria decision making (MCDM) technique, is introduced to illustrate how sustainability indicators and climate change vulnerabilities can be represented in the analytical system to link climate change impacts, adaptation, and regional sustainability evaluation.

4.4 Adaptation Policy Evaluation

A set of existing and possible adaptation options to deal with vulnerabilities of climate variation and change will be identified for multi-stakeholder consultation and multi-criteria evaluation. An inventory of existing and potential adaptation options will be developed. The options inventory will include descriptions of the options and relevant information. Numerous potential adaptation options are available for dealing with vulnerabilities to climate change. An initial screening process will be conducted to reduce the number of options for further detailed evaluation. The multi-stakeholder consultation will help to arrive at a collective group recommendation on the selection of adaptation options for further multi-criteria evaluation.

4.4.1 *Design Indicators to Measure Regional Sustainability*

The research procedure follows with an identification of sustainability indicators. In this study, indicators are evaluation criteria or standards by which the effects of climate change and/or the efficiency of alternative adaptation options can be measured. Indicators of the economic, social, and environmental dimensions of regional sustainable development (RSD) will be identified. Successful implementation of the sustainability concept will require new approaches that link the climate change impact assessment and the sustainability evaluation. Thus, sustainability goals and indicators must be set and impacts of climate variation and change on these indicators must be identified.

There are several general frameworks that can be adopted for developing sustainability indicators. The first is a domain-based framework that groups indicators into three main dimensions of sustainability (economic, environmental, and social). The three-dimensional nature of sustainability and the need to make trade-offs (e.g. between economic growth and environmental quality) require maintaining these three components in a dynamic balance. Sustainability indicators thus, should include economic, social, and environmental information in an integrated manner. Another important framework is a goal-based indicator system. Goals usually reflect the major development concerns of a nation or a region. For example, some concerns represent national or regional objectives of economic viability, maintenance of the resource base, and minimizing the impacts of climate change on natural ecosystems. Each goal is composed of a number of attributes or indicators that are measurable by using existing sources of information in most cases. Other types of indicator frameworks include sector-based, issue-based, cause-effect, and combination ones. No single indicator would be sufficient enough to determine sustainability or non-sustainability of a region or a system. A set of goals and/or indicators is required in sustainability evaluation. Notwithstanding the risks in using aggregated indicators, there are also risks in using too many indicators.

4.4.2 *Multi-Stakeholder Consultation and Multi-Criteria Evaluation of Adaptation Options*

Multi-criteria options evaluation (MCOE) of adaptation measures is one of the major components of the study. The MCOE will be used to identify desirable adaptation measures by which decision makers can alleviate the vulnerabilities and to take advantage of positive impacts associated with climate change in the region.

To select desirable measures among alternatives, multi-stakeholder consultation (MSC) and MCOE will be used to relate impact information to decision making requiring subjective judgement and interpretation. In this study, alternative options will be evaluated by relating their various impacts to a number of relevant indicators. The results of various impacts generated in the previous step will be used as references for ranking the performance of each adaptation option against each sustainability indicator. These indicators are used as multi-criteria by which the strengths and weaknesses of the various adaptation options can be evaluated. The analytic hierarchy process (AHP) developed by Saaty (1980), a multi-criteria decision making (MCDM) technique, will be adopted to develop an adaptation evaluation tool to identify the priorities of sustainability goals/indicators, and to rank desirability of adaptation options (Yin, 2001).

The approach AHP takes is to ask stakeholders to determine his/her preference between two options of how it contributes to each criterion (sustainability indicator) given certain impacts of the options. In this exercise, a stakeholder compares two options at a time (pairwise comparison). Then stakeholders will specify their judgements about the relative importance of each option in terms of its contribution to the achievement of the overall goal. That is, in our case, to alleviate the adverse consequence of climate change. It is expected that the AHP method will provide an effective means for the synthetic evaluation of general performance levels of alternative adaptation options based on a multitude of evaluation criteria. The result of the AHP is a prioritized ranking indicating the overall preference for each of the adaptation options.

Yin (2001) developed an IA approach, assisted by AHP, to evaluate a number of adaptation options that could be undertaken to reduce vulnerabilities associated with climate change in the coastal region and communities of Georgia Basin (GB) in Canada. The AHP application in the GB study included a series of workshops and internet based surveys with participation of a broad range of public and private stakeholders, and policymakers from different affected sectors to identify sustainability indicator priorities, as well as a series of desirable adaptation policies. The AHP facilitated the participation of regional stakeholders in climate change impact and adaptation option evaluation. Results of the AHP analysis are presented in the project final report (Yin, 2001).

5. Capacity Building and Stakeholder Participation

The project has been building committed partnerships with multi-stakeholders in the process of the project. An essential part of the stakeholder engagement strategy is the establishment and participation of the Chinese Steering Committee (SC) and Expert Committee (EC) consisting of key government agencies and experts responsible for China's international cooperation on climate change issues and national communications. The Chinese agencies and experts in SC and EC are also playing important roles in coordinating AS25 activities with other international collaboration projects in China (Canada-China Cooperation in Climate Change, C5 and UK-China projects). The C5 project is funded by the Canadian International Development Agency (CIDA) under the Canada Climate Change Development Fund. The UK-China joint project focuses on assessing potential impacts of climate change on Chinese agriculture.

The IA approach requires multi-stakeholder participation, and thus workshops, survey, and community engagement methods have been employed to involve multiple stakeholders, policymakers, and experts in the project implement process. An internet website of the AS25 was established to provide an effective way to reach a large number of stakeholders, and can be found at http://210.28.133.139/AIACC/website/index.htm.

To engage stakeholder and provide capacity building, individuals have been contacted and workshops have been held aimed to improve local policy makers and scientists' knowledge on climate vulnerabilities and adaptation capacity. For example, a workshop and training was organized in August 2002 at Lanzhou, China. At the workshop, a team of interested parties developed a conceptual integrated assessment framework. Through presentations by researchers and stakeholder representatives and group discussion, the workshop reached a common understanding regarding the methods among the investigating partners, and the stakeholders. The workshop-training course enabled local scientists and stakeholders to have a better understanding of integrated assessment and policy evaluation. Main contents covered in the training course included climate change, resource use conflicts, IA methodologies, economic analysis methods, multi-criteria decision making techniques, multi-stakeholder consultation, sustainable development, and gender and equality issues.

6. Acknowledgements

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chapter IV

Climate Change Impacts, Indicators and Assessments

PAPER 8
Methods for the Geographic Allocation of Climate Change Vulnerability Indicators in the Heihe Basin

PAPER 9
Regional Assessment of Climate Change Impacts in Canada: Okanagan Case Study

PAPER 10
War as a Social-Ecological Response to Climate Change in Ancient China

PAPER 11
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Characterizing Adaptable Systems: Moving from Simulation Models to Adaptation Policy

8 paper

METHODS FOR THE GEOGRAPHIC ALLOCATION OF CLIMATE CHANGE VULNERABILITY INDICATORS IN THE HEIHE BASIN

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ABSTRACT: Vulnerability to climate change is an increasingly relevant topic for "at risk" communities and ecosystems. An abundance of literature describes risk, impact, sensitivity and vulnerability with regard to climate change. These attributes of human and natural systems are difficult if not impossible to observe and measure, complicating their quantification. This paper presents an approach for quantitatively synthesizing these concepts. The use of indicators is a useful method of quantifying resource vulnerability. This paper presents a part of the research work of the AS25 project, a sub-project of the Assessments of Impacts of and Adaptation to Climate Change in Multiple Regions and Sectors (AIACC) focusing on an arid region of North West China. The paper reviews approaches for the formulation of indicators for agricultural, water resources and socioeconomic vulnerability to climate change in the Heihe River Basin. Quantitative issues involved with indicator formulation, computation and geographic allocation are discussed. Methods of fuzzy set construction are proposed for continuous, categorical, and qualitative indicators.

KEYWORDS: vulnerability, indicators, climate change, Heihe River, AS25 project

1. Introduction

The response of society and the environment to climate change is becoming a global concern (IPCC, 2001; Turner et al., 2003). In particular, the vulnerability of natural and human systems carries import for the future allocation of resources and planning of development (Kates et al., 2000). For this reason, the concept of vulnerability is related to concepts of sustainability, risk, social equity, and ecological stability (Vogel, 2001; Luers et al., 2003; Moss et al., 2001). Clearly, vulnerability, as an issue spanning such an array of resources and disciplines, requires an integration of information types for its assessment and evaluation. The "integrated assessment" approach has been suggested as an effective framework for analyzing this complex aspect of human-land systems (IPCC, 2001; Turner et al., 2003;

Polsky et al., 2003; Yin, 2001). Integrated assessment, as used here, implies a human dimension to environmental vulnerability.

Complicating the assessment is the fact that climate change vulnerability is generally not measurable or observable in the traditional sense. Additionally, the concept of vulnerability changes in context across spatial scales ranging from the individual human to country or global levels of aggregation (Polsky et al., 2003; Turner et al., 2003). It also changes in context geographically, as vulnerability in the middle of a city will likely be determined by a different set of criteria than vulnerability on a farm, or in a forest. However, climate change vulnerability can be conceptualized over multiple scales and arenas as a function of sensitivity (*s*), exposure (*e*), and adaptability (*a*) or lack thereof, as the case may be (Clark et al., 2000). From a probabilistic perspective, the likelihood (P) that a particular system of interest may be vulnerable is therefore expressed by the relationship:

$$\text{Vulnerability} = P(s)*P(e)*[1-P(a)]$$

With zero probability of any one of these factors (and 1-P(a) is considered as a factor), it can be argued that the system is not vulnerable. Unfortunately, as previously noted, these probabilities are very difficult to measure and must be estimated, determined by proxy, or otherwise qualitatively designated. In fact, the assumption that vulnerability can somehow be expressed in terms of various combinations of these three attributes is a necessary simplification for investigation of vulnerability in a variety of forms. Some researchers have suggested that a vulnerability including an adaptation term actually represents a "minimum potential vulnerability" and should be distinguished as such (Luers et al., 2003). This line of reasoning could be extended to the first terms of the equation as well, in that sensitivity is actually a form of endogenous vulnerability and the combination of sensitivity and exposure (to some form of climate change) indicates the degree of exogenous vulnerability (see Villa and McCleod, 2002; Vogel, 2001). The combination of adaptability with either endogenous or exogenous vulnerability would therefore indicate the respective minimum potential vulnerability. These terms will be used throughout this paper as descriptors of how indicators represent components of vulnerability. While Kaly and Pratt (2000) described a similar concept for the Environmental Vulnerability Index (EVI), it is not based on the probabilistic concept of vulnerability put forth above.

The use of indicators is valuable for the quantification and geographic allocation of vulnerability (United Nations, 2001; Moss et al., 2001). Since vulnerability is such a slippery subject to begin with, indicators may even be considered necessary for a description that is not completely qualitative and narrative. In order to assess vulnerability at a regional scale, a sufficient variety of indicators must be selected. This is necessary to insure that vulnerability at multiple spatial scales is represented, and that all components of the vulnerability equation are adequately represented. While it may not be possible to ensure equal representation, spatially or otherwise, the analysis should be transparent in terms of revealing these potential biases.

This paper presents methods for the geographic quantification and synthesis of vulnerability indicators. The objectives of the study were to devise a method to elucidate geographic patterns of vulnerability to climate change. In order to meet this objective, we conceptualize the elements of vulnerability and present indicators designed numerically represent these elements.

2. Study Site

The selection and spatial allocation of indicators is discussed in regard to the Heihe River basin, in North West China, illustrated in Figure 1. This area, located approximately between 37° and 43° North latitude and 97° and 103° East longitude, spans a wide variety of ecosystems and population densities. The basin encompasses approximately 128,000 square kilometers, with land cover ranging from irrigated agriculture to barren desert and including cities and other settlements of varying degrees of development. Elevation ranges between 688 and 5675 meters above sea level, with some of the highest areas experiencing extended periods of snow cover. Precipitation is generally between 100 and 250 millimeters per year, but can experience high variation geographically and temporally. Due to the wide variation in land cover, climate regime, and societal development, it is essential that vulnerability indicators are of sufficient number to capture the possible combinations of endogenous, exogenous and potential vulnerability at a variety of spatial scales.

3. Indicators

For practical reasons, the data sources and indicators considered here address spatial vulnerability at a limited number of spatial scales: square

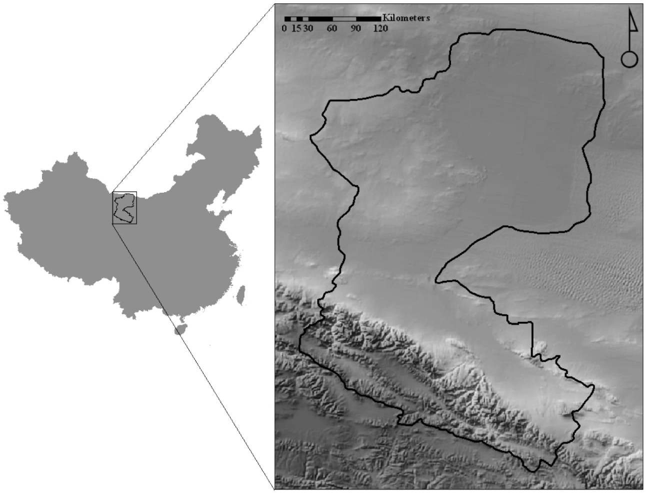

FIGURE 1

The Heihe River Basin.

kilometer, sub-watershed or water allocation district, and basin wide or regional scale. While some data are considered that represent vulnerability at the individual (health, per capita income) scale, these data are aggregated to the kilometer or county scale by necessity. Other data at intermediate scales are also presented, but will be either downscaled or aggregated to match the one-kilometer grid cells or county administrative units. Data sources are presented, where known, and indicated as to how they can be used in the calculation of the indicators.

The indicators derive from four fundamental categories: climatic, socioeconomic, hydrologic, and agro-ecosystematic. Clearly, these four categories are interrelated and it would be very difficult to create indices for any one category that are mutually exclusive of the others. Climatic indicators are the exception to this statement, though the other categories of indicators may incorporate climatic elements as exogenous vulnerability components. It is assumed that society and land cover at the Heihe basin level are of negligible influence on climatic indicators. The perceived representation in terms of the sector (socioeconomic, hydrologic, agricultural) and the vulnerability component in terms of exogenous or endogenous influences is described for each indicator and listed in Table 1.

Table 1

Potential Vulnerability Metrics and Their Components

Indicator	Computation	Required Data	Sector	Vulnerability Type	Indicator Source
Dry periods	# of months over the last 5 years with rainfall >20% lower than 30 year average for that month	Monthly precipitation past 30 years and projected 5 years	Climate, hydrology	Exogenous	Kaly and Pratt, 2000
Runoff yield change	(Projected yield)/(baseline yield)	Precipitation (baseline and projected), DEM, landcover, soil, other hydrologic model requirements	Climate, hydrology	Exogenous, endogenous	Kepner et al., 2004
Runoff ratio	(Surface discharge)/(rainfall)/(unit area)	Precipitation (baseline and projected), DEM, landcover, soil, other hydrologic model requirements	Climate, hydrology	endogenous	Lane et al., 1999
Irrigation ratio	∅(water yield – irrigation)scenario/(water yield – irrigation)baseline	Water yields and irrigation requirements (baseline and projected)	Climate, hydrology, agriculture	Exogenous, endogenous	Izaurralde et al., 2003
Irrigation deficit	Water yield – irrigation demand	Water yields and irrigation requirements (baseline and projected)	Climate, hydrology, agriculture	Exogenous, endogenous	Qi and Cheng, 1998
Price	Intersection of supply and demand	Price of water	Hydrology, socio-economic	endogenous	Feitelson and Chenoweth, 2002
Per Capita Water Resources	(annual surface water supply)/(population)	Water yields, population	Hydrology, socio-economic	endogenous	Multiple studies
Domestic deficit	Water yield – domestic demand	Water yields, domestic demand	Hydrology, socio-economic	Endogenous	Srdjevic et al., 2003
Dependence ratio	(water transfer volume) / (domestic demand)	Water transfers, domestic demand	Hydrology, socio-economic	Endogenous	Lane et al, 1999
Consumption ratio	(domestic demand)/(water)	Water yields, domestic demand	Hydrology, socio-economic	Endogenous	Moss et al., 2001
Shortage	Average of (shortage)/(demand) over every occurrence of shortage	Water shortage, domestic demand	Hydrology, socio-economic	Endogenous	Srdjevic et al., 2003

Table 1 Continued

Indicator	Computation	Required Data	Sector	Vulnerability Type	Indicator Source
Crop yield	Tons/hectare of crop	Crop yield	Agriculture	Endogenous, potential	Multiple studies
Yield index	(crop ET stressed)/(crop ET max)	Evapotranspiration, water availability, meteorological data	Agriculture, hydrology, climate	Endogenous	Thomas, 2000
Yield reduction	(yield w/o irrigation)/(yield with irrigation)	Crop locations, water yields, meteorological data	Agriculture, hydrology, climate	Endogenous	This study
Irrigation ratio	(irrigated land area)/(cultivated land area)	Crop area, irrigation area	Agriculture, hydrology	Endogenous, potential	Lin and Shen, 1996
Risk of hunger	(food energy required by population) – (food energy available from crops)	Crop productivity, energy conversion factors, population	Agriculture, socio-economic	Endogenous	Rosenzweig and Parry, 1994.
Crop land per capita	(cropland per unit area)/(population per unit area)	Crop area, population density	Agriculture, socio-economic	Endogenous	This study
Livestock per capita	(livestock by species per unit area)/(population per unit area)	Livestock, population	Agriculture, socio-economic	Endogenous, potential	Heilig, 1999
Proximity to other land use	Distance to urban or desert pixels	Agriculture, urban, land cover data	Agriculture, socio-economic	Endogenous, exogenous	This study
Income per capita	Income/population	Income, population	socio-economic	Potential, endogenous	Multiple studies
Institutional wealth	GDP, institutional credit rating	GDP, institutional credit rating	socio-economic	Potential	Feitelson and Chenoworth, 2002
Ginni index of income equity	Sum of differences between idealized income distribution and actual distribution	Income distribution by population	socio-economic	Potential, endogenous	United Nations, 2001
Poverty index	Fraction of population represented by the lower quartile of income	Income distribution by population	socio-economic	Potential	This study
Employment diversity	Sum of [(employment fraction)*(natural log employment fraction)]	Employment by sector, industry	socio-economic	Potential, endogenous	This study
Health	Life expectancy, infant mortality, disease incidence	Life expectancy, infant mortality, disease incidence	socio-economic	Potential,	Moss et al., 2001

4. Mapping and Scaling

The reason for choosing quantifiable indicators for the estimation of vulnerability is in part to facilitate spatial allocation. As discussed, the indicators may represent phenomena at disparate spatial scales. The first question is, therefore, how to geographically distribute the indicators. For the purposes of this study, several spatial scales have been considered ranging between square kilometer and county administrative unit. These scales were chosen entirely on the basis of data availability and other logistical reasons. The important consideration in this case is the computation of indicators at the appropriate scale. For example, precipitation and crop yield are spatially variable and more accurately represented at a spatial scale less than the county unit (Figure 2). On the other hand, institutional frameworks that define social vulnerability may be administered on the county level and therefore would not be represented accurately by the square kilometer. Thus data that represents various components of the vulnerability equation may be mapped at different scales.

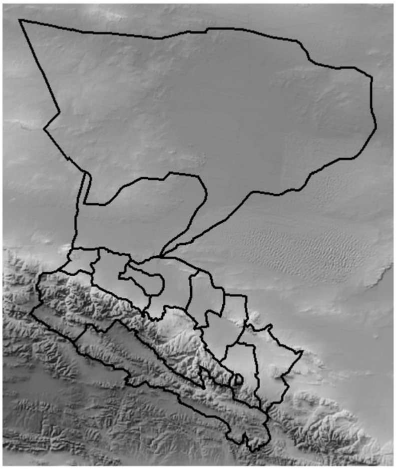

FIGURE 2

Counties of the Heihe Region.

The scaling issue is related to how the data should be conceptualized. Specifically, how observable phenomena, whatever forms the basis of the indicator, is actually related to vulnerability. Some information, such as available water for growing crops, may have a non-linear relationship with vulnerability - when the amount of water declines below a certain point, complete crop failure is expected. Consistent with the probabilistic definition of vulnerability, each indicator should be scaled to between 0 and 1, or a range between "not at all likely" and "100% likely." The question then becomes how to translate income, water shortage, yield reduction, or whatever is the indicator of interest to this scale.

Assimakopolous et al. (2003) present "Fuzzy Membership Functions" for converting continuous data to a membership grade between 0 and 1. The functions are defined as follows, where indicator value = x and c and d are parameters:

$$\text{Membership function} = f(x,c,d) = 1/(1+[(x-c)/d]^2)$$

In the case of a vulnerability ranking, the membership grade corresponds to probability of vulnerability. The membership function must be designed to reflect the relationship between the indicator value and the probability of vulnerability accurately as represented by the fuzzy membership value. Figure 3 shows how the membership function parameters presented by Assimakopolous et al. (2003) can be adjusted, based on expert judgment, to reflect vulnerability accurately. The parameter c is a threshold that defines the relative maximum location of the membership function (see Figure 3a) and d is a parameter that defines function width at 0.5 fuzzy membership (see Figure 3b).

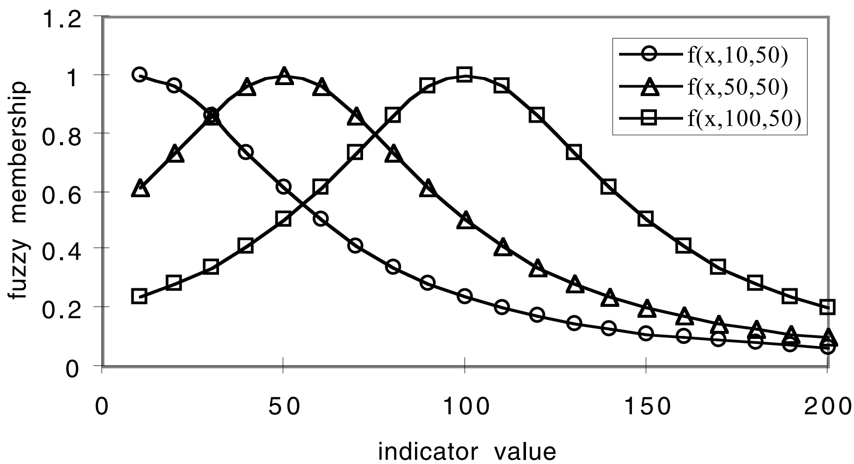

FIGURE 3A

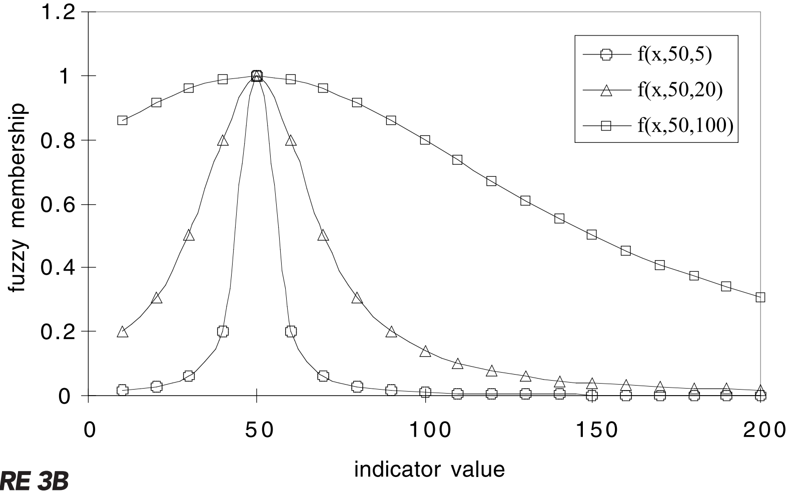

FIGURE 3B

FIGURE 3

Effect of c and d parameter variation in the fuzzy membership functions. 3a: the effect of varying c, the threshold value; 3b: the effect of varying d, the width of function parameter.

These functions should be defined according to the data. Linear or other relationships could also be defined as a way of transforming indicator values to vulnerability probability. Figure 4 shows the distribution of population density values in the Heihe basin according to two fuzzy membership functions. Scaled population data were allocated to fuzzy membership categories by dividing each population value by the maximum population density in the Heihe basin. A log transformation of the population results in a different distribution across the membership categories. As illustrated in Figure 4, log transformation of the population spreads low population densities over several fuzzy membership categories and compresses high population density into the upper fuzzy membership scale. The result is that vulnerability, as indicated by population density, is more evenly distributed over a scale of 0 to 1 according to the fuzzy membership function defined by:

$$\text{Membership function} = f(\text{population}) = \ln(\text{population})/[\ln(\text{maximum population})]$$

This function is useful from a cartographic perspective in terms of visualizing the spread of vulnerability according to population density. It is also valuable from an analytical perspective in that the geographic region is represented by a full range of vulnerability values after transformation by the membership function. The important consideration is whether the function logically describes the way an indicator actually "indicates" the likelihood of vulnerability. Assuming the relationship is accurate, it is then possible to convert spatially allocated indicator values to a map of vulnerability probability, with values between 0 and 1.

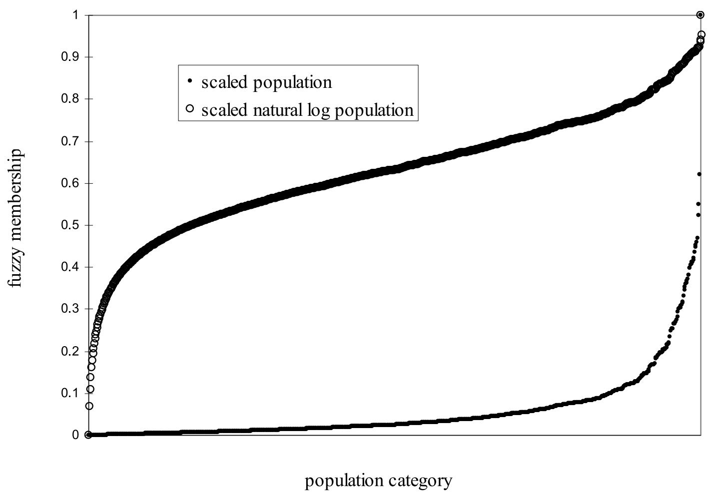

FIGURE 4

The use of a natural log transformation as a fuzzy membership function for population density in the Heihe Basin.

The previously discussed functions relate to the fuzziness of membership to only one category: vulnerable to climate change (or not). It may also be instructive to designate an arbitrary number of vulnerability classes, each corresponding to a particular level of probability. Let us assume there are 10 classes of vulnerability, ranging from 0-0.1 (low probability of vulnerability) to 0.9-1.0 (vulnerability extremely probable). Using the membership functions discussed above, it would be possible to allocate these values spatially, such that each pixel receives a probability corresponding to one of the classes of vulnerability. In general, the definition of a fuzzy partition of n observations (pixels) into c classes (vulnerability categories) is defined such that each pixel is represented by a vector with values Vi (Foody, 1994; McBratney and Moore, 1985):

$$\{V_1 \ldots V_c\};\ V_i \in [0,1];\ \Sigma V_i = 1,\ i=1 \ldots c$$

In the context of vulnerability to climate change, this data organization becomes somewhat abstract. A fuzzy partition of the vulnerability probability classes would thus organize the information such that each vector entry describes the probability that the probability of vulnerability is in a particular class. While it may sound odd, this is actually just an awkward way of expressing the uncertainty of exactly how vulnerable a particular pixel may be. In this sense, a fuzzy partition formalizes the uncertainty with regard to vulnerability probability.

Using GIS and image processing approaches, a variety of methods have been proposed for how to accomplish this allocation (Foody, 1994; Maselli, 2001). However, these methods rely on a posteriori knowledge of the distribution of values within "training" areas. In the case of vulnerability to climate change, this is not the case (some of the empirical methods discussed above are an exception). For this reason, alternative methods are required.

Assuming that some number (*n*) of vulnerability indicators have been computed and geographically allocated, that would imply that in any one pixel, there are *n* different levels of vulnerability. A simple fuzzy partition could be constructed using the frequency distribution of pixel values over the vulnerability classes. For example, if an equal number of layers had probability of vulnerability in the highest and second to highest classes and no other classes were represented, the top two vulnerability classes would receive 0.5 values. It should be noted that there is potential for bias in this method (Srdjevic et al., 2003; Kaly and Pratt, 2000; Lane et al., 1999). The source of the bias derives from the original choice of indicators. Due to the equal weighting, if indicators representing one type of vulnerability or sector are over represented, then the fuzzy partition of vulnerability will be biased. Srdjevic et al. (2003) present an unbiased method of weighting based on information "entropy," but due to the regional extent of the analysis, this method is considered unfeasible. However, provided the choice of indicators is transparent, any potential biases in the ultimate classification can be taken into consideration.

5. Discussion

This paper presents a wide variety of indicators describing various sectors and various combinations of sensitivity, exposure and adaptability. It is often easy to exclude exogenous vulnerability from the indicators: either it includes climate data or it does not. If an indicator fails to account for a possible climate future or any climatic effects at all, it is fairly safe to say that it represents purely some combination of endogenous and minimum potential vulnerability. Amalgamation of indicators into an index is complicated and possibly biased because it is difficult to quantify the precise amounts of endogenous and minimum potential vulnerability. Even geographic overlay analysis runs the risk of over representation based on subjective rendering schemes and the information inherent to the indicators. It is recommended that any interpretation of a composite index be performed with prudent use of professional judgment.

This dilemma is exemplified by the problem of combination of data at different scales. If an indicator mapped at the county scale represents minimum potential vulnerability (for example, social adaptability to water shortage) and another indicator mapped by square kilometer represents exogenous vulnerability (for example, projected water shortage in terms of demand minus supply), is it appropriate to multiply the two to derive a composite vulnerability? This is the temptation since, according to the theoretical framework, probability of exposure, multiplied by the probability of sensitivity, multiplied by the probability of lack of adaptation would give the probability of vulnerability to climate change. In practice, however, it may be impossible to insure an equal weighting of exposure, sensitivity, and adaptation in the multiplication of probabilities. For this reason, concatenation of indicators into an index is problematic and should be performed with caution.

While it would be beneficial to control bias through the careful choice of indicators, this strategy is constrained by information availability and/or credibility. An integrated assessment of vulnerability on a geographic basis is thus limited to available data sources. Using what is available, an eclectic mixture of indicators may emerge and require synthesis into meaningful policy data. In order to facilitate this process, the organization of indicators into logical categories that represent specific sectors will help to clarify the information derived from the analysis.

The methodology proposed in this paper is untested. However, many of the indicators presented have been used successfully in other parts of the world. As such, this study lays the foundation for a comprehensive compilation of indicators and is intended as a framework from which to proceed in data acquisition efforts. In that sense, the potentially considerable task of assembling, formatting, and interpreting multidisciplinary information about climate change vulnerability is focused by a conceptual foundation.

6. Conclusion

The intention of this study was to provide an assortment of indicators and assessment techniques that would enable regional mapping of vulnerability. The indicators were chosen with regard to known data sources and may not be representative of the best or most up to date information available. However, the probabilistic foundation on which the study is based is a framework that can be used to interpret any number of other indicators. The method and approach for the compilation of indicators, geographic allocation and synthesis is valid for other sets of data as well. Of course, the better the data used to derive the indicator in the first place, the more confidence can be had in its descriptive power.

One potential shortcoming of the probabilistic approach is that vulnerability is scaled between 0 and 1. While this may be useful in defined regions of interest, it may obfuscate differences between regions, especially internationally. Thus, areas that receive vulnerability ratings close to one (extremely vulnerable) may experience vastly different magnitudes of social and environmental impacts from climate change, depending on their geographic and international context.

The method proposed here is intended to benefit future studies that aim to compile regional estimates of vulnerability. The types of data required, the linkages between sectors, and some mathematical approaches to the formulation of indicators are merely presented as a guide for the establishment of a vulnerability geographic information system. Some of the methods may not be appropriate at local or national scales. This consideration of scale will be important in the determination of what indicators are necessary and feasible for the inclusion in any potential study of vulnerability. Additional research is needed to test the approaches presented in this study.

7. Acknowledgments

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9 paper

REGIONAL ASSESSMENT OF CLIMATE CHANGE IMPACTS IN CANADA:
OKANAGAN CASE STUDY

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ABSTRACT. A collaborative study on climate change and water management in the Okanagan region of British Columbia, Canada, has been underway for several years. An interdisciplinary approach is used, incorporating participatory processes as part of the research on regional adaptation experiences and consideration of future responses. Results of hydrologic and water demand research efforts indicate that future climate changes are likely to result in reduced water supply, increased water demand, and an increased frequency of high risk years in which high demand and low supply occur concurrently. The region has experienced droughts in recent years, and several communities and water purveyors have initiated measures to manage water demand. Future climate change will require a portfolio of supply and demand measures, and need to be considered as part of a basin-wide strategy that integrates with regional development plans.

Keywords: water resources management, climate change, adaptation, participatory integrated assessment, Okanagan region

1. Introduction

Human-induced climate change, evolving from continued increases in atmospheric greenhouse gas concentrations, represents a problem of great complexity. If the world warms as projected by global climate model simulations, there will be implications for climate-sensitive natural resources, and the communities that depend on them. One example is water resources. A warmer climate will affect all aspects of the hydrologic cycle, leading to changes in streamflow and available water supplies. Demand for water is also likely to change, both for supporting agriculture as well as ecosystems, industries and cities.

A number of case studies have been carried out for various watersheds around the world (Arnell et al., 2001). These illustrate the sensitivity of watersheds to recent climatic trends, as well as to future climate change scenarios. The number of people experiencing increased water scarcity is expected to rise.

Improved understanding of the human implications of changing water resource conditions requires increased research efforts in hydrology and water demand, but in addition, we must recognize the importance of the regional context of governance and decision making. The severity of projected impacts, and the ability of regions to respond, will depend on the region's exposure, vulnerability and adaptive capacity. Previous experience with droughts and other climatic extremes provide opportunities to examine how regional stakeholders planned for such events, and acted on knowledge and advice provided by professional staff and regional constituents (e.g. large irrigators, municipalities, watershed committees).

One approach that can be considered when assessing the bio-physical and human implications of climate change is a collaborative interdisciplinary research effort, which is based on developing a partnership between researchers and stakeholders. This is meant to create an exercise in shared learning. Dialogue processes are critical to this process, extending beyond simply performing an outreach function. In this approach, dialogue contributes important information on how adaptation options may be considered by governments, private enterprises, and community groups. Advocates of this approach, known as participatory integrated assessment (PIA), suggest that this can lead to an increase in stakeholder commitment to both the study process, as well as to subsequent use of research findings in policy decisions. As well as shared learning, this approach can create a sense of shared ownership in problem framing and study results. Rotmans and van Asselt (1996) have described integrated assessment as a process that can promote active dialogue and knowledge sharing between scientists, in the form of interdisciplinary research, and local knowledge holders, who use their experiences and judgements to help frame research questions and express response options that satisfy the region's interests. A participatory approach can complement research produced through quantitative models and fieldwork (Hisschemöller et al., 2001).

This paper describes a case study of the Okanagan region of British Columbia, Canada. It is a semi-arid watershed, around 8,200 km^2 in area. The region is experiencing rapid population growth, doubling since the 1970s. Agriculture is very important to the regional economy (Figure 1), and almost half of the region's cropland is irrigated.

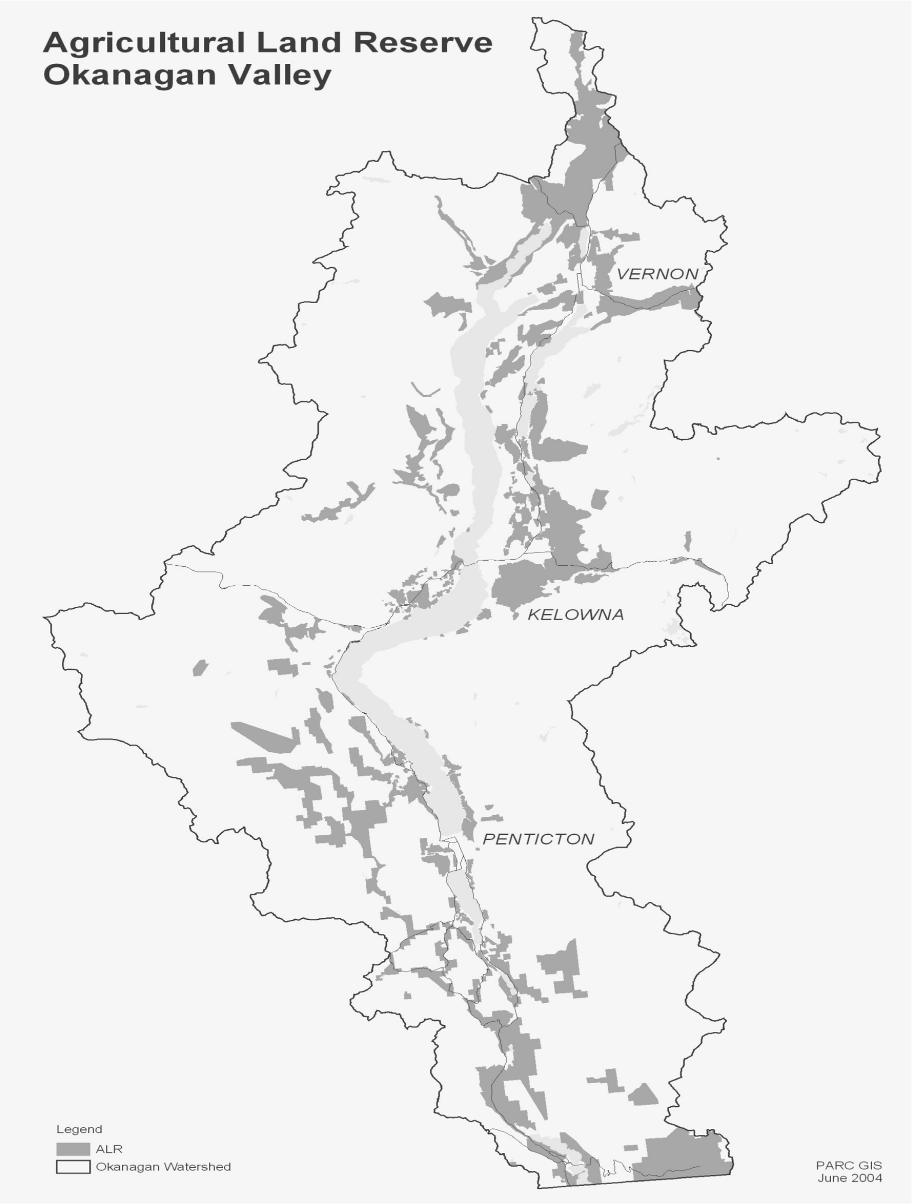

FIGURE 1

The Agricultural Land Reserve (ALR) in the Okanagan Basin, British Columbia, Canada (Neilsen et al., 2004b).

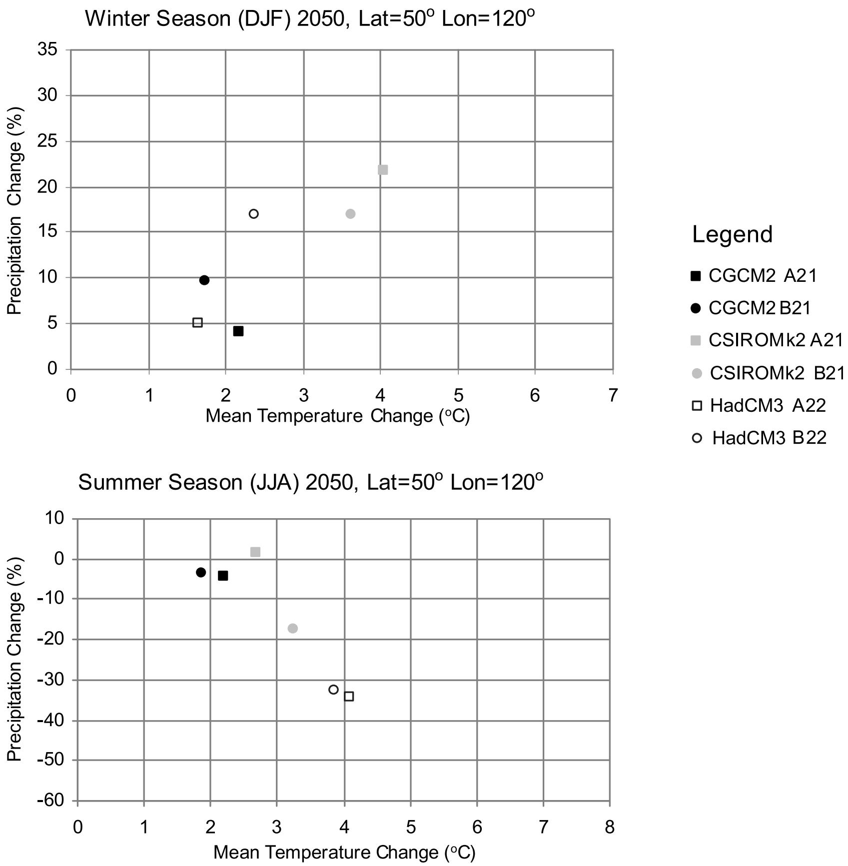

FIGURE 2

Scatterplots of projected changes in average daily temperature (degrees Celsius) and precipitation (percent) for the 2050s relative to 1961-90 for winter (top) and summer (bottom) for three GCMs and two SRES scenarios for southern BC (Taylor and Barton, 2004).

2. Climate and Hydrology

Scenarios of future climate change were obtained from the results of 3 global climate models and 2 scenarios of global greenhouse gas emissions. The climate models selected were Canada's CGCM2, Australia's CSIROMk2 and the United Kingdom's HadCM3 (Figure 2). The emission scenarios were A2 (high growth) and B2 (low growth) from the Intergovernmental Panel on

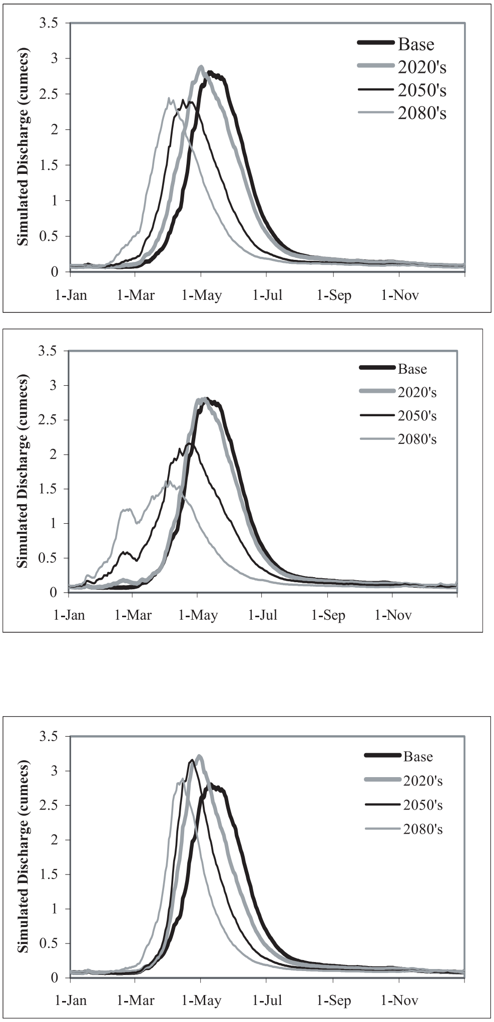

FIGURE 3

Impacts of climate change scenarios on Whiteman Creek, near Vernon (Merritt and Alila, 2004), using the A2 emissions scenario for CGCM2 (upper left), CSIROMk2 (upper right) and HadCM3 (lower left). *Note: Images as provided by author.*

Climate Change (IPCC, 2000). These scenarios indicate that temperatures would increase between 2 and 4 degrees Celsius by the 2050s. Winter precipitation would increase between 5 and 20 percent. Summer precipitation remains the same in some cases, and declines in others. The worst case is for HadCM3-A2, with a summer precipitation decrease of 30 percent (Taylor and Barton, 2004).

The climate scenarios were used as input to a hydrologic model, the University of British Columbia (UBC) Watershed Model, in order to simulate changes in streamflow and water supply. Results show that for all 6 scenarios, the annual peak streamflow would occur earlier in the year due to earlier snowmelt. However, the nature of the peak would vary among the scenarios. An example is shown for Whiteman Creek in the north Okanagan (Figure 3). The CSIROMk2 showed lower peaks extending over a longer period, while the HadCM3 scenarios showed a more compressed peak, higher at first but then becoming lower than present day peak flows (Merritt and Alila, 2004).

Estimates of annual water supply were generally lower than present day supplies. These reductions would be modest during the 2020s, but would become more severe during the 2050s and 2080s. For a reservoir in the southern Okanagan, near the city of Penticton, the worst case reduction would be 35 percent by the 2050s and 66 percent by the 2080s (Merritt and Alila, 2004).

3. Water Supply and Demand

Water demand for agriculture and residential users was determined based on established local relationships between climate and crop type or population growth, respectively (Nielsen et al., 2004a; 2004b). A longer warmer growing season is expected to lead to increased water demand on a per hectare (agriculture) or per capita (residential) basis, assuming no change in water delivery policy or technology. The increased growing season temperatures are expected to lead to increased evapotranspiration. Once this estimate is provided, there could be an opportunity to look at the effects of various options to reduce water demand.

Although most of the summer precipitation scenarios describe decreases in June to August rainfall, the demand functions used in this study are based only on temperature. Winter demand in the Okanagan is assumed to be unaffected by climate change. It is also assumed that there is no direct effect of elevated atmospheric carbon dioxide due to the inconclusive nature of the literature on such effects as they pertain to irrigated crops and orchards (Neilsen et al., 2004b). These various assumptions, however, contribute to the

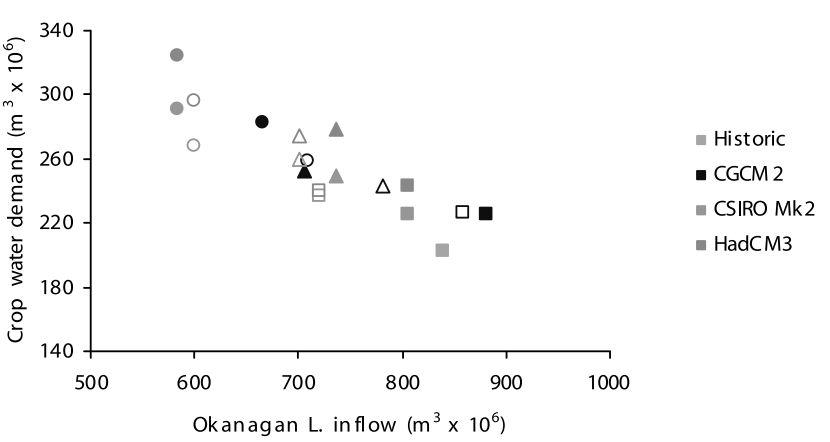

FIGURE 4

Comparison of estimated demand for irrigation water in the Okanagan Basin and estimated inflow into Okanagan Lake under historic conditions and six climate scenarios at three time slices: 2020s (■), 2050s (▲), 2080s (•). Filled symbols are A2 scenarios and open symbols are B2 scenarios. (Neilsen et al., 2004b).

uncertainty associated with scenario-based studies of climate change impacts and adaptation.

Crop water demand for the region as a whole is projected to increase by 30 percent or more by the 2080s (Figure 4), compared with the estimate for the 1961-1990 historic climate (Neilsen et al., 2004b). Projected decreases in Okanagan Lake annual inflows are 15-30 percent. Residential water demand is also expected to increase, primarily because of projected population growth, but climate change would accelerate this increase (Neilsen et al., 2004a). This scenario of reduced supply combined with increased demand suggests an increasing risk of water shortages during the next several decades.

4. Adaptation—Experiences & Dialogue

The Okanagan region is no stranger to managing for water shortages. Water managers and planners have foreseen potential problems for regional water resources, such as the implications of population growth (Obedkoff, 1994). Case studies of early adopters of alternative management strategies indicate that there is an ordered sequence of stages, where local actors a) detect a signal, b) attribute this signal to a particular cause, c) make a decision to respond, d) implement the decision, and e) evaluate the effectiveness of this response.

There were four case studies, two on demand reduction through metering, one on water reclamation and one on amalgamation of 4 separate municipal utilities into one regional water delivery system (Shepherd, 2004). These cases reveal that although the basic stages are followed, each case has its own specific conditions that create challenges and opportunities for adaptation to climate change. Briefly, these are a) values and perceptions toward the resource, b) financial aspects, and c) regional politics and policy. There are both objective and subjective aspects. Analysis of these cases suggests that the two metering cases represent strategies that are more likely to be successfully implemented. The other two would have to overcome more barriers, both technical, financial, and/or institutional (Shepherd, 2004).

Subsequent dialogue with regional water interests focused on the future scenarios of climate change. Local and whole basin workshops were organized during the winter of 2003-2004 (Tansey and Langsdale, 2004). The objectives were to report on research findings, to gain local insight on the feasibility of various adaptation options, and to discuss issues associated with the potential implementation of these options as part of an adaptation 'portfolio' at the local and whole basin scales. A wide range of options was available for discussion, including augmenting supplies with increased storage capacity or access to additional surface water and groundwater sources, and managing demand through metering, education, regulation and new delivery technologies (e.g. drip irrigation).

The two community workshops were held in Oliver, British Columbia, Canada, a small town in the southern Okanagan, and the Trepanier area, an unincorporated region near Kelowna experiencing rapid population growth. These communities had quite distinct reactions to the various options. Oliver favoured an approach that would enable it to maintain its focus on agriculture and avoid rapid population growth, while Trepanier wanted to anticipate rapid growth with access to more sources. Both were interested in expanded groundwater use, but were concerned about potential environmental implications (Tansey and Langsdale, 2004).

Bringing this dialogue to the scale of the whole basin proved to be difficult. There was indeed a different character to this dialogue, one that was broader, more strategic than the local discussions. An important theme that emerged from here was the need for integration of water and land use planning, and for some form of basin-wide governance on water issues (Tansey and Langsdale, 2004).

5. Conclusion

A warmer climate, as described in the scenarios used in this study, would lead to reductions in annual water supply and increases in agricultural and residential water demand in the Okanagan region of British Columbia, Canada. Many adaptation options are available, and the region has had previous experience with many of these, but each one comes with its own attributes and challenges, and some may be easier to implement than others.

The study's interdisciplinary approach, and the collaborative aspects with regional water interests and expertise, enabled the development of a positive working relationship, and an experience of shared learning. It is hoped that this establishes a good foundation for continuing collaborative efforts in the future.

The final report of this study (Cohen et al, 2004a) is now available. During 2004-2006, there will be a new phase on developing a dialogue on adaptation policy. This will be supported by an exercise to build a decision support model of the Okanagan system, through a group model building process (Cohen et al., 2004b).

6. Acknowledgements

This study was a collaborative between researchers from Environment Canada, Agriculture and Agrifood Canada, University of British Columbia, British Columbia Ministry of Water Land and Air Protection, and regional partners. Support was provided by a grant from the Climate Change Action Fund; project A463/433 (now Climate Change Impacts and Adaptation Directorate), Natural Resources Canada, Ottawa. Opinions expressed here are those of the author and not necessarily those of Environment Canada and the study partners.

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10 paper

WAR AS A SOCIAL-ECOLOGICAL RESPONSE TO CLIMATE CHANGE IN ANCIENT CHINA

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ABSTRACT: In recent years scientists have studied the phenomenon of climate change intensively and its implications for the future of the human race. By contrast, there has been little study on the dramatic effects of climate change upon human society in history. In this study we explore the relationship between climatic change and war in China, by comparing high-resolution paleoclimatic reconstructions with the known incidence of war in China over the past millennium. We demonstrate a remarkable correlation between climatic change and the incidence of war. Wars broke out more frequently during cold phases. We suggest that the reduction of thermal energy input during cold phases resulted in the shrinking of livelihood resources in the traditional agrarian society, which in turn led to armed conflicts or wars between states, tribes and peoples on the lands with different carrying capacity.

Keywords: climate change, war, ancient China, temperature anomaly, correlation, agricultural production

1. Introduction

The idea that climate change can produce important social, cultural and economic changes in human society is not new. As wars are socially-organized armed conflicts, and often have economic or cultural causes, it should not be surprising that climate changes, which can seriously affect the level of food production, have been an important cause of war. However, the assumed relationship between climate change and war has not yet been substantiated with scientific evidence. Historians have often looked for political, social or economic causes of wars (Evera, 1999;Seabury and Codevilla, 1989) but the relationship between climate change and war has never been systematically examined.

Over the last thirty years, scientists around the world have carried out intensive research on past climate changes. Research in the last decade, in particular, has yielded significant improvements in high-resolution paleoclimatic reconstructions of the last millennium, using multi-proxy data networks with a focus on a global-warming trend. The conclusion is that the last century was the warmest in the last millennium (Jones et al., 2001; Mann et al., 2003). These refined paleoclimatic records provide a strong base for analyzing climatic change and war associations. Meanwhile, in the course of China's long history of civilization, voluminous documentation in the palace archives of different dynasties, dating back to 880 B.C., systematically recorded all major events. This valuable and comprehensive documentary repository provided a rich database for studying wars.

2. Methods

In this research, we use four independent sets of data, covering climate change and the incidence of warfare respectively in China during the last millennium, to investigate the influence of climate change on warfare. Briffa and Osborn (2002) have chosen the five most representative and recent climate series of the last millennium in the northern hemisphere to discuss the differences between the records of various independent studies (Figure 1A).

Despite the diverse sources of data, all five high-resolution climate records register a close match between their warm and cold phases and highly significantly correlated with each other. Such congruence of data acquired independently by different authorities suggests a high degree of accuracy with reference to both temperature and timing. These climate series provide a rather reliable basis to investigate the relationship between climate changes and historical events, in this case, wars in China. The records from A.D.1000 to 1980 have been adopted as the standard climate variations in this study.

These records were reconstructed by using multi-proxy data, which were achieved from tree ring, coral, ice-core, borehole and historical document studies, including those from China. The data were recalibrated with linear regression against the 1881-1960 mean annual temperature observations averaged over the land area north of 20 degrees North and the results smoothed with a 50-year Gaussian filter. Those recalibrated records were then averaged in order to quantitatively define the boundaries of the cold and warm phases. A cold or warm phase was determined whenever an average temperature anomaly had an amplitude exceeding 0.14 degrees Celsius. This delimitation enabled the authors to equalize total lengths of cold and warm phases during the last millennium.

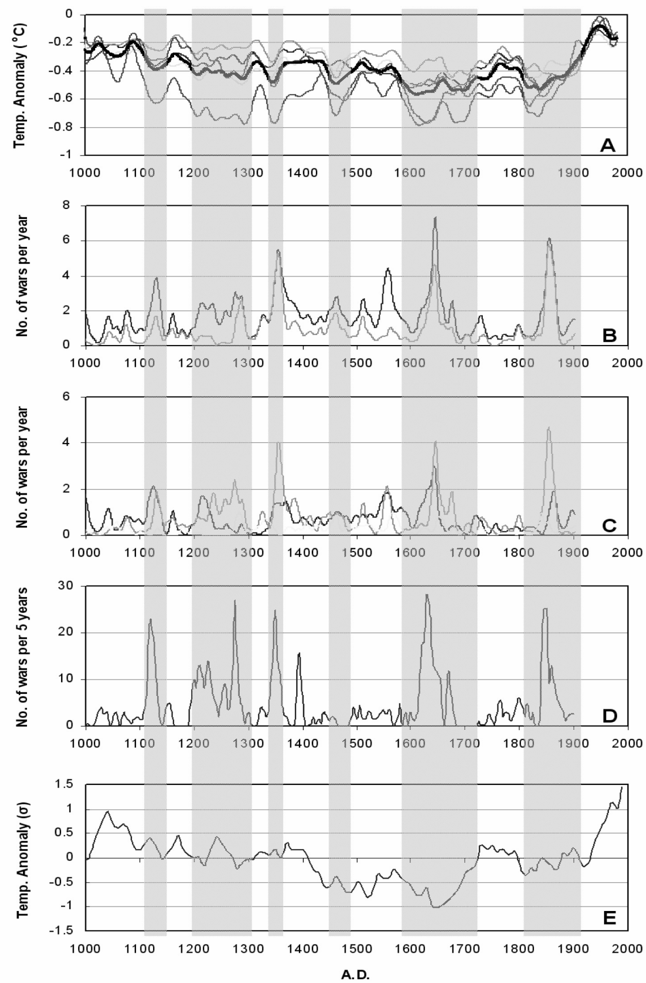

FIGURE 1

Climate changes and incidence of wars in China during the last millennium.

A. Normalized temperature change records for the last millennium for land areas in the northern hemisphere north of 20 degrees: Mann (1998,pink); Briffa (2000, turquoise); Jones (1998, dark blue); Cowley and Lowery (1997, dark red); Esper (2002, blue); and the average of these five normalized series (black). Cold phases are shaded as gray strips. **B.** Frequency of all wars (dark blue) and frequency of rebellions (pink). Data is smoothed by Gaussian 50-year lowpass filter. **C.** Frequency of wars, in North China (dark blue); in Central China (pink); and in South China (yellow). Data is smoothed by Gaussian 50-year lowpass filter. **D.** Number of wars per five years in China recorded by Lee (1931). E. Temperature anomaly data of China reconstructed by Yang et al (2002).

Six major cycles of warm and cold phases between A.D. 1000 and 1911 are identified. The boundaries between warm and cold phases were delineated at the mean temperature point between minimum and maximum values of two contiguous phases on the averaged reconstruction. The warm phases are A.D. 1000-1109, 1153-1193, 1303-1333, 1360-1447, 1488-1582, 1718-1805 and the cold phases A.D. 1110-1152, 1194-1302, 1334-1359, 1448-1487, 1583-1717 and 1806-1911. The aggregated duration of the cold phases is 459 years and of the warm phases 453 years. Similar cycles have been shown in many other reconstructions of climate change both in China and in the northern hemisphere generally (Mann et al., 2003; Zhang, 1981; Wang, 1990; Ge, et al., 2002).

The latest record with a lower resolution of a 10-year scale for China was also chosen for comparison between local record and those of the land area north of 20°N (Figure 2E) (Yang 2002). The series is only used as a comparison due to its lower resolution. The record also approximately agrees with those of hemisphere scale. However, half of the cold phase during 1200-1300 A.D. was a warm phase (>0 sigma units) in this reconstruction.

Our data on the incidence of warfare was derived from a multi-volume compendium that exhaustively catalogues all known wars in China between 800 B.C. and A.D. 1911 (ECCMH, 1985). This compendium lists a total of 1,672 wars between 1000 and 1911, and these were used as the database for this study. Only the year of inception, number, participants and location of the wars from this authoritative treatise are used as reliable data for scientific analysis in the present study in order to avoid bias that might result from the diverse sources of information. Based on the identity of the participants in a particular conflict, we classified wars into two groups: rebellions and others (state wars and tribal wars).

Based on a conventional classification of China's physical regions (Zhao, 1986; and Ren et al., 1985), we divided the wars into three different geographical regions for this study as shown in Figure 2: (1) North China, which is characterized by continental semi-humid, semi-arid and arid temperate climates and economic activities that were mainly pastoral agriculture; (2) Central China, which has a subtropical climate dominated by monsoons and has historically served as China's major rice producing area; and (3) South China, which has both southern subtropical and tropical climates and cultivation that enjoys a long growing season with double- or triple-cropping in a year.

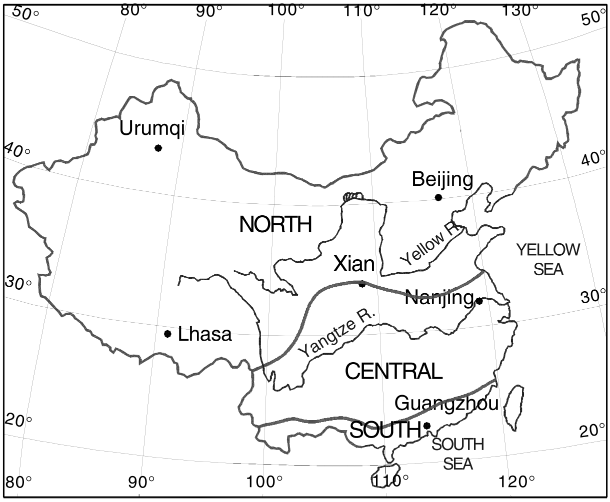

FIGURE 2

Physical regions of China.

In the statistical and frequency analysis, the war data were smoothed by a Gaussian filter with a 50-year interval in order to make it comparable to Briffa's temperature series. Another set of war data (Lee, 1931) provides a diagram of war frequency over time. The war frequency from 1000-1910 A.D. on the diagram was reproduced for this study. As the exact number of wars cannot be retrieved from the diagram, it is only used as a comparison figure to our primary statistics of war frequency (Figure 1D).

3. Results

As with variations in climate, war frequency in China also demonstrates a cyclic pattern. Typically, a turbulent period is followed by a relatively tranquil one (Figure 1B). Eight out of the ten peaks with a high frequency of wars (above 2 wars per year) coincide with the cold phases. The three highest peaks stand out well above the others. Two of these occurred in the coldest phases (< –0.5 degrees Celsius), and the third may represent a carry-over from the previous long cold phase (only a 30-year warm phase separated two cold phases). All cold phases have one or two high frequencies of war. Only two high war frequency peaks fall outside the cold phases (both during the sixteenth century). The two aberrant peaks were mainly the result of wars against pirates intruding from overseas and nomadic invaders from the north. Pirate raids accounted for around 50% of the total incidence of wars in the 1550s (ECCMH, 1985). Rebellions appear to be the dominant category of war in the record (Figure 1B).

The incidence of rebellions is highly correlated with climate changes, and all high frequency rebellion incidences fall in the cold periods. In warm and wet South China, variations in the incidence of wars were less sensitive to changes in temperature (Figure 1C). The outbreak of wars in North China often had a close association with cold phases. All seven highest war frequencies (>2 wars per year) in Central China occurred in cold phases and the peaks neatly followed the cold phases. It is also interesting to note that wars in North China broke out immediately after the onset of a cold phase, except during the cold phases in the fourteenth and nineteenth centuries, when China was ruled by northern nomadic peoples (the Mongols and the Manchus respectively). Compared to war frequencies from Lee (1931) (Figure 1D), of the 9 highest war peaks (10 wars per 5 years), 8 fall in the cold phases.

To compare with Yang's complete China temperature series, 8 out of 10 high frequencies of total war (>2 wars per year) and 4 out of 5 rebellion high war peaks fall in cold times. In Central China, 5 out of 6 high war peaks occurred in the cold periods. For Lee's war series, only 5 high peaks are in Yang's cold periods.

To refine this analysis, the number of wars and their occurrences and the war ratios in both cold and warm phases are shown in Table 1. Their relative distribution shows a pattern consistent with the above observation. The Pearson's correlation coefficients between war frequency and temperature anomalies have been calculated at the annual scale. The Pearson's correlation coefficients between war frequencies and temperature anomalies have been calculated at the phase, decadal and annual scales. The highest frequency of total wars, rebellion wars and wars in Central China in each climatic phase are significantly correlated with the lowest temperature and mean temperature in the phase. The numbers of total wars, rebellion wars and wars in Central, South and North China are all significantly correlated with the temperature variation of the Northern Hemisphere in the annual scale (Table 2), which also indicates that the most highly correlated war categories are the wars in Central china and rebellion wars.

Table 1 Number of wars and ratios of wars in cold and warm phases in different war categories

	TOTAL	REBELLION	CENTRAL	NORTH	SOUTH
Cold phases (459 years)	994	536	462	351	116
Warm phases (453 years)	678	275	237	278	110
Ratio of wars (cold/warm)	1.45	1.92	1.94	1.25	1.04

Table 2 Pearson's correlation coefficients between number of wars and the temperature anomaly from AD 1000 to 1911 in China

	N = 902 (LAG = 0 YRS)	N = 897 (LAG = 0 YRS)	N = 892 (LAG = 0 YRS)	N = 887 (LAG = 0 YRS)	N = 882 (LAG = 0 YRS)	N = 877 (LAG = 0 YRS)	N = 872 (LAG = 0 YRS)
Total	-0.223***	-0.264***	-0.285***	-0.285***	-0.265***	-0.231***	-0.190***
North	-0.106**	-0.144***	-0.153***	-0.135***	-0.096**	-0.041	+0.018
Central	-0.225***	-0.269***	-0.299***	-0.310***	-0.303***	-0.285***	-0.261***
South	-0.112**	-0.087**	-0.070*	-0.067*	-0.078*	-0.092**	-0.100**
Rebellion	-0.247***	-0.279***	-0.297***	-0.297***	-0.280***	-0.254***	-0.228***

• = P<0.05, ** = P<0.01, *** = P<0.001.
War Data is smoothed by Gaussian Filter (year = 50)

The correlations were also run for different time lags at the annual scale in order to gauge how the delayed climate impact upon agricultural production was reflected socially in the form of wars. The highest correlation coefficients for the four war categories have a time lag of 10-15 years, except for south China where war occurrence had no time lag. Compared to the wars in Central China, wars in North China are only significantly correlated with the temperature anomalies with a shorter time lag of 10 years. It appears that climate change caused a more rapid social response (war) in North China than in Central China. Less significant correlations were found for South China. The outbreak of wars led to the collapse of dynasties during A.D. 1000-1911. All dynastic changes following high war frequencies in the study period basically occurred in cold phases, except the collapse of the Yuan Dynasty which happened just a few years after the end of a short cold phase. Of the six cold phases, five led to dynastic collapses during the last millennium.

4. Analysis

The high degree of match between war frequencies and cold phases, higher war ratios in cold phases, and the significant correlations between war frequency and temperature fluctuations in the last millennium seems unlikely to be merely accidental. The explanation for this striking correlation may be that the reduction of thermal energy input in cold periods was the root cause of many social unrests and uprisings. China was an overwhelmingly agrarian society throughout this period. Traditional agriculture was very much dictated by the whims of climate and weather conditions.

Any reduction of thermal energy input would impact upon agricultural production. For example, China's agricultural yields between 1840 and 1890 (a cold period) were between 10% and 25% lower than between 1730 and 1770 (a warm period) because of a shortened growing season, an increase in the number of frost days, and frequent cold spells during the cold periods (Gong et al., 1996).

Cold weather resulted in poor harvests, as shown by the history of rice cultivation in the middle and lower reaches of the Yangtze River, where double cropping of rice failed during the cold phases and started again in warm phases (Gong et al., 1996). A reduced food supply would trigger famine, tax revolts, and a weakening of state power. The shortage of livelihood resources would also be aggravated by population growth that had occurred in the preceding warm period. Rebellions would therefore be more likely to break out during cold phases, and it can be seen that the highest three peaks of wars were dominated by peasant wars (ECCMH, 1985). Domestic unrest also opened the gate for foreign invaders and sharpened competition for a shrinking resource base between states, ethnic groups and tribes.

The geographical distribution of wars further supports the hypothesis that climate change has had a major influence on warfare in China (Figure 2C). In wet tropical and subtropical South China, a drop in temperature during a cold phase would often have a less serious effect on agricultural production than other parts of China, and would not have caused the same degree of social unrest. In contrast to South China, Fig 2C reveals a marked increase in wars of Central China in cold phases. However, in Central China wars tended to break out some time after the start of a cold phase and the major outbreaks were characterized by low frequency and high amplitude. The reason is probably because, in Central China (unlike North China), surplus farm products could be stored to serve as a cushion in difficult times and social dissatisfaction therefore would have taken longer to reach a breaking point.

Grazing was the principal means of sustenance in North China, and this was sensitive to a fall in temperature. Sensitive agriculture brought about a quick response (a shorter time lag) of social unrest, many of which were characterized by incursions by desperate nomadic warriors from the Mongolian grasslands into the fertile plains of Central China. Compared with Central China, the outbreaks exhibit a lower amplitude and shorter frequency. The sensitive response, plus the facts that people in the north freely shifted southward (Fang, 1992) and that livelihood resources could be transferred from the south to the north during the northern nomadic occupation (400 years) may explain why the war ratio between cold and warm phases and the correlation coefficients between temperature anomaly and war numbers in North China (Tables 1 and 2) were not high compared with Central China.

In addition to temperature, some authors (Zhang et al., 1997 and Yang and Shi, 2001) considered that the fluctuations of precipitation in history also influenced social evolution. Indeed, the 13th century drought in China may be one of controlling factors on 13th century high war frequency. However, compared with temperature change, the regional differences of precipitation variation were much higher and there is no high resolution precipitation series from multi-proxy records for the last millennium. Therefore, the degree of precipitation impact on war frequency will rely on the completion of high-resolution reconstruction of paleoprecipitation records.

5. Conclusion

The findings of this study are of great theoretical significance. Historians have long tended to look for economic, political, and ethnic explanations or causes for wars. These traditional classifications, however valid the explanations they provide, do not adequately take into account the effects of climate change. Our research indicates that climatic change in China – specifically, a cooling of the climate – has created conditions favorable for the outbreak of wars, and in extreme cases has helped to overthrow dynasties. The ancient Chinese philosopher Mencius (374-288 B.C.) perceptively envisaged a cycle in which a period of order was perforce followed by a period of disorder. The Chinese believed generally that a minor disturbance was expected every thirty years and a major one every hundred years (Hsu, 1995).

Interestingly, during the last millennium the cold phases of the averaged reconstruction could be divided into long ones, each lasting 105-133 years, and short ones of 25-43 years. Lee (1931) also found out such a cyclic pattern of war, but could not explain it. The major disorders often coincided with the collapse of dynasties. Western scholars have described the rise and fall of dynasties as a "dynastic cycle", the study of which has engendered numerous economic, evolutionary and developmental explanations of Chinese history (Elvin, 1973; Hartwell, 1973). These cyclic theories tried to explain the rise and fall of dynasties as the consequence of social evolution or internal mismanagement. The results from this research suggest that climate change is associated with the social unrest and armed conflicts and should therefore be incorporated in cyclic theories.

While wars will always have their specific political, social and economic causes, we should no longer ignore the long-term effects of natural forces on human society. Seen from a broad perspective, Nature appears to have profoundly influenced the course of China's history during the last millennium. The influence of climate change on war adds a new dimension to the classical concept of Darwinism and environmental determinism.

6. Acknowledgements

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11 paper

HOW SHOULD CANADA ADAPT TO CLIMATE CHANGE:
DEBATING THE MERITS OF A TECHNOLOGICAL FIX VERSUS A BEHAVIOURAL APPROACH

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ABSTRACT: This paper is a discussion on whether climate change adaptation should focus on the use of existing, and the development of new, technologies or whether it should focus on the root causes of vulnerability - behavioural change and risk perception. The technological fix argument is that resources should be put into promoting existing technologies that have been shown to be effective but underutilized, and the development of new technologies. The behavioural change argument is that behavioural change is essential, and the notion that one must choose either a technological or a behavioural solution is a false dichotomy. The paper concludes that technology will undoubtedly play a large and important role in climate change adaptation, but by itself is not sufficient to solve the adaptation problem. Behavioural changes are necessary as well - indeed they are likely to be the more crucial factor.

Keywords: climate change, adaptation, technology, behavioural change

1. Introduction

This paper is a discussion on whether adaptation should focus on the use of existing, and the development of new, technologies or whether it should focus on the root causes of vulnerability - behavioural change and risk perception. The authors recognize that any future initiative and policy will include both technology and behaviour, but the issue of emphasis is subject to disagreement and requires further discussion. Brad Bass' recent research has encompassed first hand experience with new technologies, such as green roof infrastructure, simulating the adoption of new energy technologies and simulating the emergence of new strategies. David Etkin's research has included an assessment of natural hazards and disasters across Canada, hail and tornado risk in Canada, impact assessments of catastrophic events such as the 1998 Ice Storm in Quebec and the role of vulnerability in increasing loss and how responses to hazardous events increase vulnerability.

2. The Technological Approach to Adaptation

A technological approach argues that resources should be put into promoting existing technologies that have been shown to be effective but underutilized, the development of new technologies such as nanotechnology and policy, which encourages early adoption of underutilized or new technologies. There are five components to this argument:

1. Behavioural change is difficult to sell, difficult to implement and is not politically popular.
2. We do not have a culture that allows for the emergence, experimentation and discarding of maladaptive behaviours at a rate that is necessary to cope with the rapid onset of new events.
3. Technological change has already worked to reduce environmental impacts.
4. Many of the impacts that we will have to deal with are already present and can be mitigated through existing technologies.
5. There are future impacts that will be larger, but there are existing technologies that can reduce the damage, and we can accelerate the development of new technologies that are already on the horizon.

Although behavioural changes have occurred on a societal level, changing people's behaviour is an extraordinarily difficult task (Beer, 1975; Burton, 1993). This has been recognized for millennia. For example, it is strongly echoed in many of the major world religions, i.e. Judaism and Islam legislate behaviour while Buddhism proscribes a regimented, long-term program of meditation that may take a lifetime. In our modern context, most of us have had to experience the difficulties of change on a personal level, involving weight-loss reduction, ending procrastinating behaviours, learning a new skill, learning how to let go or learning how to slow down.

Similarly, we have failed on a societal level, with the result that some of our personal issues, such as obesity, are now societal issues. Despite our level of education we still prefer the automobile to public transit, cycling or walking even in those areas that are conducive to these alternatives. We still prefer the throw-away and disposable and where we do not prefer this, we have come to expect it (e.g. light bulbs, fashion and cars). People are slow and reluctant to move out of their comfort zones. Thus, behavioural adaptation to risk tends to be incremental and insufficient as a result of cognitive conservatism (Janoff-Bulman, 1992), which refers to the reluctance of people to accept or reinterpret information that runs contrary to their worldviews.

Two successful changes serve to illustrate this point. As a global society, we agreed to the Montreal Protocol to reduce emissions of clorofluorocarbons (CFCs) to mitigate the destruction of the stratospheric ozone layer. This agreement was lauded as a model for others in that it brought on board governments and industry. However, at the time, one of the major producers of products with CFCs already had the alternative product available and would not suffer an economic loss - thus had no reason to oppose the Protocol. The success of the Montreal Protocol is based on a technological fix, not a behavioural change, i.e. reduce the use, manufacture and sale of air conditioners. In the meantime, industrial sectors that did not oppose the Montreal Protocol are opposing the Kyoto Protocol.

Another lauded change in behaviour was the blue box program in Ontario (household recycling), requiring the separation of waste into different streams. The success of this program is due to the fact that it involved no real change. People were not asked to reduce their amount of waste, only to dispose of it in a different manner. Given the fluctuation in demand for recycled goods, many of them still sit in warehouses, unsold and unused. What recycling has done for many products is transfer the storage from the landfill to above-ground repositories.

Later in this book, Bass discusses how important the emergence of new behaviours was in allowing the agents in the COBWEB simulation model to adapt to environmental change. Although this might appear as a contradiction to this stance, it should be noted that the simulations suggested that the speed at which new ideas emerge in that artificial world was also critical to their success and the adaptability of the population. Outside of the realm of culture, where experimentation is constant and rapid, most of our institutions are fairly rigid in how things get done and allow for little experimentation and risk (Holling and Gunderson, 2002; Leadbeater, 1999). This may be due to the bureaucratization that seems to creep into any organization beyond a certain size threshold or the inability to account for the activity of innovation (Leadbeater, 1999). In fact, this rigidity that creeps into many large bureaucracies may be the best argument against a behavioural emphasis on adaptation as large institutions have been the most resistant to those behavioural changes required to foster the rapid emergence of innovation.

On the other hand, we have had great success with technological change in the environmental area. For example, all of our appliances and furnaces are much more energy efficient than they were ten years ago and this efficiency has been increasing every few years. Houses that are built post-1980 tend to use far less energy per square metre than pre-1980 houses. Our vehicles still pollute, but less so than in the last few years (though there are many more of them). These changes were far more successful than attempts to get consumers to reduce their demand for energy. The imposition of standards forced industry to create more environmentally friendly products. When government has set new standards, industry-wide, they may be opposed, but they are implemented and are effective. It is important to note that these energy saving or emission reduction innovations were not widely adopted until they were legislated. As is evident from other technological realms when an alternative technology is available (beta vs. VHS; MAC OS/Linus/Unix/OS2 vs. Windows; rotary vs. combustion engine) even if it is better in certain areas of performance, it is not necessarily adopted on a widespread scale without external regulation or incentives.

The imposition of new standards was successful because they were incorporated into existing practices without trying to change behaviour. Environmental objectives were achieved through a change in technology enforced by policy.

Two specific impacts of climate change will be used to illustrate this point; the severity of precipitation events and heatwaves. More severe spring and summer storms are expected to lead to increased stormwater runoff which may lead to flooding and more combined sewer overflow events. We may face summers that have more frequent, extreme and/or longer heatwaves. There are several available technologies to reduce stormwater runoff at the source, for example, on the roof, reduce the flow into the drainage system on the road, channel the water and store it (retention ponds, artificial wetlands). These technologies are all currently available, and can be retrofitted into existing buildings and roads and easily adapted to new residential, commercial or industrial developments.

Heatwaves are not just a matter of discomfort, but they can increase mortality, increase air pollution and related illnesses and tax the system, leading to more brownouts or blackouts. There are two basic technological approaches to cope with more frequent or more extreme heatwaves. One is to reduce the contributions from the city itself, i.e. reduce the heat that is generated by hard surfaces. These surfaces can be cooled by light or reflective surfaces, vegetation with sufficient moisture for evapotranspiration or wetter surfaces. A second approach is to reduce the demand for electricity generated by natural gas, coal, oil and nuclear sources using solar and wind power, technologies that are currently available in today's market. In both of these scenarios, there are no required changes to lifestyle, only to the technology that supports the lifestyle.

There are several barriers to the adoption of new technology, cost being one important factor. Although these technologies have a higher upfront cost, encouraging their adoption could probably best be implemented through legislation. Experiences in other North American cities (Residential Energy Conservation Ordinance in San Francisco, USA; the cool roof policy in Chicago, USA) and countries (German legislation to replace the vegetation removed from new buildings) have been successful in increasing the adoption of current technologies, and have not had a negative economic impact.

Finally, there are extreme events, as indicated by recent flooding in Edmonton, Alberta, Canada and Peterborough, Ontario, Canada, or the ice storm that knocked out the hydro corridors bringing power into Montreal, Quebec, Canada in 1998. If these communities become less vulnerable to these events then technology will probably have played a large role. For example, Quebec could adapt to future ice storms by building infrastructure that is more resistant to ice accretion, building redundancy with alternative power generation and transmission infrastructure or by introducing earlier failsafe thresholds that will allow systems to fail earlier but with less damage.

During the 2004 flood in Peterborough, Ontario, Canada only two small sections of the city were damaged, primarily due to their location. There are a range of technological measures that could be introduced to reduce flood damage. There are a few discussions, such as Mulhall (2002) that indicate the potential for new adaptation technologies that will offer us far higher levels of protection in order to cope with some of these events.

Obviously, just having technology is not a solution. It has to be used. However, experience has shown that new standards for construction, energy efficiency, emissions and landscape conservation have been very effective at promoting the adoption of these new technologies and have been effective at meeting the environmental and policy targets.

3. The Behavioural Critique

The 'technological fix' argument raises a number of interesting and valid points regarding the balance between technological and behavioural solutions. Arguments in this section are that (1) behavioural change is essential and (2) the notion that one must choose either a technological or a behavioural solution is a false dichotomy – neither one necessarily detracts from the other though the issue is often presented as such.

In this regard, arguments for reliance upon technological solutions are ultimately flawed. They require faith in the idea that all problems can be solved through the use of science and technology. There are, however, classes of problems not subject to such solutions – such as war, poverty and crime. For example, the main difficulty in solving the problem of war is that for many people it is not a problem in need of a solution, but rather a solution to a problem. Problems that are human-centered require human centered solutions, not just more technology. Natural disasters fit into this category.

The argument for an emphasis on behavioural change rests upon the following notions:

1. People have to choose to use technology in order for it to make a difference. This requires a change of behaviour.
2. Vulnerability is not caused by a lack of technology, but social and political factors.
3. The application of technological fixes has often backfired as a result of a lack of consideration of behavioural change. For example, research has shown that changes in risk-taking behaviour tend to accompany and nullify changes in technology that is intended to mae us safer. Changing motivation and risk perception is generally much more effective.
4. Many environmental problems are rooted in our use of technology. The idea that technology can be used to solve problems created by technology is fundamentally flawed. Environmental problems (of which climate change is one example) are deeply rooted in our relationship with the natural world, our values and our worldview. These all lay outside the realm of technology.

5. The tragedy of the commons is, in many ways, being enacted on national and global scales. Many of the behavioural choices people make that emphasize individual gain over social good act ultimately to the detriment of all. Technology cannot solve this problem – a social process is required.
6. Changes in behaviour, though difficult to engender, do occur when sufficient motivation exists. Simply because a solution is difficult to achieve is a poor reason to choose an alternate but seemingly easier approach that will fail.

Natural disasters affect Canadians and people around the world in devastating ways. The knowledge to prevent or greatly mitigate these events exists, but is often not used (White et al., 2001). Thus, we continue to build on flood plains in spite of the knowledge that it will eventually result in a flood disaster. Having knowledge or tools does not mean that they will be used – that can only happen when people make decisions and choose actions that use them. Disasters occur because vulnerable communities exist. This vulnerability is partly a function of the built environment, but also exists because of social and environmental issues. Poverty, access to power, emergency management legislation, disaster financial assistance and many other social and economic factors contribute to disaster occurrence or resilience, depending upon how they are structured. Wisner et al. (2004) discuss the progression of vulnerability to hazards in society, beginning with root causes and then progressing to dynamic pressures and unsafe conditions. Technology addresses the unsafe conditions aspect of vulnerability, but not the root causes or dynamic pressures, and from this point of view is a band-aid solution.

One part of adapting to climate change means dealing with more natural disasters - particularly those related to heat waves, flood and drought. Research has shown that much vulnerability exists not because of a lack of knowledge, but rather through a lack of application of it. The importance of behavioural adaptation has been emphasized many times in the hazards literature, along with the failure of structural mitigation measures that often make the ultimate cost of disasters worse (Mileti, 1999). There are technological approaches to dealing with all of these problems that tend to emphasize supply side economics (e.g. provide more power or water as it is demanded), but behavioural change that addresses demand can also be very effective and provide a series of co-benefits to society and the environment (e.g. conservation).

Perrow (1999) notes that while some technological fixes reduce error, others sometimes create new accidents or are used to justify riskier environments or to compensate for poor organization or system design - and when system failure occurs increased reliance on such support systems (e.g. power, water, air conditioners) can make a disaster all the greater. In fact, one of the driving forces that has been increasing social vulnerability to disasters is increased reliance on technological support systems.

Canada has the knowledge and technology to solve most current environmental problems. Not doing so is primarily a result of an unwillingness to accept the constraints or costs of doing so. It can be argued that better technology will reduce constraints and therefore allow for better adaptation - but the problem with this argument is that many risks associated with technology continue to grow and outstrip benefits (Beck, 1992) and we require increasing amounts of ingenuity to deal with these new hazards (Homer-Dixon, 2000). Thus, from a philosophical perspective reliance upon technology sets up a vicious circle, where new technology creates new risks that then require new technology, and so on. Successful adaptation requires breaking out of this negative cycle.

Albert Einstein said “Today's problems cannot be solved by thinking the way we thought when we created them.” The traditional paradigm of technological-fix is not likely to solve problems created by technology, where those problems are human-centered.

Another issue with the techno-fix solution is that it is based upon the idea that the problem is external to people - like the notion that natural disasters are caused by nature. Walt Kelly might have been responding to this concept when he said “We have met the enemy and he is us.” Recent thought has moved away from this notion - for example, the paradigm of natural disasters has shifted from one that was largely fatalistic to one that recognizes their occurrence primarily as a result of human activities that create vulnerable communities - putting the locus of control within the human sphere. This shift allows for proactive actions on the part of people to become more resilient. It is a worldview based upon self-empowerment instead of fatalism.

Vanderburg (2000) discusses the effect of technology on society, saying “Here we encounter the fundamental contradiction in technological and economic growth. At the micro level, we find technical and economic rationality; at the macro level, technical and economic irrationality." The main problem is, he states, that micro decisions in these fields are primarily guided by measurable performance values that are incompatible with human life, society and the biosphere. It is like the tragedy of the commons, where maximizing individual benefits act to the detriment of the collective; thus - a global society that is unsustainable but still growing. What is needed is a shift from an 'economy of technology' to an 'ecology of technology' that "includes the consideration of undesired outputs, and the meaning and value of all inputs and outputs by means of which technology is embedded in, depends on, and interacts with its contexts". This shift requires a different worldview that emphasizes the subjective, environmental values and behavioural change.

Perrow (1999) notes that although technological fixes can be error-reducing they sometimes are used to increase performance values or are excuses for poor organization or poor system design, in which case they can increase risk. For example, Handmar (2000) noted that one of the main purposes of flood warnings in Australia is to justify development in flood-prone areas. This is an example of a problem that is human-centered and not solely addressable by a technological solution. It must be noted that a significant part of the increased vulnerability to extreme weather that has been observed in recent decades is a result of societies increased reliance upon technology and lifelines, and the consequences when complex systems fail in unexpected ways.

4. Synthesis

It was previously argued that choosing either a technological or a behavioural approach is a false dichotomy as adaptation will inevitably involve both to some degree depending on the impact. In fact, a technological approach tends to address supply side economics (e.g. providing more power or water to meet increasing demands that do not affect lifestyle or economic growth) whereas behaviour adaptation tends to address demand side (e.g. conservation), which can have a variety of co-benefits to society and the environment.

One example might be the use of appropriate technology as part of a strategy to address the root causes of vulnerability. As the most vulnerable populations tend to be the most poor, they are least likely to be able to afford a technological approach to adaptation. This argument is very much oriented to the technological trends in industrial society where new technological innovations have allowed machinery to replace labour in the production process.

A fundamental tenet of microeconomic theory is that there are alternative means to achieve the same output utilizing different mixes of capital and labour. The theory assumes that the mix will be determined by the available budget. As budgets increase, the tendency is to increase the capital-to-labour ratio. At a meeting of geographers in 1984, Bass and Yapa (1984) argued that providing poorer populations with an appropriate level of technology, one that was geared towards local knowledge, needs and geography might provide a means to provide these populations with access to the means of production, thereby increasing their income and perhaps the political power of these populations. Yapa (2002) has shown that technologies that improve standards-of-living are willingly adopted, but their long-term success at reducing poverty will depend on the ability of the local population to purchase, understand and maintain them. Thus the role of technology in reducing poverty, and hence vulnerability is recognized, but this example also recognizes that the technology must be appropriate to the specific geographical context if it is to be adopted by the local population.

5. Conclusion

Immanuel Kant once said that "Science is organized knowledge. Wisdom is organized life." Adapting to a changing environment is not just a problem of science; it is also a problem of how people view their relationship to the natural world and how societies choose to live, the risks they are willing to accept and the actions they are willing to take to deal with those risks. Technology will undoubtedly play a large and important role, but by itself is not sufficient to solve the adaptation problem. Behavioural changes are necessary as well - indeed they are likely to be the more crucial factor.

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12 paper

CHARACTERIZING ADAPTABLE SYSTEMS:

MOVING FROM SIMULATION MODELS TO ADAPTATION POLICY

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ABSTRACT: Developing a capacity for adaptation is an important component of policy development. This paper uses an agent-based model to conduct a large number of experiments. The model incorporates research into artificial life simulations and Holland's work with genetic algorithms and classifier systems. The research is based on the simulation platform, Complex Organization and Bifurcation Within Environmental Bounds, or COBWEB. COBWEB simulates how a system of autonomous agents adapts to variation and sudden changes in the resource base. COBWEB was set up as a generic system of agents in an environment, but can be configured to represent an ecosystem or a social system. In COBWEB, when the population is well adapted to its environment, an increase in resources is followed by an increase in population, which in turn is followed by decreasing resources, that is, the predator-prey pattern in ecology. In environmental change experiments conducted for this paper, the system was most sensitive to changes in the energy cost of activities, particularly movement, and the amount of energy available from resources. This was highlighted in two sets of experiments designed to mimic invasive species and the response of the system to climate change, expressed as a change in the length of seasons. COBWEB also allows for experiments with communication and memory. A series of experiments was conducted with very low rates of resource production, in other words, a resource scarcity. Without communication, all of the agents died out. With communication, the probability of survival for the whole population increased by 50 percent. The simulations highlighted the characteristics of a well-adapted system and the importance of threshold values, energy, communication and memory in adapting to variability and change. A system that is well-adapted to its current environmental variability is characterized by a balance between population and resources that is quite resilient to minor changes in various parameters that define its environment. However, at the margins, there are threshold values which, when crossed, produce more significant changes. This paper demonstrates the importance of energy and communication within a system, but it also raises questions as to the required speed at which society must develop innovative adaptive strategies to cope with environmental change.

Keywords: climate change, adaptation, COBWEB, model simulation, ecosystems, complexity, populations, resources, memory, communication, energy

1. Introduction

Socio-economic and ecological systems are subject to a wide variety of stresses, many of which are associated with the atmosphere. Although a great deal of political will is being expended on slowing down, halting or reversing various atmospheric changes, at least in one case - that of climate change - the international agreements recognize the need for adaptation to a different atmosphere. Most studies of adaptation in this context look at specific locations, specific impacts and the recommendation of specific measures to reduce vulnerability or the expected level of damage. While this is necessary to develop specific responses to specific impacts it does not explicitly address the question as to whether any system, be it ecological or social, is adaptable or how to encourage adaptability. Although we can provide scenarios of impacts that may occur within certain time periods in the next century, the uncertainties and the surprises that occur in any complex systems suggest that developing a capacity for adaptation is also an important component of policy.

One step to develop this capacity is to examine the properties of systems to discover those characteristics that are important in creating a capacity to adapt, regardless of the specific stress. Buz Holling, using induction, has characterized what he terms the adaptive cycle based on specific case studies of several ecosystems, resource management and social phenomena (Holling, 1986; Holling and Gunderson, 2002). The adaptive cycle emphasizes the importance of connectedness, resource potential, destructive events and reorganization. A second approach is to begin with systems theory itself, which might lead to an emphasis on redundancy, diversity and the clarity of communication. A third approach is to use a generic simulation model to conduct a large number of experiments, taking advantage of the speed available on most desktop computers. This approach underlies the research into artificial life simulations and Holland's work with genetic algorithms and classifier systems.

This paper builds upon this third approach to develop a characterization of adaptable systems. The advantage of this approach is that it can be used on its own or in conjunction with either of the other two approaches by providing a platform to test the importance of various characteristics in creating the capacity to adapt to change. The research is based on the simulation platform, Complex Organization and Bifurcation within Environmental Bounds or COBWEB for short. COBWEB is a robust simulation platform that simulates how a system of autonomous agents adapts to variation and sudden changes in the resource base. COBWEB can be set up as a generic system of agents or it can be configured to represent an ecosystem or a social system.

2. The COBWEB Simulation Platform

The COBWEB software platform and variables have been described in Bass et al. (2002), Suh et al. (2004) and Bass and Chan (2004). COBWEB offers many unique features as a simulation model:

1. It allows for multiple resources, each with its own variability;
2. Environmental change can be introduced suddenly at any point in the program;
3. The agents are classified according to the similarities in their genetic code;
4. It allows for resource preferences amongst the agents;
5. At any point in a simulation, the user can alter the quantity and location of resources, agents and barriers;
6. The agents can exhibit both biological and social behaviours; and
7. The software is both flexible and portable.

COBWEB is implemented in Java to provide flexibility and portability. It consists of a two-dimensional multiple resource environment, autonomous agents and barriers to movement. The resource growth is simulated with a cellular automata algorithm. The grid size is flexible and the user can choose either hard boundaries, (an agent hits the boundary is turned around), or wrap around boundaries (an agent hits a boundary and emerges on the opposite side of the grid). The agents are genetic algorithms, a software representation of genetic code consisting of a string of 1's and 0's that determines behaviour at every time step. It is essentially a map or computer program that associates an input with a specific output. The string is randomly assigned at the beginning of a simulation, but changes to the code occur in offspring through mutation and breeding. Other behaviours are available that are initialized at the start of the simulation. For example, each agent has a distinct probability that it will share information with another agent or whether or not it will mate with another agent. Each agent is also assigned a resource preference at random, which can be used to assign an agent more energy from the preferred resource than from other resources.

The genetic code determines what action the agent takes in the environment. In the current version of COBWEB these actions are restricted to turning left or right, moving forward, consuming resources, and clustering together with other agents. The agent also has additional code that is not genetically determined but consists of information about the environment and information communicated by other agents. If the strategy represented by the genetic array and non-genetic information does not lead to sufficient accumulation of energy, the agent and its strategy is eliminated from the environment. If sufficient energy is accumulated, the agent can reproduce, thereby copying its strategy or recreating a strategy that has been eliminated from the system.

The genetic code or strategy and the resource preference or agent type are randomly assigned at initialization. It is important to note that the strategies and the agent types are not connected in the model. Different agent types could in principle have similar strategies, and multiple strategies can emerge within the same agent type. Using a scheme developed for characterizing variations in soil composition (Hu et al., 2004), COBWEB colours the agents based using a red-green-blue spectrum, with one red, green and blue agent acting as three genetic markers. The other agents receive a colour based on their similarity to these three markers with similar agents receiving different shades of the same colour (see Figure 1).

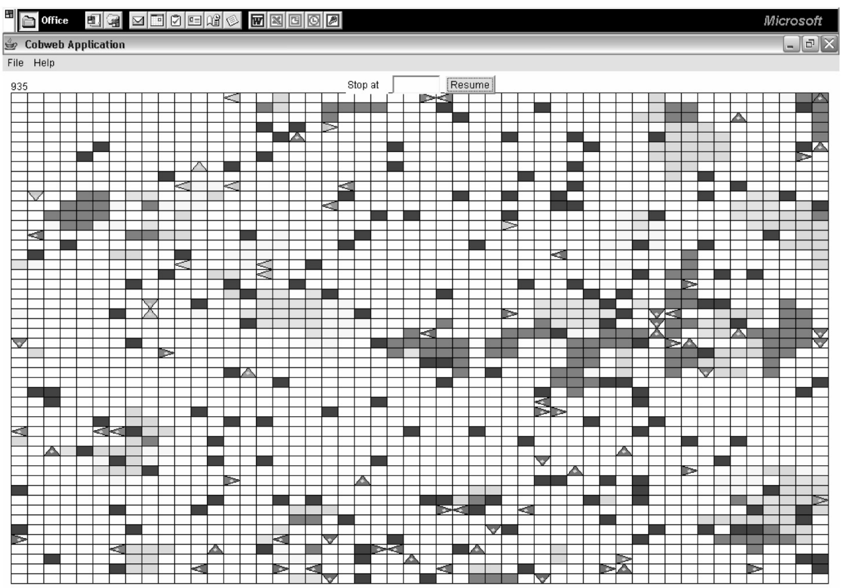

FIGURE 1

A COBWEB simulation in which the agents are triangles, resources are grey squares and stones are black squares.

COBWEB was not developed in a vacuum. It was meant to represent a complex system that builds on the work of Holling (creative destruction, reorganization and the presence of multiple attractors), Holland (recombination of genetic code to produce new strategies), and Hansell et al. (bifurcation, semi-stability and sudden change) (Hansell et al., 1997; Holland, 1995; Hollling, 1986). It was assumed that if COBWEB was built as a system of autonomous agents, making their own decisions, these properties of a complex system discussed by Holland (1995), Holling (1986) and Hansell et al. (1997) would emerge in various experiments. To some extent, COBWEB has been extraordinarily successful, both in representing complexity and in illustrating adaptation. As with most projects of this sort, every new set of experiments, every new user and with every new version (Version 2.4b is available and Version 3.1 is under development) raises new questions and uncovers new limitations.

3. What Was Learned: Population and Resources

In COBWEB, when the population is well adapted to its environment, an increase in resources is followed by an increase in population, which in turn is followed by decreasing resources, i.e. the predator-prey pattern in ecology. Within this pattern, a maximum and minimum value emerges for the population, resources and energy stored by the agents. Typically, the system goes through a period of large oscillations in resources and population before settling into this stable state (see Figure 2). However, there are several nuances in this state that are quite revealing.

The range of variation within a maximum and minimum value, suggesting a system that is well-adapted to its current environmental variability, is characterized by an optimum number of agents to maintain stability. Within this optimum, one or two dominant strategies tend to emerge quite rapidly, and are typically confined to one type of agent as defined by the resource preference. In many experiments, other strategies will emerge over time, challenging the dominant strategies and sometimes remaining in the system, yet the overall predatory-prey pattern, with its minimum and maximum population and resources remains in place with little variation.

In space, the story is quite different. Based on the movement of the agents, the strategies seem to fall into three categories: remain in one place, traverse long distances and movement with a range defined by the cluster of agents. Stable spatial clusters emerge, and if there are multiple strategies, they are

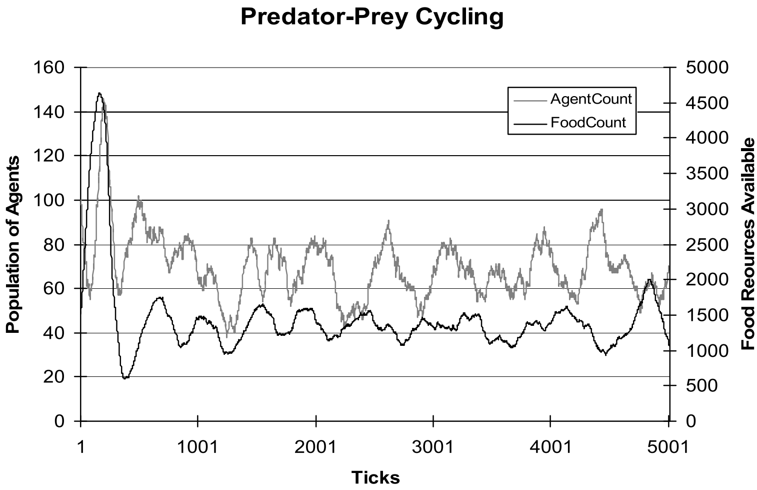

FIGURE 2

Output illustrating relationship between population and resources that characterizes a system that is well-adapted to current environment.

often located in different parts of the grid. The spatial patterns do not last and typically change between 500 and 1000 time steps. Sometimes these patterns follow the emergence of new resources, but at other times clusters will emerge away from the largest resource concentrations.

As expected though, even within this stable state, surprise and bifurcation is possible. Each agent type of COBWEB is associated with about 18 parameters. The stable state is quite robust to changing these parameters within a well-defined window. Depending on the initial set-up, there are threshold values for several parameters, that when crossed, will produce a different result. Often, crossing the threshold would lead to the elimination of all agents or the reemergence of a new population and new stable state. Surprise occurred within a simulation with the emergence of semi-stable attractors, that is, an apparently stable state that undergoes a sudden and dramatic change without any external intervention (i.e., a change in the environment).

In the environmental change experiments, the system was most sensitive to changes in the energy cost of activities, particularly movement, and the amount of energy available from resources. This was highlighted in two sets of experiments designed to mimic invasive species and the response of the system to climate change, expressed as a change in the length of seasons. In simulating an invasion by an external set of agents, the invasion was only successful if the invaders required less energy to move or could extract more energy from resources. To achieve a 100 percent success rate, it was necessary to increase the total amount of energy in the system either through the existing mix of resources or through adding a new resource.

Climate change was represented by a change in the growth rates of the resources with higher growth rates representing the wet or growing season. In these experiments, the system had the most difficulty in adapting to a change that both altered the length the wet/growing season and the dry/winter season. When the wet/dry season was lengthened/shortened, the population expanded to match the increase in resources. Occasionally, with a longer wet season, the system maladapted to the change as the population consumed all of the resources too quickly and subsequently died out. In the opposite experiment, the population would often die out, even if the rate of resource growth during the dry season was marginally less than in the wet season.

4. What Was Learned: Social Factors

COBWEB allows for experiments with communication and memory. Although these characteristics may be found to some extent in an ecological context, they are more frequently associated with human systems. Communication means that an agent transfers information from its communication buffer into another agent's buffer. The memory is where the agents store information about the environment at each time step. In both cases, this new information is a string of 1's and 0's so that it can be added to the genetic code, thus combining nature and nurture. The initial experiments with memory indicated that the new information did indeed alter the behaviour of an agent, i.e. the agent modified its strategy.

Further experiments were conducted on individual agents and on the system as a whole. In the first set of experiments, we tracked an individual agent. Increased success was measured by the probability of survival and having descendants and the length of survival and the number of descendents. Adding memory and communication led to an equal or slightly higher probability of increasing life spans and having descendants. What was more remarkable is that when an agent with memory and/or communication did survive and reproduce, they were prone to live longer and have far more descendants than an agent without memory or communication.

In testing the impact on the system, we examined both the number of agents and the energy in the system as we varied the size of the memory and the communication buffer. Increasing the amount of information that could be communicated resulted in a larger population, but it was confined to one agent type and resulted in the reduction of the average energy per agent, a reduction that grew larger as the communication buffer was increased in size.

A series of experiments was conducted with very low rates of resource production, in other words, a resource scarcity. Without communication, all of the agents died out. With communication, the probability of survival for the whole population increased to 50 percent. The probability increased by 10 percent with linear increases in the communication buffer. Increasing the size of the memory led to a larger agent population, again confined to one type. With further increases in size, multiple types of agents survived, eventually resulting in the survival of all four types, but the overall population decreased below the baseline.

The most recent iteration of Version 2 includes a Prisoner's Dilemma option. When two agents meet, they have the option of cooperating and sharing energy resources or trying to steal energy resources. Although this requires a great deal more testing, the initial simulation runs with this option suggested that cooperation pays off, as the cheaters did not survive. Part of the reason might have been that the cooperators would remember an agent that had cheated them in the past and would be unlikely to have any further contact with that agent. However, these initial experiments had a very low probability of asexual reproduction. Hence, cheaters could only mate with other cheaters, but this may have been hampered by the constant efforts to steal energy. When the probability of asexual reproduction was increased, the cheaters were far more successful and could out-compete the cooperators.

5. Comparison with other Hypotheses of Adaptation

COBWEB has not been used to replicate other hypotheses of adaptation, and a comparison with the broad range of thinking across a myriad of disciplines is beyond the scope of this paper. However, there are correspondences with Holling's adaptive cycle, Scheffer's work on shallow lakes (Scheffer, 1998) and Byers and Hansell (1996) ideas on semi-stability. Although these works were all targeted towards ecological adaptation, Holling and Gunderson (2002) have expanded the discussion to a broad range of social systems.

Holling and others have developed a theory of adaptation that does not characterize adaptive systems so much as it describes the dynamic of adaptation. Usually represented as a figure 8 diagram, Holling proposed that many complex systems exhibit a similar pattern beginning with rapid growth, stability, creative destruction and reorganization. The first stage allows the early opportunists (the r species in ecology) to take advantage of a new situation. Their success paves the way for other participants (the k species in ecology) who create a stable, if not resilient system, but a system that is based on tightly connected networks and resources that are bound up within the system and not readily accessible. The period of creative destruction, forest fires or pest outbreaks in ecology, are a necessary part of the adaptive cycle as they create space for new organisms or experiments, and lead to a system that is better adapted to a change in the environment. These new experiments are the period of reorganization as the system prepares to begin for the early opportunists. This period of reorganization determines whether a similar system reappears or something different, and perhaps unexpected, emerges in its place.

At initialization, COBWEB resembles the first stage of the adaptive cycle, and in most cases reaches the stable stage before 1000 time steps, a time step being defined as that interval when every agent makes one move. At smaller spatial scales, this type of process appears to occur in a manner not altogether different than described in Holling et al. (2002). Pockets on the COBWEB grid appear to reach a stable state that may last for 500 to 2000 time steps, only to collapse, followed by a reorganization of the resource base and the mobile agents. At smaller time scales, new strategies are often being introduced, but at this point these temporal changes have not been linked with the spatial changes. Although COBWEB can be set up to introduce a wide-spread environmental change, these changes have not been devastating enough to represent creative destruction as that was not the objective of the experiments.

COBWEB does reflect the findings of Scheffer (1998) and Hansell et al. (1997). As reported above, the long-term pattern often exists within a well-defined boundary of parameter values, and this solution is quite resilient to incremental change. Yet these changes led to the discovery of threshold values, beyond which, the system would flip to a different state or attractor, similar to Scheffer's discussion of shallow lakes. However, these simulations were run in a statistical not dynamic mode, i.e. the changes were made at initialization, in a large number of experiments (Bass et al., 2002; Suh and Bass, 2004).

Over the long term, the temporal predator-prey pattern that characterizes the balance between resources and population will collapse quite suddenly and quite surprisingly, suggesting the presence of a semi-stable attractor, a state that appears stable but is imperceptibly shifting to another state or a bifurcation point (Hansell et al. (1997); Bass et al., 1998). As COBWEB is not based on either a set of nonlinear differential equations or an iterated function system, it is not possible to test for semi-stable attractors in a formal manner.

If the emergence of a semi-stable attractor is interpreted as a destructive event, we find some correspondence to Holling's adaptive cycle. In many cases the system died out or the new state or attractor consisted solely of the resources. However, in a few cases, a small group of mobile agents survived and were able to reestablish the population or accumulated and conserved enough energy to survive at significantly reduced numbers. The fact that the changes in space occur at short frequencies, and the collapse of a semi-stable attractor occurs at much longer frequencies also indicate a correspondence with Holling and Gunderson's suggestion that these cycles occur at multiple scales and have a spatial structure (Holling and Gunderson, 2002). The newer versions of COBWEB will provide a better platform for testing hypotheses of adaptation across a broad range of systems.

The development of COBWEB is itself an adaptive process and has followed a dynamic that very much resembles Holling's adaptive cycle. It began with a rush of ideas as this was a new ground for Adaptation and Impact Research Group research, corresponding to the shift from phase 4 to phase 1. The first version was ready in 1999 and was used as a research tool while the code was altered in minor ways to provide a more realistic simulation. This was stage

2, the stable stage. At some point, the research team realized that we could not proceed in this manner without a major revision of the software, phase 3 and the revision itself, which led to something different and a new research cycle. This has occurred three times, but is deemed to be a necessary component of the development of COBWEB, allowing us to cope with new challenges from the research and policy communities.

6. Important Characteristics of Adaptable Systems

The simulations highlighted the characteristics of a well-adapted system and the importance of threshold values, energy, communication and memory in adapting to variability and change. A system that is well-adapted to its current environmental variability is characterized by a balance between population and resources that is quite resilient to minor changes in various parameters that define its environment. However, at the margins, there are threshold values which when crossed, produce more significant changes. Adaptation to change was far more likely to be successful if the available energy was increased or remained constant.

Both communication and memory increased an agent's life span and the number of descendents. At a system-wide scale communication between agents enhanced the rate of survival for the whole population under a relative scarcity, albeit for only one type of agent. Memory (i.e. storage of environmental information) also enhanced system-wide survival of the agents, particulary the survival of multiple agents. The Prisoner's Dilemma option suggests a further role for communication and memory. In a system that favoured collaboration, cheaters did not prosper.

The experiments on memory and communication and some limited work on barriers to reproduction, suggest that one other characteristic of an adaptable system is an environment that rapidly fosters experimentation with new ideas that match the speed of environmental variation and change. These new strategies occur through mutation in asexual breeding, genetic crossover in sexual breeding, through communication and through memory. The exact balance of these four determinants of new strategies has not yet been discovered and will require further research.

The emergence of bifurcation points or semi-stable attractors also indicates that the trajectory of a complex system can move in surprising ways, without warning. In many cases, the agents were not able to adapt to this change indicating that what appears to be a successful adjustment in the short term may have other unintended and unpredictable consequences.

7. Conclusions - Translating Theory into Policy

Do the COBWEB simulations provide any insight into future policy, geared towards increasing adaptability? In an obvious sense, the answer is yes. It highlights the importance of energy, both in terms of what is available and in terms of required energy costs or expenditures. Thus an increase in the cost of energy resources, without widely available alternatives, may increase the difficulty of maintaining our current standard of living.

The role of communication and memory were important in adapting to changes in the availability of energy. Memory, which is the storage of new information collected directly from the environment, alters an agent's strategy. This is akin to creating a new forecast as to the best location for new resources. The anticipatory nature of the memory has been discussed in Bass et al. (2002), but it suggests an important role for monitoring and the capacity for using new information.

Communication occurs through electronic infrastructure, but COBWEB emphasizes the importance of face-to-face contact, which could just as easily be interpreted as a high degree of social capital. Social capital has been linked to the capacity of communities to adapt to economic changes at different scales.

However, there are other aspects to COBWEB that are more intriguing for the policy of adaptation. Burton (2004) suggested that promoting an adaptation policy agenda is plagued by a lack of a measuring instrument, equivalent to greenhouse gas emissions for the mitigation camp. He suggests insurance losses due to weather as it would be an easily understood measure. Insurance losses provide some indication of societal vulnerability but is only a proxy for characterizing the adaptive capacity of any system.

Developing an index or indices may be important not only for measuring performance, but to provide an early warning with regards to a bifurcation in the system trajectory or a semi-stable attractor. Hansell et al. (1997) suggest a method for using an index to predict a change in system trajectory, but the method requires a long time series of data for which insurance losses may not be adequate. COBWEB suggests that an index based on energy or the relationship between population and energy is a suitable index of adaptability. Beer (1975) proposes how this information could be collected on real time at a suitable temporal scale to develop the capacity to predict change and suggests an alternative method based on the use of simulation models which is in line with Holling (1986) and the detection of a semi-stable attractor (Byers and Hansell, 1996).

Perhaps the most challenging aspect of COBWEB for policy, particularly geared towards increasing adaptability, is the rapid emergence and testing of new strategies. Discussions on how to foster this type of experimentation are usually confined to institutions (exceptions include the work of Stafford Beer (1975) and Charles Leadbeater (1999)) due the widespread cultural change that is required for success. It is difficult enough to implement within an institution, let alone within society as a whole, although Beer was involved in the design of a system in Chile that involved real-time monitoring of industrial output and citizen participation in political decisions through electronic communication. Unfortunately, this experiment was cut short by the overthrow of the government through a military coup in 1973.

What would be required to develop and test new ideas at a pace analogous to that in COBWEB or at a pace sufficient to match environmental variability and change? A growing body of literature has linked the emergence of creative solutions to an environment of collaboration, which in turn is a result of investments in building up social capital, both in the community and in industry. Michael Porter has written extensively the development of industrial clusters, competitive and complementary activities located within a small geographic range that allows for frequent personal contact. Similar proposals have been made, and experiments have been conducted, to create artist clusters in communities, but even investing in something as small as parent-child drop-in centres can lead to establishment of social networks and increased social capital in a community. The Prisoner's Dilemma experiments in COBWEB suggest that when the barriers to collaboration are lowered, collaboration does occur and the collaborators are more successful in adapting to the environment.

Charles Leadbeater (1999) also discusses the need to rethink the way in which we create, store, pay for and disseminate knowledge if we are to increase the rate of innovation and experimentation. Most of our societies have a very centralized and hierarchical means of producing and distributing knowledge, particularly specialized knowledge. In COBWEB, knowledge is extremely decentralized, allowing for frequent experimentation of new strategies. A more decentralized means of creating and spreading knowledge will expose us to more diverse ideas, competition between ideas and a higher rate of innovation. Although the Internet can act as a high-speed dissemination conduit, achieving a level of innovation analogous to what can occur within COBWEB will require rethinking the way in which we fund research, the role of universities and the pre-university education system.

Policies around energy, social capital, communication infrastructure and information are not novel, but on the energy side, it may require a broader exploration of how different the future should look from the past, as the adaptations to energy shortages often produced a smaller population, and perhaps new behaviours. The other policies are more problematic in that we do not have consensus on the value of communication, social capital and information. Outside of funding the construction of communication infrastructure, programs that build social capital or provide more information are frequently subject to funding cuts or, at the discussion phase, may be the first elements discarded from a discussion on new policy.

The crux of the issue was outlined by Charles Leadbeater (1999) in his book *Living on Thin Air.* We are living on a 15th century attractor with respect to financial accounting. We still live in the world of Luca Paccioli, a Franciscan monk and mathematician who created double-entry book-keeping, or the debit and credit that is the heart of financial accounting, an attractor that has proved quite stable. Yet all of those assets that might be labelled broadly as information are not recorded in this system; they were not valued by Professor Paccioli and we still find it extremely difficult to put value on those things that appear important, if not critical, to creating an adaptable system.

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chapter V

AGRICULTURE

PAPER 13
Adaptive Capacity to Climate Change in the Agriculture of Northeastern China

PAPER 14
Contribution of Climate Warming to the Increased Yield Over the Past Two Decades: A Case Study of Rice Crops in Heilongjiang Province, Northeast China

PAPER 15
Climate Change Impacts and Adaptation: Rice Plantation in Northeast China

13 paper

ADAPTIVE CAPACITY TO CLIMATE CHANGE IN THE AGRICULTURE OF NORTHEASTERN CHINA

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ABSTRACT: Socio-economic indicators are selected to examine the adaptive capacity of Northeastern China to the impacts of climate change on agriculture. The approach is focused directly on the underlying determinants of adaptive capacity. The analytic hierarchy process (AHP) method is used to prioritize indicators to assess the potential contributions of various aspects to the systems coping capacities. Indicators are compared and analyzed. Web-mapping technology is introduced to visualize and disseminate the results.

Keywords: climate change, adaptation, indicators

1. Introduction

Climate change will result in a set of diverse and location specific impacts on agricultural production. A growing literature suggests that while climate mitigation strategies are necessary, that alone is unlikely to be sufficient. As the impact studies have shown, climate change from previous emissions of greenhouse gases will have to be confronted by all countries. Therefore, pursuing a complementary strategy of enabling the agriculture sector to adapt to climate change and negate many of the expected adverse impacts is equally, if not more, urgent (Adger and Kelly, 1999; Burton et al., 2002). A host of recent impact studies show that reducing vulnerability to climate change by strengthening the adaptive capacity of the agriculture sector can reap substantial benefits (IPCC, 2001). The issue of how to make the agricultural sector more resilient to expected climate change has become extremely relevant to policy makers in the developing countries and international donor agencies (Adger et al., 2003).

Given the range of current vulnerability and diversity of expected impacts, there is no single formula that can be followed. Instead, increasing adaptive capacity of the agriculture sector will require a host of complementary measures. The evidence suggests that it is necessary to overcome various factors that contribute to vulnerability regardless of the temporal dimension of climate change. In particular, low per capita income, high dependency on subsistence agriculture and natural resources, weak governmental and institutional capacity, prevalence of preventable and non-preventable diseases, high incidence of armed conflict, and dependence on aid have been identified as issues that make economic development and growth challenging (Desanker, 2002; Adger et al., 2003; Klein and Smith, 2003). Human communities have a huge capacity for coping with climate change. Adaptive capacity at the moment relies on information and social capital.

Vulnerability assessment is a key aspect of anchoring assessments of climate change impacts to present development planning. Methods of vulnerability assessment have been developed over the past several decades in natural hazards, food security, poverty analysis, sustainable livelihoods and related fields. These approaches - each with their own nuances - provide a core set of best practices for use in studies of climate change vulnerability and adaptation (Chambers, 1989; Bohle and Watts, 1993; Burton et al., 1993; Lin, 1996; Downing et al., 1997; Adger and Kelly, 1999; Downing et al., 2001).

Changes in the mean conditions that define environments can actually be experienced most noticeably through changes in the nature and/or frequency of variable conditions that materialize across short time scales. Adaptation necessarily involves reaction to this sort of variability (Downing et al., 2001; Yohe and Tol, 2002).

Many definitions of adaptive capacity exist (IPCC, 2001; Burton et al., 2002; Adger et al., 2003 Dolan, et al., 2001); broadly speaking it may be described as the potential or capability of a system to adjust, via changes in its characteristics or behaviour, so as to cope better with existing climate variability, or with changes in variability and mean climatic conditions. The realization of adaptive capacity occurs as adaptation serves to enhance a system's coping capacity and increase its coping range, and therefore decrease its vulnerability, with respect to particular type of climate hazard. Having adaptive capacity depends on the resources available for adaptation, the ability of those who need to adapt to deploy these resources effectively, and their willingness to do so. The resources that contribute to a human system's adaptive capacity include natural resources, financial capital, human capital, knowledge of risk, appropriate social institutions for managing risks, and appropriate technology (Bohle and Watts, 1993; Jones, 2001; Brooks and Adger, 2003).

While social determinants of adaptive capacity are difficult to observe and measure, some aspects of adaptive capacity, including physical infrastructure, resources and the distribution of those resources, may be assessed relatively easily both at national scales and at lower or higher levels of aggregation. A number of sets of national-level indicators developed within the UN system are used to build up a picture of national performance or status in areas as diverse as human health and economic trade (for example, data assembled by the World Health Organization, the World Bank, the United Nations' Development Programme, and others). Some proxies for generic adaptive capacity at the national level can be borrowed easily from other data sources for an initial holistic assessment of generic adaptive capacity (Downing et al., 1997). Adaptation efforts by governments and civil society must be targeted at specific groups within vulnerable countries, and further research into the underlying causes of vulnerability at the sub-national scale are necessary (Burton, 2001; IPCC, 2001; Jones and Boer, 2003; Adger et al., 2004).

The climatic stimuli and their responses for a particular locale, activity or social grouping can be used to construct a coping range if sufficient information is available. The coping range is a template that is particularly suitable for understanding the relationship between climate hazards and society. It can be utilized in risk assessments to provide a means for communication and, in some cases, may provide the basis for analysis (Burton, 2001; Jones, 2001).

It is important to understand the boundaries of systems' coping ranges – thresholds beyond which the consequences of experienced conditions become significant. Judging adaptive capacity depends upon both defining a coping range and understanding how the efficiency of any coping strategy might be expanded by adopting new or modified adaptations (Smit et al., 2000). The coping range is usually specific to an activity, group and/or sector, though society-wide coping ranges have been proposed (Yohe and Dowladabadi, 1999; Yohe and Tol, 2002).

Critical thresholds are defined as any degree of change that can link the onset of a critical biophysical or socio-economic impact to a particular climatic state (Pittock and Jones, 2000). Critical thresholds can be assessed using vulnerability assessment and mark the limit of tolerable harm (Smit et al., 1999; Pittock and Jones, 2000). For any system, a critical threshold is the combination of biophysical and socio-economic factors that marks a transition into vulnerability. The construction of a critical threshold can be used to limit the coping range. If this threshold can be linked with a level of climate hazard, then the likelihood of that threshold being exceeded can be estimated subjectively if the relationship is known qualitatively, or calculated if the relationship is quantifiable (Cai and Smit, 1996; Feenstra et al., 1998; Jones et al., 2002; Liu, 2002).

Agriculture is an important sector of the economy in Northeastern China that is sensitive to climate change. Projected changes in climate are likely to have both positive and negative effects on agriculture in the region (Lin et al., 2004). The purpose of this paper is to evaluate the adaptive capacity to climate change on agriculture in the Northeastern China by assessing the socio-economic coping capacity and its indicators; and to examine the feasibility of the analytic hierarchy process (AHP) method in determining the weights and the values or scores for adaptive capacity indicators.

2. Methodology

2.1 Background of case study region

Northeast China is located in the northern part of the natural realm of Eastern Monson China, and comprises of Heilongjiang, Jilin and Liaoning Province and part of the Inner Mongolia Autonomous Region. The area totals about 800,000 km2 and has a human population of about 106 Million (1999). Northeast China plays a vital role in China's economic development with its fertile land, developed industry and higher urbanization. It is one of the most important suppliers of commercial food grains and economic crops (soybean, sugar beets, etc.) in China. Northeast China, which has a full set of industrial bases, will be coming under the domestic and overseas spotlights in the near future. As transportation networks and capital goods manufacturing develop in the future, this area is largely expected to grow by leaps and bounds.

Northeast China is a hot spot of land use, partly because of its relatively high food production potential, and partly because of its rapid socio-economic change. Studies in China project that northeast China is one of the regions most vulnerable to warming temperatures (Zhang and Wang, 1993). The following are some projections of climate change impacts in northeast China:

- Increase in temperature, and either an increase or decrease in precipitation resulting in flooding or eventual water supply shortages;

- Increase in severity and frequency of extreme weather such as damaging floods and droughts;
- Crop production will be affected on remaining arable land. However the predicted impacts to crop yields vary widely due to the uncertainty around water supply and the possibly positive effects of CO_2 on production practices;
- Large shifts in the remaining boreal forests and increased forest fire and desertification; and
- Wider distribution of many vector-borne diseases.

The key social vulnerabilities in the region are:

- Where resource-dependent communities have their resilience undermined by increased exposure to the physical stresses in water availability, agricultural impact, and other sensitivities; and
- Where sustainability and equity (Munasinghe, 2000) are sacrificed for economic growth, exposing larger parts of the population to impacts.

Research indicates that northeast China is one of the warming areas in China over the last 100 years (Ding, 2003). The annual precipitation has been decreasing since 1965 while average temperatures have risen by up to 1 degree Celsius. Warmer and drier trends are very significant in the recent decade. Temperature increases occur mainly in winter, while annual totals of precipitation have decreased in Northeast China due mainly to changes in summer precipitation (Zhai et al., 2003).

Previous studies on the region suggest that, in general, areas in the mid to high latitudes will experience increases in crop yield. Climatic variability and change will endanger sustained agricultural production in the region in the coming decades. The scheduling of the cropping season as well as the duration of the growing period of the crop also would be affected (Tshinghua University, 1999; Zhang et al., 2003; Lin et al., 2004).

The observed impacts of changes in regional climate warming that are relevant to agriculture are related to increasing yield trends in Northeast China. With the expansion and advancement in phenologies of agricultural pests, rice, wheat, and corn production could meet adverse impacts as well as shortened growth periods caused by a continuously warming climate (Zhang et al., 2003; Lin et al., 2004; CCChina, 2004).

2.2 Process of adaptive capacity assessment

In order to determine the weights (wi) and the values or scores for the adaptive capacity indicator, the analytic hierarchy process methodology has proved to be an extremely useful tool.

The Analytic Hierarchy Process (AHP) methodology is particularly convenient for comparing different investment alternatives and is a well-known tool for decision-making in operational analysis. It has been applied mostly for decision making in operational and risk analysis for evaluation of project alternatives and to a lesser degree in evaluation of environmental consequences. Researchers have used the AHP methodology for a combined cost–benefit analysis and environmental assessment of a petroleum pipeline project. This methodology was applied for comparing four different locations for a domestic airport in Iceland from the economical and environmental point of view. The AHP methodology is based primarily on comparison values instead of on assessing scores and weights directly. The numerical scale used is 1–9, where 1 is the “equivalent” value/importance, 3 is a “slightly” superior value/importance, 5 is “some” superiority, 7 is “considerable” superiority and 9 is “outright” superiority, with the even numbers in between applied if necessary. The calculation process can be described as follows:

STEP 1: To obtain the weights, wi, to be associated with each adaptive capacity factor, form the comparison matrix A. Each factor is compared with all other factors on a numerical scale (described above) according to importance. If the comparison is consistent, the elements {aij} will satisfy the conditions: aij = wi/wj=1/aji, aii = 1.0, aik_akj = aij, (i, j, k=1, 2, . . . n).

STEP 2: For each of A’s columns, divide each entry by the sum of entries of the corresponding column. This yields a new matrix Anorm, in which the sum of the elements of each column vector is 1.0.

STEP 3: By forming the average value of all elements in a row, an estimate of the “best” value for the vector of the weights, w*={wi*},is obtained. As the comparison values are selected without due considerations of the conditions in Step 1, they are bound to be both biased and inconsistent. However, the averaging method reduces such inconsistency and bias.

STEP 4: It is necessary to check the consistency of the solution obtained in Step 3. Firstly, all rows of A are proportional to the first row. Therefore, if wT={w1, w2,. . . wn} is the vector of the weights, AwT = nw, where n is the number of environmental factors involved. Thus, for perfect consistency, the vector of weights will be one of the eigenvectors of A and n is one of the eigenvalues. Actually, since all rows are dependent, the rank of the matrix A is one. Secondly, the trace of the comparison matrix A is the sum of all eigenvalues, i.e. should be equal to n since all other eigenvalues are zero as the rank of A is one. The actual vector w* obtained in Step 3 differs from the "consistent" eigenvector w, whereby Aw * T = kw*. Since w* is not perfectly consistent, k6 n. From the above relation, k can be calculated and should not differ much from n. The difference (k_n) is the consistency condition. The consistency index (CI) is then defined as the relative fraction CI=(k_n)/(n–1), which is equivalent to the standard deviation of the evaluation error and the mean deviation of each comparison element aij from the true ones. Now, introduce the random index (RI), which is defined as the mean deviation of randomly selected comparison values aij from the true ones. The consistency ratio, CR = CI/RI, should be less than 0.1 for all matrices A with n>3 and less than 0.08 for n = 3 to yield satisfactory results.

STEP 5: Repeat the same process for each of the environmental factors for all three alternatives to obtain the scores or values of the utility functions. The main problem is to provide impartial and consistent comparison values. There are many methods for avoiding inconsistency and biased comparison of the environmental factors. For instance, one person may be an "environmentalist" and overemphasize nature conservation in comparison with other factors. Another person is economically minded and will have a tendency to prioritize economical factors at the cost of environmental ones. This is well known, and no two individuals will make the same decision regarding comparison values. One way is to set up a broad panel of experts and have them reach a consensus regarding the comparison values and scores. This is wrought with all kinds of problems related to consensus reaching and dominant personalities. The Delphi method tries to avoid this by having the individual experts work independently of each other and let the coordinator form a final consensus. Another way is to let various individuals rate the different alternatives and transform the averages to relative values.

2.3 Analytic Hierarchy Process (AHP) software

In this case study, the commercial AHP software, Expert 2000, was used to conduct analysis in the expert workshop and in-house post-processing. The following features in this software package specifically address the above discussions:

1. There are three different paired comparison types, Importance, Preference and Likelihood. Importance is most appropriate when comparing objectives or criteria. Preference is appropriate when comparing alternatives with respect to their covering objective. Likelihood is appropriate when comparing the likelihood of uncertain events or scenarios, such as in risk analysis.
2. There are three pairwise comparison assessment modes. Verbal judgments are used to compare factors using the words Equal, Moderate, Strong, Very Strong, Extreme. Equal requires no explanation. Extreme means an order of magnitude – about 9 or 10 to 1. Judgments between these words, such as Moderate to Strong are also possible. Graphical judgments are made by adjusting the relative length of two bars until the relative lengths of the bars represent how many times more important one element is than the other. Numerical judgments are made using a nine-point scale, representing how many times one element is more important than another.
3. The inconsistency measure is useful for identifying possible errors in judgments as well as actual inconsistencies in the judgments themselves; this is accessed from the Priorities Window of the software. Inconsistency measures the logical inconsistency of your judgments. For example, if you were to say that A is more important than B and B is more important than C and then say that C is more important than A you are not being consistent. A somewhat less inconsistent situation would arise if you would say that A is 3 times more important than B, B is 2 times more important than C, and that C is 8 times more important than A. In general, the inconsistency ratio should be less than 0.1 or so to be considered reasonably consistent. The priority window also shows how many missing judgments are in the set of objectives being compared.

2.4 Comparison of results

As already mentioned, the decision making involved in forming the comparison matrix need not be perfect, that is, consistent in the sense that all conditions listed under Step 1 are fulfilled. However, the AHP method systematically reduces built-in bias and renders good estimates for the weights and the scores. In this study, nine different individuals (AC1– AC9, see Table 1), the authors being AC1, provided comparison values independently of each other. The comparison framework as outlined above was carefully explained to each evaluator, who were asked to quantify accordingly the comparison values for all environmental factors and alternatives.

Table 1 Adaptive capacity indicators and their weights

INDICATORS OF ADAPTIVE CAPACITY	WEIGHTS
Gross domestic product (GDP) per capita	0.296
Gross output value of farming, forestry, animal husbandry and fishery	0.031
Gross industrial output	0.288
Area of cultivated land under management per capita	0.031
Irrigated area per capita	0.080
Total power of agricultural machinery	0.078
Electricity consumed in rural area	0.093
Consumption of fertilizers	0.062
Output of major farm crops per capita	0.040

2.5 Data sources and database

The data used for the indicators are mainly taken from the "Statistical Year Books" of Liaoning, Jilin, Heilongjiang province and Inner Mongolia Autonomous Region respectively from 2001 to 2003. The selected indicators are determined by consulting results of expert workshop and by data reliability and accessibility. The database for Web-mapping and geographic information system (GIS) model was created.

3. Results and discussion

The adaptive capacity is divided into five grades according to the calculated relative values of the indicators. Their classification is shown in the Table 2.

Table 2 Classification of the adaptive capacity

ACp	0 – 20	20 - 40	40 - 60	60 - 80	80 – 100
Grade	1	2	3	4	5
	Weakest	Weak	Medium	Strong	Strongest

The preliminary results of the present adaptive capacity in the Northeastern China are shown in Figure 1.

The assessment of adaptive capacity is conducted at three levels – the provincial, county and regional level. In the provincial level, the Laioning province has the strongest adaptive capacity and the eastern parts of the Inner Mongolia Autonomous Region show the weakest adaptive capacity. The Jilin province has a medium adaptive capacity while the Heilongjiang province has a strong adaptive capacity in the in the years 2001 and 2002. In the year 2000, both the Liaoning and the Heilongjiang provinces show the strongest adaptive capacity (Figure 1a).

In the county level the counties in the Eastern Liaoning Peninsula, in the Changchun region, in the Daqing region and in the Harbin region show the strongest adaptive capacity. The weakest adaptive capacity counties are distributed in the eastern parts of the Inner Mongolia Autonomous Region, in both western and eastern Jilin and Heilongjiang provinces, where most of the counties are mountain and forest regions. The results for the years 2000 to 2002 show the same tendency (Figure 1b).

The same is shown at the regional level as in the county level. The Eastern Liaoning Peninsula, Changchun region, Daqing region and Harbin region have a strongest adaptive capacity, where the industry is much stronger than other regions in the Northeastern China (Figure 1c).

By the classification of adaptive capacity the regions with the strongest adaptive capacity are distributed in the regions with strong industry and wealthier economics (Figure 1d).

The study has shown that economic, institutional, political, social factors are likely to play an important role in enabling the agricultural sector to adapt to climate change. Strong industry and trade make regions such as Dalian and Daqing register a higher adaptive capacity, where GDP and gross industrial output are higher than in the other regions in Northeastern China. All of the province capitals, the political and social centers, have a strong adaptive capacity. The remote mountain areas, grassland and forest region have a relatively weak adaptive capacity.

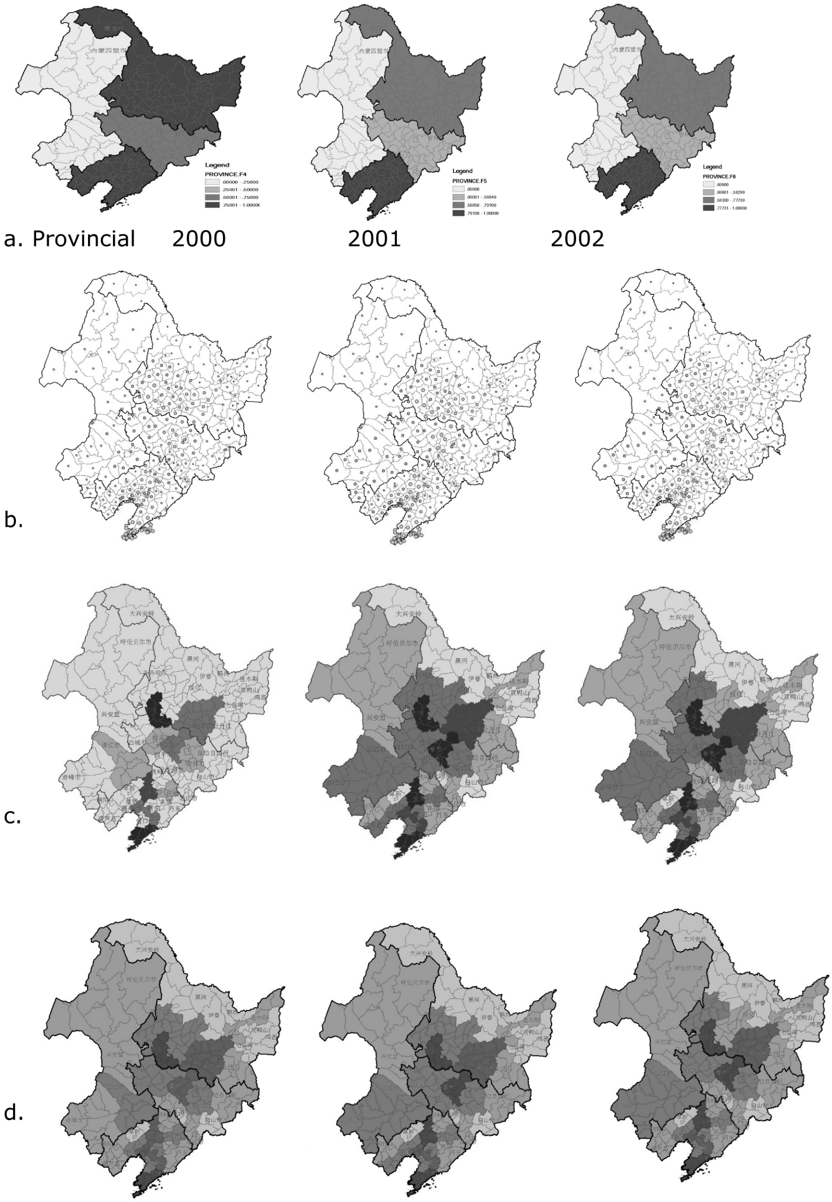

FIGURE 1

Adaptive capacity in the Northeastern China

It is not sufficient to identify the vulnerability of a system to climate change by assessing the present adaptive capacity, since the climate and socio-economic scenarios are not combined with the assessment proceeding.

4. Concluding Remarks

The Analytic Hierarchy Process methodology is particularly convenient for comparing different investment alternatives and is a well-known tool for decision-making in operational analysis. The AHP method has proved to be an extremely useful tool and systematically reduces built in bias and renders good estimates for the weights and the scores.

The economics, institutional, political, social factors are likely to play an important role in enabling the agriculture sector adapt to climate change. The regions with relative strong economics are likely to have a strong present adaptive capacity.

The present adaptive capacity was evaluated in this study, but it is not sufficient to identify the vulnerability of a system to climate change by assessing the present adaptive capacity, since the climate and socio-economic scenarios are not combined with the assessment proceeding.

Future work should build upon this analysis by examining case studies at the sub-regional level in order to determine to what extent the results obtained here may be generalized. While indicators have their role to play, they can only capture the most general aspects of adaptive capacity when applied at the regional level. It is, therefore, important to develop our understanding of vulnerability by examining how it arises in a variety of contexts, paying attention to the relative importance of various social, economic, political, geographic and environmental factors in different counties, and also to the hazard-specific nature of vulnerability. The exploration of regional climate and socio-economic scenarios, and assessment of adaptation options need to be enhanced by vulnerability assessment proceeding.

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14 paper

CONTRIBUTION OF CLIMATE WARMING TO THE INCREASED YIELD OVER THE PAST TWO DECADES:

A CASE STUDY OF RICE CROPS IN HEILONGJIANG PROVINCE, NORTHEAST CHINA

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ABSTRACT: Studying the impact of the existing climate warming to crop yield is an effective approach for understanding the impacts of climate change on agriculture. However, it is difficult to separate the contribution of climate change and human activities in such a study. Traditionally, the real yield is separated into trend yield that fits the real crop yield by a trend line dependant on time only; and the fluctuant yield which is the residual yield between the real yield and the trend. The fluctuant yield is regarded as the climatic yield. The main disadvantage of the traditional method is that it could not show the contribution of a climatic trend to the yield trend. In this paper, a new method, which may overcome the disadvantage of the traditional method, is put forward to calculate a climate yield with a climate trend. In the new method, a referenced period that satisfies the hypothesis of the traditional method is selected to construct a function on the dominant meteorological factor and climate influence coefficient by regression. The function can be used to calculate the climate's influence coefficient of other years. Rice yield in Heilongjiang province is restricted mainly by temperature. A case study on the contribution of climate change to rice yield change from 1952 to 2000 is made in this region. The results show that, although non-climatic forces have likely dominated the trends in rice per unit area yield in Heilongjiang province, the impact of climate warming on rice production becomes more and more prominent during the past 20 years. The real rice yield per unit area in the 1980s is 30.6 percent higher than that in the 1970s. The increased yield due to a warming climate was from about 12.8 to 16.1 percent of the real increased yield. The real rice yield per unit area in the 1990s is 42.7 percent higher than that in the 1980s. The increased yield due to warming climate was about 23.2 to 28.8 percent of the real increased yield.

Keywords: climate change; agriculture; rice; China

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) report, the average global surface temperature has increased by 0.6±0.2 degrees Celsius since the late 19th century (IPCC, 2000). Global change as signaled by global warming has become a reality that human beings have to face. Among many aspects impacted by the climate change, agriculture is one of the most sensitive. Current conclusions about the impacts of global warming on agriculture was drawn mainly from the results of models under a given climatic scenario. According to the IPCC (2000) report, agricultural production in the mid-latitude regions will be positive if the temperature rises within a few degrees. Beyond this range, the impacts will be negative (Zhang Qingyang et al., 2001). In China, the simulated results of a future climate show that by the year 2050, almost all the planting systems would be significantly changed due to the climate warming. The multi-cropping index will increase, and the cropping pattern will be diversified. Yet the imbalance between precipitation and evaporation, the thirsty demand for water by the land, and the shortening of the growing season will eventually lead to the reduction of main crop yields in China (Wang Futang, 2002).

On the other hand, the last two decades were the warmest period of the 20th Century (IPCC, 2000). It is an effective way for understanding the impact of global warming on agriculture by linking the warming to the agricultural production during this period. Yet the research is difficult to carry out because contrary opinions exist with regard to the integrated effects of climate change and the advancement in technology. Recently, Lobell and Asner (2003) estimated the effect of climate change on the yield of maize and soybean in the USA since the 1980s, but their research methods were questioned immediately (Gu Lianhong, 2003). J. Reilly et al. (2003) studied the impacts of climate change on American agriculture and showed that these impacts might be often overshadowed by other factors. Therefore, it is quite difficult to identify out the climate impact based on the historical statistical data. It is necessary to assume that the technological conditions should be the same at any given time in order to prove the impacts of climate change on agricultural production (J. Reilly et al., 2003). Undoubtedly, there are different opinions on how to evaluate the contribution of climate change and technology to agricultural production. The argument also implies the necessity to distinguish the two, especially when technology is developing fast while the world is getting warmer and warmer.

Heilongjiang Province is located in the most northern part of China. It is one of the areas most sensitive climate change in China, and it has experienced significant climate warming over the past 20 years (Sha Wanying et al., 2002). The crop structure in the province is restricted mainly by the temperature and sensitivity to temperature change. In the past twenty years, the crop structure and total yield in Heilongjiang has undergone dramatic changes. Rice has become a major crop in this region, whose plantation area is only smaller than that of soybean and maize, and total yield is the largest of all (Jiao Jiang, 2002). Generally, rice requires warmer temperature for growth and is more sensitive to climate change than other crops such as wheat and maize in Heilongjiang Province. The temperature during the growth season in Heilongjiang Province is near the lower temperature limit for the optimal growth of rice (Chinese Planting Administration, 2002). This paper aims to quantitatively estimate the contribution of climate warming to the increased yield in the condition of fast development of agricultural technology through a case study in Heilongjiang Province. For this purpose, a new method is developed to estimate the contribution of climate warming on the increase of rice yield in Heilongjiang Province.

2. Data and Methods

The climate data used in this paper are air temperature and precipitation data at 22 weather stations in Heilongjiang Province from 1952 to 2000. The selected stations represent the climate conditions of the total planting area of rice, because among them, 20 stations are located in regions having rice planting; with 14 stations located in regions having a large area for rice planting (see Figure 1). The data of the rice yield per unit area from 1952 to 2000, come from the *Economic Statistic Year book in Heilongjiang Province* (1988-2001) (Heilongjiang Provincial Statistic Bureau, 2001).

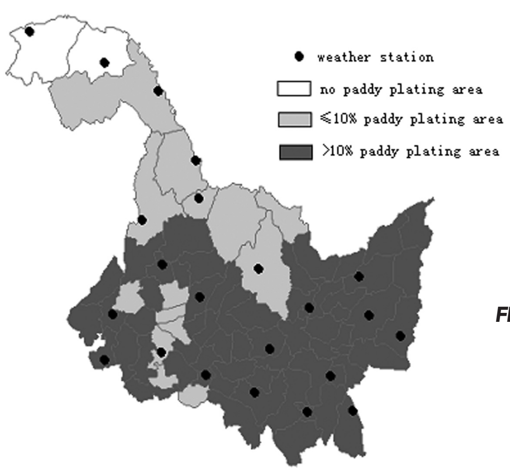

FIGURE 1

Weather stations and percentage of paddy area to the total planting area of wheat, maize and rice in 2000 in Heilongjiang Province

2.1 Temperature sequence in growth season

Growth of the crops in Heilongjiang is associated primarily with the climate conditions during the growth season from May to September (Sun Yuting et al., 1986). According to the data from 22 climate stations, the precipitation and the accumulated average monthly temperature for May-to-September of each year from 1952 to 2000 are calculated. Using the precipitation ($R_{5\text{-}9}$) and the accumulated monthly average temperature ($T_{5\text{-}9}$) from 1961 to 1990 as standards, the anomaly of precipitation ($\triangle R_{5\text{-}9}$) and the anomaly of accumulated average temperature ($\triangle T_{5\text{-}9}$) for May to September are calculated (see Figure 2).

Statistical analysis software, SPSS, was used to test the differences in the statistical significance for the temperature of May-to-September among the 1970s, 1980s, and 1990s.

2.2 Calculation of climate impact coefficient

How to separate the rice yield determined by climate change from the total rice yield is the key in evaluating the influence of climate change. Traditionally, the real yield is separated into trend yield that fits the real crop yield by a trend line depended on time only, and the fluctuant yield which is

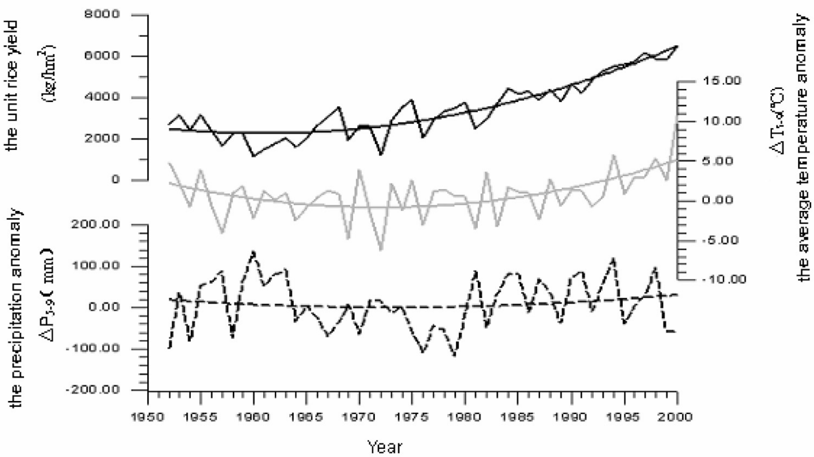

FIGURE 2

Changes of the temperature, precipitation and the rice yield per unit area for 1952-2000 in Heilongjiang Province.

the residual yield between the real yield and the trend. The trend yield is regarded to reflect the growth of productivity in history and the fluctuant yield is regarded as the climatic yield. (Wang Futang, 1991)

$$Y = Y_t + Y_w + e \qquad (1)$$

In formula (1), Y is cereal crop yield per unit area (kg/hm^2); Y_t represents the trend yield (kg/hm^2); Y_w stands for fluctuant yield; and e is the yield caused by random factors which are often ignored in calculation.

Based on the above, the functions of a cubic polynomial, exponential function, and 5-year running mean are used to fit the trend yield and to separate the climatic rice yield per unit area from 1952 to 2000 in Heilongjiang Province. Despite differences, all the results show that before the 1980s, the climatic yield of rice had significant correlation with temperature and less dependence on precipitation. After the 1980s, the dependence on precipitation remained insignificant, but the correlation between climatic yield and temperature decreased (see Table 1). Moreover, in the 1990s, the fluctuation of the climate yield further decreased, resulting in less correlation to temperature. Such a result might lead to a conclusion that the climate impact on rice production decreases as the temperature increases. In fact, it is a misunderstanding. The problem lies in the hypothesis that climate is assumed to be a steady sequence without tendency, but not all the periods accord with it. The climate factors may also have long-term tendency, which impacts on crop production too. The trend yield fitted based on the Formula (1) often includes the climatic yield contributed by the long-term climate trend without the technological factors. It is unavoidable to make errors when

Table 1 Correlation coefficients between climatic yields fitted by different regression and temperature and precipitation in Heilongjiang Province

PERIOD	CLIMATIC FACTORS	Y1W (EXPONENTIAL FUNCTION)	Y2W (CUBIC POLYNOMIAL)	Y3W (5-YEAR RUNNING MEAN)
1961-1980	T	0.667*	0.621*	0.636*
	P	-0.247	-0.297	-0.144
1981-2000	T	0.582*	0.394	0.307
	P	-0.045	0.076	0.119

Note: *significance level is 0.01, T is the anomaly of accumulative average temperature ($\triangle T_{5\text{-}9}$), R is the anomaly of precipitation ($\triangle R_{5\text{-}9}$).

analyzing the relation between crop yield and climate change. In the case of the trend yield of rice in Heilongjiang Province fitted above contains not only the contribution by the advancement in technological measures, but also the contribution by the climate warming. That is the deficiency of the method above.

In order to overcome the deficiency of the traditional method, a modified method is presented, that is, to select a reference period and to establish a function by regression on the relation between rice yield per unit area and temperature within the referenced period, then to estimate the contribution of temperature change to the rice yield per unit area beyond the reference period (Wang Yuan et al., 2004). The so-called reference period must simultaneously satisfy the following three conditions. First, the temperature change during this period has little long-term trend, with permissible short-term fluctuations; and the fluctuant yield is highly and steadily correlated to temperature change. Second, technological development exerts a gradual impact on the yield during the period, instead of an abrupt impact by sudden or rapid technological innovation. Third, the yield change caused by expansion of rice-planting area is ignored. In such a defined referenced period, Formula (1) can practically work. In another words, the trend yield obtained by regression reflects the influence of human activities, while the fluctuant yield represents mainly climatic influence during the referenced period.

Crop yield per unit area is surely varied under different technological conditions, as well as the contribution of temperature change to total crop yield. The contribution of climate to the crop yield per unit area is described by the temperature impact coefficient expressed below.

$$\alpha = Y_w / Y_t \qquad (2)$$

In formula (2), α is the temperature impact coefficient, which may be calculated according to the relationship between the temperature and the climatic yield separated from real rice yield during the referenced period. To imitate the temperature effect function in the crop potential productivity formula, a quadratic function is employed to estimate the temperature impact coefficient α.

$$\alpha(T) = aT^2 + bT + c \qquad (3)$$

In equation (3), T is the anomaly of accumulative average temperature ($\triangle T_{5\text{-}9}$) from May to September. a, b, and c are the coefficients which may be calculated by using non-linear regression in SPSS software. The temperature impact coefficient calculated from the above regression equation could reflect the sensitivity of unit crop yield to climate change under the technological conditions in the referenced period. The higher the climatic influence coefficient gets, the more sensitive the unit crop yield responds to the temperature change.

2.3 Estimation of the contribution of climate warming to the increased unit rice yield

From the equations (1) and (2), the climatic yield and the technological unit yield could be deduced as equations (4) and (5) respectively.

$$Y_w = \alpha Y_t = \frac{\alpha Y}{1+\alpha} \tag{4}$$

$$Y_t = \frac{Y}{1+\alpha} \tag{5}$$

The contribution of climate warming to the increased rice yield per unit *(W)* can be expressed by the ratio of an increase in the climatic yield (the climatic yield after climate warming minus that before climate warming) to the increase in the real yield (the real yield after climate warming minus that before climate warming).

$$W = \frac{Y_{w(n)} - Y_{w(i)}}{Y_n - Y_i} \times 100\% \tag{6}$$

In equation (6), $Y_{w(n)}$ and Y_n represent the climate yield and the real yield in the *n*th period when after climate becomes warming, respectively; and $Y_{w(i)}$ and Y_i represent the climatic yield and the real yield in the *i*th period before the *n*th period, respectively.

3. Results

3.1 Climate Change from May to September in Heilongjiang Province

The climate in Heilongjiang Province has been getting warmer since the 1980s. The temperature change since the 1980s could be divided into three periods separated by 1987 and 1993. The anomaly of accumulative average monthly temperature from May to September in these three periods, were 0.20 degrees Celsius, 0.36 degrees Celsius and 4.48 degrees Celsius higher than that in the 1970s, respectively. The significant warming has occurred since 1994 (Figure 2).

On the decadal scale, the climate warming started from the 1980s, but the warming in the 1980s was limited, which had not exceeded the amplitude of temperature fluctuation during the 1960s and the 1970s, although the extreme low temperature like in 1969, 1972, and 1976 did not occur again in the 1980s (see Figure 2). The warming in the 1990s was remarkable. The anomaly of accumulative average monthly temperature from May to September in 1990 was 3.58 degrees Celsius higher than that in the 1970s. In other words, the monthly average temperature increased 0.72 degrees Celsius during May-September in the 1990s. The temperature in the colder years in the 1990s was similar to that of warmer years during the 30 years before the 1990s.

3.2 The impact of temperature change on rice yield per unit area in Heilongjiang Province

Rice is one of the crops sensitive to temperature change. The suitable temperature required by different rice varieties is varied. The mean temperature during the growth season from 1981 to 2000 in Heilongjiang Province (not including the Daxing'anling Mountains region) was below the optimal mean temperature demanded by the dominant rice varieties planted in Heilongjiang Province, while the maximum temperature was around the optimal maximum temperature *(Chinese Planting Administration, 2002; Liang Guangshang, 1983; Chinese Institute of Rice et al., 1988)*. This means that the climate warming since the 1980s acted as a positive impact on rice growth and yield because the warming has not exceeded the optimum temperature limit in the majority areas of Heilongjiang Province.

The temperature impact coefficient α is the index that quantitatively reflects the impact of temperature on the crop yield per unit area. In order to establish the regression equation between the temperature and the temperature impact coefficient α from the statistic data in Heilongjiang Province, the referenced periods that satisfied the standards as described above were identified. Abrupt increases in the rice yield per unit area occurred around the years 1965, 1983, and 1992 (see Figure 2), which divided the changes of the rice yield per unit area into four periods of 1952-1964, 1965-1981, 1983-1991, and 1992-2000. The fluctuant yield and trend yield were separated by fitting the trend with linear equation in each of the four periods. The coefficient between the temperature and the α (the percentage of rice fluctuant yield to the trend yield) is 0.51 for 1952-1964, 0.75 for 1965-1981, 0.79 for 1984-1991, and 0.32 for 1992-2000, respectively. 1965-1981 and 1984-1991 are selected to be the referenced periods because the temperature exhibited fluctuations without obvious long-term trends and the coefficient between temperature and fluctuant yield were high enough during these two periods (see Figure 3).

Based on formula (3), a quadratic function is drawn for the temperature impact coefficient α during the two referenced periods (equation (7) for 1965-1981, and equation (8) for 1984-1991) respectively, (see Figure 4). Whereas the

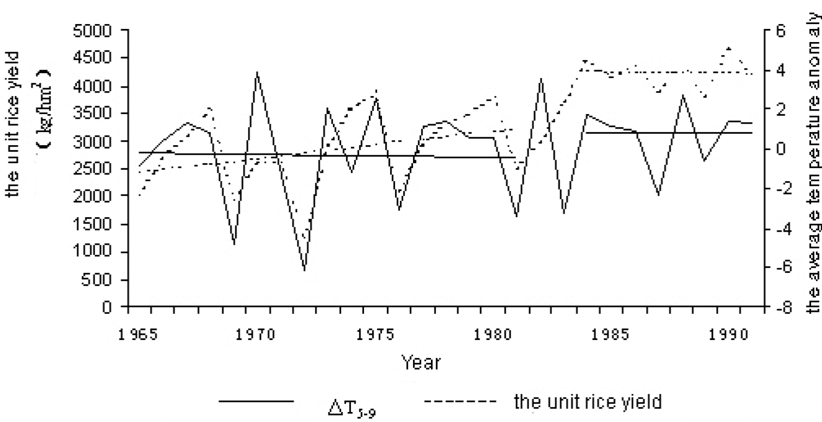

FIGURE 3

Changes in temperature and rice yield per unit area for two referenced periods in Heilongjiang Province samples in the period of 1984-1991 were a little bit small in numbers, the symmetry axis for the equation (7) during 1965-1981 is employed by the equation (8) on the assumption that the optimum temperature for rice growth did not change.

$$\alpha_1(T) = -0.001897T^2 + 0.074306T + 0.023026 \qquad R^2=0.67 \quad (7)$$

$$\alpha_2(T) = -0.000894T^2 + 0.034999T + 0.025456 \qquad R^2=0.65 \quad (8)$$

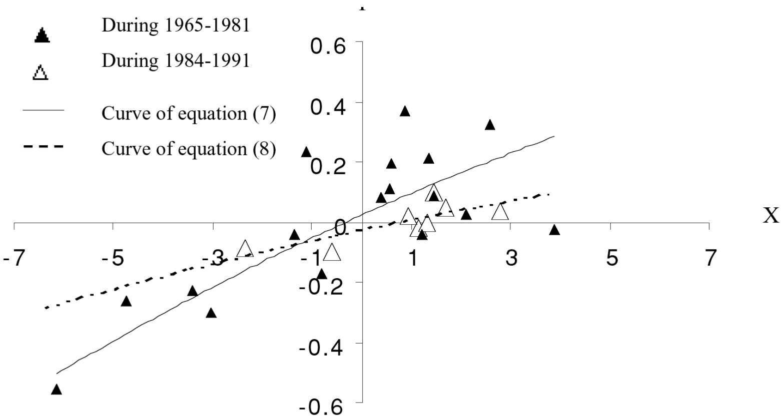

FIGURE 4

Relationship between temperature and impact coefficient of temperature for 1965-1981 and 1984-1991.(Y axis shows temperature impact coefficient, X axis shows temperature during May to September (degrees Celsius))

The temperature impact coefficients obtained from equations (7) and (8) represent the relative sensitivity of rice yield per unit area to climate change in Heilongjiang Province under the two different technological conditions during 1965-1981 and 1984-1991 respectively. To compare the equations (7) and (8), it is found that the advancement in technology did not only increase the rice yield per unit area, but also reduced the sensitivity of the rice yield per unit area to temperature change which is shown by the decreased percentage of climatic yield out of the total yield under a similar amplitude of temperature change.

3.3 Contribution of the decadal climate warming to the increased rice yield per unit area in Heilongjiang Province

According to the equation (2), the change of rice yield per unit area results from the combined impacts by both technological renovation and climate warming. It is hard to completely separate the two factors. On one hand, advancement in technology increases the rice yield per unit area, as well as reduces the sensitivity of rice growth to temperature changes. On the other hand, the climate warming allows the introduction of rice variety with high yield. The impact of climate warming on rice yield per unit area in the past two decades in Heilongjiang Province occurred under the fast changes in technological conditions. Thus, the technological change needs to be given a full consideration when calculating the contribution of climate warming to the increased yield. The temperature impact coefficient is calculated from the function that is established in the referenced period. It is reasonable to use the decadal average temperature to calculate the decadal temperature impact coefficient approximately, because the temperature impact coefficient calculated from the anomaly of decadal accumulated average monthly temperature during May-September is not much different from that on a year-to-year basis of the 10 years.

The average rice yield per unit area in the 1980s was about 4000kg/hm^2 which is about 30.6 percent higher than that in the 1970s. Such an increase occurred mainly around 1983, when the rice yield per unit area jumped from 3000 kg/hm^2 to 4000 kg/hm^2. After this abrupt rise, the rice yield per unit area fluctuated around 4000 kg/hm^2 depending on the rise or fall of the temperature (Figure 2). The dry and thin rice planting, which was being widely applied in Heilongjiang Province around 1983, was the dominant reason for the large-scale increase in rice production in the 1980s. Such a technique may increase the rice yield per unit area by 10 to 20 percent (Zheng Hua et al., 1999), which equals about 32.1 to 65.4 percent of the increased yield.

Another important reason for the increase in the rice yield per unit area is the agricultural policy since the 1980s that aroused the farmers' enthusiasm for production. Although the air temperature rise in the 1980s was not significantly different from that of the 1970s in statistics, the contribution of climate warming to the increase in rice yield per unit area cannot be ignored. With the assumption that the sensitivity of the rice yield to temperature change is maintained as in 1965-1981, the reference period of 1965-1981 may be used for estimating the contribution of climate warming to the increase of the rice yield per unit area in the 1980s. If the technological yield did not change, the increased yield brought by climate warming accounted for 12.8 percent of the total increased yield per unit area from the 1970s to the 1980s. If the technological yield increased gradually with the trend as that in 1965-1981, the contribution by climate warming would be 16.1 percent of the increased yield. That is, the contribution of the climate warming to the increased yield per unit area is 12.8-16.1 percent in the 1980s (see Table 2).

Table 2 Contribution of climate warming to the increased rice yield during past two decades in Heilongjiang Province

DURATION	1971-1980	1981-1990	1991-2000
Anomaly of temperature ($T_{5\text{-}9}$, referenced to 1961-1990)	-0.316	0.210	3.260
Average yield per unit area` (kg/hm^2)	2985	3897	5561
Increased yield than the former decade (kg/hm^2)	n/a	912	1664
Part of increased yield per unit area for climate warming than the former decade (kg/hm^2)	n/a	117~147	386~480
Contribution of the climate warming to the increased yield per unit area than the former decade	n/a	12.8-16.1	23.2~28.8

As compared to that of the 1980s, the climate warming in the 1990s underwent a significant change. However, the impact on the yield per unit area by technological advancement was also enhanced. For example, the temperature in 1995 was similar to that of 1986 with little difference in other climate conditions, but there was a difference of 1272 kg/hm^2 in the rice yield per unit area. Such a change was likely the result of technological change. The technological advancement also lowers the sensitivity of rice growth to climate warming. Therefore, it is probably more practical to estimate the contribution of the climate warming to the increased rice yield per unit area in the 1990s, based on the temperature sensitivity of the rice yield per unit area in the reference period of 1984-1991 than that in 1965-1981. If the technological yield did not change, the increased yield brought by climate warming accounted for 23.2 percent of the total increased yield per unit area from the 1980s to the 1990s. If the technological yield increased gradually with the trend as that in 1984-1991, the contribution by climate warming would be 28.8 percent of the increased yield. That is, the contribution of the climate warming to the increased yield per unit area is about 23.2 to 28.8

percent from the 1980s to the 1990s. It means an increase of about 9.9 to 12.3 percent in rice yield per unit area by climate warming in the 1990s, as compared to that of the 1980s. So, the impact of climate warming on rice yield in the 1990s is stronger than that in the 1980s.

In sum, the unit rice yield increased 2575 kg/hm^2 from the 1970s to the 1990s, in which the total increased yield for climate warming was 503-627 kg/hm^2. Thus, the contribution of the climate warming to the total increased yield per unit area is between 19.5-24.3 percent.

4. Conclusions

From the analysis above, it is concluded that:

1. From the 1970s to the 1990s, the accumulated average monthly temperature during the growth season in May-September increased 3.58 degrees Celsius, being equivalent to an increase of 0.72 degrees Celsius for each month during May-September in Heilongjiang Province. The climate warming largely occurred in the 1990s.
2. The climate warming increased the rice yield per unit area in Heilongjiang Province. The contribution of climate warming to the increased rice yield per unit area in Heilongjiang Province is estimated in this paper. The rice yield per unit area increased 30.6 percent in the 1980s from that in the 1970s. About 12.8 to 16.1 percent was contributed by climate warming in the total increased yield. The rice yield per unit area increased 42.7 percent in the 1990s than that in the 1980s. About 23.2 to 28.8 percent was contributed by climate warming in the total increased yield. From the 1970s to the 1990s, the contribution of climate warming to the increased rice yield per unit area was estimated to be about 19.5 to 24.3 percent.
3. This case study provides a positive impact of climate warming in the past 20 years. It can be used to compare the climate impacts during different periods, and to compare the relative contribution (to food crop production) by natural and non-natural factors. It does not mean the results described in this study could be simply used for predicting the impact of further climate warming. The conclusion that the technological advancement lessens the impact of climate warming on the rice yield per unit area is drawn based on the climate warming conditions in the past 20 years. It remains to be examined whether such a conclusion is applicable under climate cooling conditions.

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15 paper

CLIMATE CHANGE IMPACTS AND ADAPTATION: RICE PLANTATION IN NORTHEAST CHINA

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ABSTRACT: The average and standard deviation of the accumulated temperature from May to September for the period 1960-1999 of Northeast China is calculated. The result shows that the heat resource in almost all of Northeast China increased during this time period. According to the quantitative relation between heat resource and rice yield per-unit-area of different rice varieties of earliest ripe, early ripe, medium ripe, medium-late ripe and late ripe, a model is established to calculate the expected rice yield per-unit-area using the method of expectation evaluation of risk-benefit decision-making. It is found that climate warming induced positive effects on rice production in Heilongjiang and Jilin provinces of China, and induced negative effects in most areas of Liaoning Province, China. Changing crop varieties or crop structure to adapt to climate warming are two main adaptation activities. The crop structure of Northeast China changed in the past 20 years, and may reflect the regional differences of impact and adaptation activities. That is, rice yield per-unit-area in Heilongjiang and Jilin provinces increased more rapidly than that in Liaoning Province; the ratio of rice sown area to main grain (rice, wheat, maize) sown area in Heilongjiang Province increased more rapidly than that in Jilin Province, and the ratio decreased in Liaoning Province. So the impact of climate warming on crop yield and structure in China should not be ignored, though it is often credited to technology and economic benefit.

Keywords: adaptation; climate warming; expected yield per-unit-area; Northeast China;

1. Introduction

There is a consensus that climate has become warmer since the 1980s (IPCC, 2000). The socio-economic, political and environmental implications of this will be significant, especially for the agricultural system in China (Wadsworth and Swetnam, 1998). In some places climate change may produce positive effects on agriculture through introduction of new crop species and varieties, higher crop production and expansion of suitable areas for crop cultivation, whereas in some regions of China the disadvantages of climate change will predominate. The possible increase in the frequency of water shortages and extreme weather events may cause lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops (Olesen and

Bindi, 2002). Many researchers have predicted the effect of future climate changes on crop production using a combination of field studies and models, but there has been little evidence relating decadal-scale climate change to large-scale crop production (Lobell and Asner, 2003). The aim of this research is to provide evidence of the impact of climate warming and relevant adaptation activities through a case study.

The research region is Northeast China located at 40 degrees North, and includes Heilongjiang Province, Jilin Province and Liaoning Province. The region is warm and wet in summer, and has a long, cold winter period. Soybean, corn, wheat and rice are the main crops planted in Northeast China. Northeast China supplies China with its main commodity grain base, but the region is short of heat resources. Cool summer hazards often hurt crops in the 1960's and 1970's in Northeast China (Zhang Yang-cai, 1991;Zu Shi-heng, 1999). Rice crops need higher temperatures than other grain crops, and are sensitive to climate warming. So the research on adaptation of rice to climate warming in the Northeast China would provide a regional example, and may be useful for proposing adaptation strategies to future climate warming.

2. Data and method

2.1 Data source

Agriculture data (1978-1999) were obtained from the Chinese Statistic Bureau including sown area and yield per-unit-area of grain (rice, wheat and corn). Meteorology data were obtained from the Chinese Meteorological Administration.

Temperatures between May and September are the main factor that impacts rice yields in Northeast China (Wang Shu-yu, 1980). The sum of average monthly temperatures between May and September ($T_{5\text{-}9}$) is calculated.

2.2 Method

Firstly, according to the relationship between extreme temperature and climate warming, the climate warming may change the probability of extreme temperature by changing the average or standard deviation of temperature. It is calculated that the average and standard deviation of the accumulated temperature between May and September ($T_{5\text{-}9}$) sequence of Northeast China.

In terms of the quantitative relation between heat resource and rice yield per-unit-area of different rice varieties of earliest ripe, early ripe, medium ripe, medium-late ripe and late ripe (Wang Shu-yu, 1980), a mathematical model was established to calculate the expected rice yield per-unit-area (Figure 1). There are a number of assumptions in this model: (a) Farmers are assumed to be rational, and economic people select dominating variety that has maximum expected yield to adapt the climate of the period; (b) Technology development is ignored; (c) and Water resources are enough for planting rice.

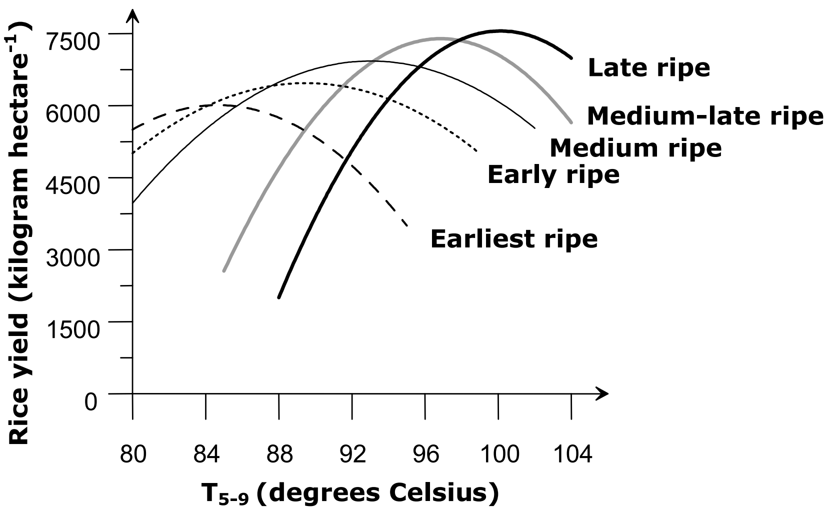

FIGURE 1

Relationship between rice yield per-unit-area of different varieties and $T_{5\text{-}9}$ in the Northeast China (Wang Shu-yu, 1980). They may be fitted by quadratic polynomials approximately.

Late ripe:	$y = -37.739x^2 + 7557.5x - 370810$;
Medium-late ripe:	$y = -34.359x^2 + 6656.5x - 315006$
Medium ripe:	$y = -17.421x^2 + 3241.6x - 143869$
Early ripe:	$y = -16.231x^2 + 2904.9x - 123507$
Earliest ripe:	$y = -23.485x^2 + 3976.5x - 162318$

For calculating expected yield per-unit-area, the reduced rate is defined as

$$x = 1 - \frac{Y(x)}{Y_{max}} \qquad (1)$$

where x is the reduced rate, $Y_{(x)}$ is actual yield, and Y_{max} is the ideal maximum yield per-unit-area.

The formula used to calculate expected yield per-unit-area is as follows:

$$EY = \int_0^1 Y(x)p(x)dx \qquad (2)$$

where EY is the expected yield per-unit-area; and *p(x)* is the probability density function of reduced rate, which can be derived by a relevant temperature probability density function. The following is the solution:

In terms of formula (1), actual yield per-unit-area is

$$Y(x) = Y_{\max} \cdot (1 - x) \qquad (3)$$

Assuming the relationship between temperature and yield per-unit-area can be approximated to a quadratic polynomial (Figure 1), i.e.

$$Y(x(t))=at^2+bt+c \qquad (4)$$

where t is $T_{5\text{-}9}$. In terms of formula (3) and (4), t is expressed as

$$t = \frac{-b \pm \sqrt{b^2 - 4ac + 4aY_{\max}(1-x)}}{2a} \qquad (5)$$

Temperatures obey approximate normal distribution, so its probability density function is

$$\varphi(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(t-\mu)^2}{2\sigma^2}} \qquad (6)$$

where μ is average of $T_{5\text{-}9}$, and σ is standard deviation of $T_{5\text{-}9}$.

According to the relationship between temperature and the reduced rate, there is

$$F_1(x)=F_2(t) \qquad (7)$$

where $F_1(x)$ is the probability distribution function of reduced rate x, $F_2(t)$ is the probability distribution function of $T_{5\text{-}9}$. In terms of the relationship between probability density function and probability distribution function, there is

$$p(x)=\varphi(t)\cdot\frac{dt}{dx} \qquad (8)$$

So the probability density function $p(x)$ is

$$p(x)=[\varphi(\frac{-b+\sqrt{b^2-4ac+4aY_{\max}(1-x)}}{2a})+\varphi(\frac{-b-\sqrt{b^2-4ac+4aY_{\max}(1-x)}}{2a})]$$
$$\cdot\frac{Y_{\max}}{\sqrt{b^2-4ac+4aY_{\max}(1-x)}} \qquad (9)$$

Finally, the actual rice sown area and yield per-unit-area were compared with the result of the model to analyze adaptation to climate warming.

2. Result

2.1 Heat resource and probability of extreme temperature

Since the $T_{5\text{-}9}$ increased notably in the 1990's, the cold period (1960-1979) is selected as the referenced period for the comparison to the warm period (1990-1999). Average and standard deviation of $T_{5\text{-}9}$ were calculated during these two time periods. There are comparative results as follows:

1. The average of $T_{5\text{-}9}$ increased in most of the stations in Northeast China. The accumulated temperatures of Jilin Province increased higher than that in the other two provinces (Table 1). The difference in average $T_{5\text{-}9}$ between the cold and warm periods is 3.09 degrees Celsius in Jilin Province, 2.57 degrees Celsius in Heilongjiang Province, and 1.89 degrees Celsius in Liaoning Province. The standard deviation of $T_{5\text{-}9}$ increased in

most of the stations in Jilin Province and Liaoning Province, however, decreased in most of the stations in Heilongjiang Province (Table 1).

Table 1 The average and standard deviation of accumulated temperatures (T_{5-9}) in Northeast China (degrees Celsius)

T_{5-9}	HEILONGJIANG		JILIN		LIAONING	
Period	1960-1979	1990-1999	1960-1979	1990-1999	1960-1979	1990-1999
Average	83.56	86.13	90.54	93.63	100.81	102.7
Standard deviation	2.52	2.05	2.79	3.15	2.46	2.87

2. Temperature (T_{5-9}) zones shifted northward and eastward, especially in Heilongjiang Province (Figure 2). The standard deviation of T_{5-9} decreased in northern areas (the region with positive) and increased in southern areas (the region with negative) (Figure 3).

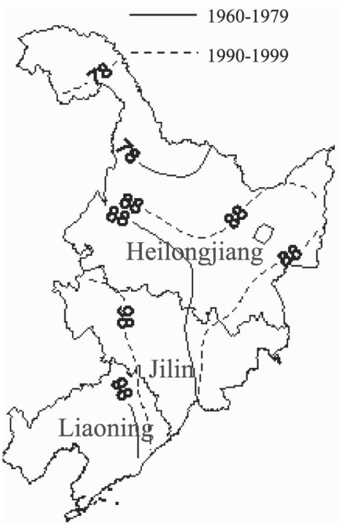

FIGURE 2

Isoline of average T_{5-9} (degrees Celsius) in Northeast China approximately.

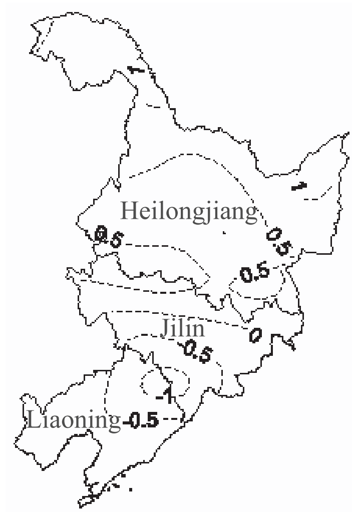

FIGURE 3

Isoline of difference of T_{5-9} standard deviations between the period of 1960-1979 and 1990-1999 in Northeast China

The Skewness-Kurtosis test indicated that the $T_{5\text{-}9}$ data obeys normal distribution during the selected cold and warm periods. Extreme climate events are defined as the probability of the event is not higher than 10 percent (Ding Yi-hui et al., 2002). Calculated from the formula (6), 80.34 degrees Celsius and 86.78 degrees Celsius are the critical accumulated temperatures ($T_{5\text{-}9}$) where the probability is less than or equal 10 percent during the cold period (1960-1979). So all the $T_{5\text{-}9}$ lower than 80.34 degrees Celsius or higher than 86.78 degrees Celsius may be regarded as extreme accumulated temperatures referring to the period from 1960-1999. During the warm period, the probability of accumulated temperature lower than 80.34 degrees Celsius was not higher than 0.23 percent, and the probability of accumulated temperature higher than 86.78 degrees Celsius was not higher than 37.5 percent (Figure 4a). The same results were found in Jilin Province and Liaoning Province (Figure 4b and Figure 4c).

In sum, the probability of extreme cold years decreased and the probability of extreme hot years increased in Northeast China during this time period.

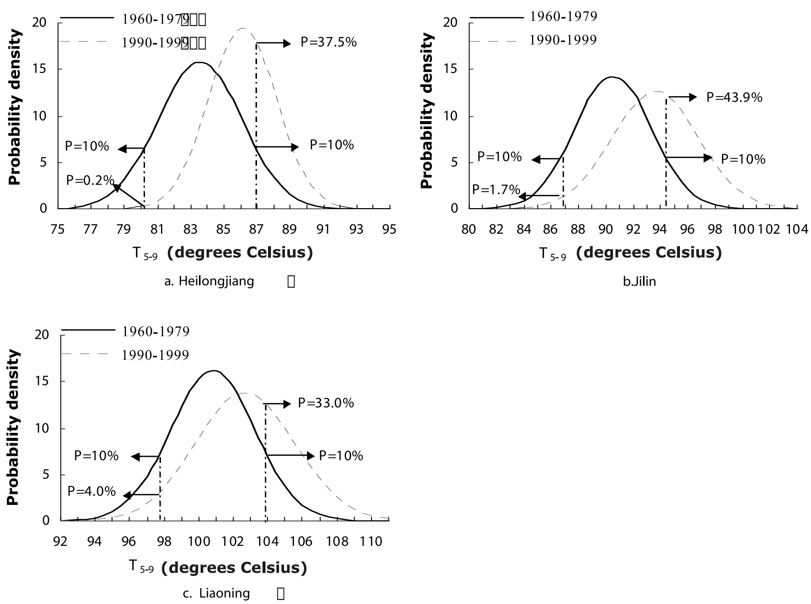

FIGURE 4

Changes of temperature probability (P) for cold and warm periods in Northeast China

The accumulated temperatures (T_{5-9}) in the North increased higher than that in South. At the same time, higher temperature variability appeared in the southern part of the region, and lower temperature variability appeared in the northern part of the region.

2.2 The impact on rice yield per-unit-area of climate warming

The expected rice yields per unit area of the main counties in Northeast China are calculated using formula (2) during the cold period and the warm period for different rice varieties of earliest ripe, early ripe, medium ripe, medium-late ripe and late ripe. It is found that during the cold period, the earliest ripening variety and early ripening variety of rice have their maximum expected yield in the north of Heilongjiang Province and the east of Jilin Province; the medium ripening variety of rice has its maximum expected yield in the middle part of Heilongjiang Province; and the medium-late ripening and late ripening varieties of rice have their maximum expected yield in Liaoning Province and the western part of Jilin Province.

As the climate warmed in the 1990's, the medium ripening variety of rice had its maximum expected yield instead of early ripening variety in some areas of northeastern Heilongjiang Province and the middle-western areas of Jilin Province. The expected yield of the late ripening variety of rice became the maximum even in some places of west-southern Heilongjiang Province and western Jilin Province (Figure 5).

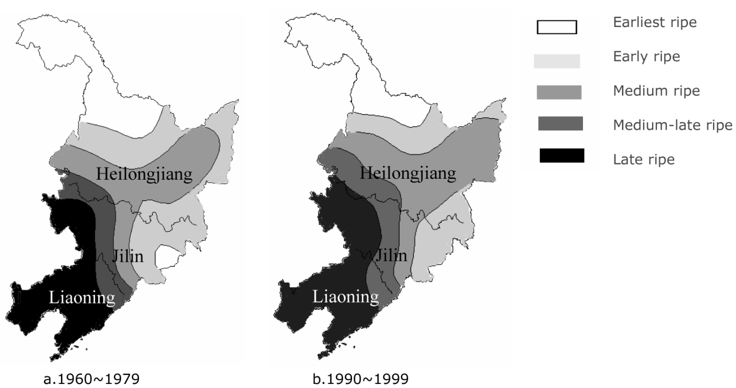

FIGURE 5

Distribution of maximal expected yield (kilogram hectare^{-1}) of different rice varieties in Northeast China

There are two main adaptation choices for changing rice varieties in Northeast China as a result of climate warming (Figure 6).

1. Planting traditional varieties of rice reduces the risk of cool summer extremes, and increases the expected yield per unit area due to the climate warming in northern Northeast China and some mountainous areas by more than 10 to 20 percent. In most areas of Heilongjiang and Jilin provinces, the expected rice yield per unit area increases about 0 to 10 percent. On the contrary, the expected rice yield per unit area in most areas of Liaoning province decreases as the climate warms.
2. In some areas of Northeast China, the originally planted variety of rice does not reach its maximum expected yield under the new temperature conditions. These could be replaced by the rice variety that provides the highest expected yield for the area. If farmers keep planting traditional varieties in some areas of Heilongjiang Province and Jilin Province, the expected yield of rice will decrease by about 0 to 10 percent due to climate warming. If farmers planted the rice varieties that need more heat, expected yields could increase by about 0 to 10 percent.

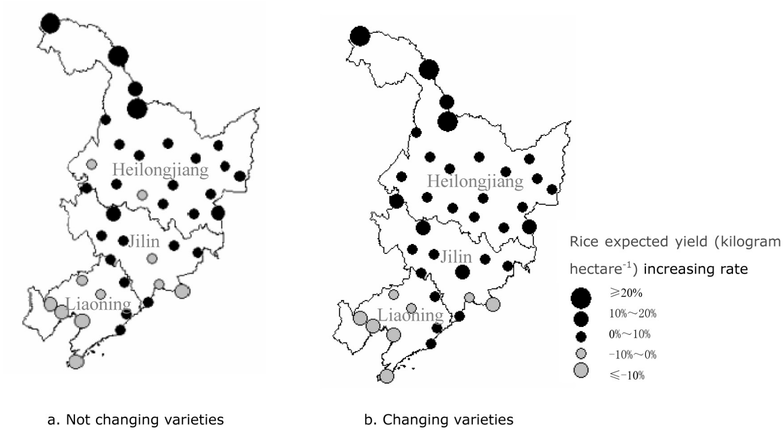

FIGURE 6

Compare increase rate (%) of changing varieties with no changing varieties in Northeast China

2.3 Rice sown area and yield per-unit-area in the past 20 years

2.3.1 Rice yield per-unit-area and climate warming

According to statistical data from 1978 to 1999 in Northeast China, the rice yield per unit area increased remarkably in the three provinces (Figure 7). Generally speaking, technology is the major factor that increases crop yield per unit area, but the impact of climate warming cannot be ignored. Figure 7 presents that the real rice yield per-unit-area of Jilin Province increased highest, and rice yield per-unit-area of Liaoning province increased lowest of the three provinces.

Heilongjiang Province and Jilin Province are short of the temperatures necessary to increase rice yields, so increasing the heat resources are more useful for these two provinces. According to the model, if farmers replaced rice varieties to adapt to climate warming, the expected yield per unit area would be much larger in both Heilongjiang Province and Jilin Province.

The late ripening variety of rice that is planted mainly in Liaoning Province is near its highest limit of optimum temperature for growth. So the expected

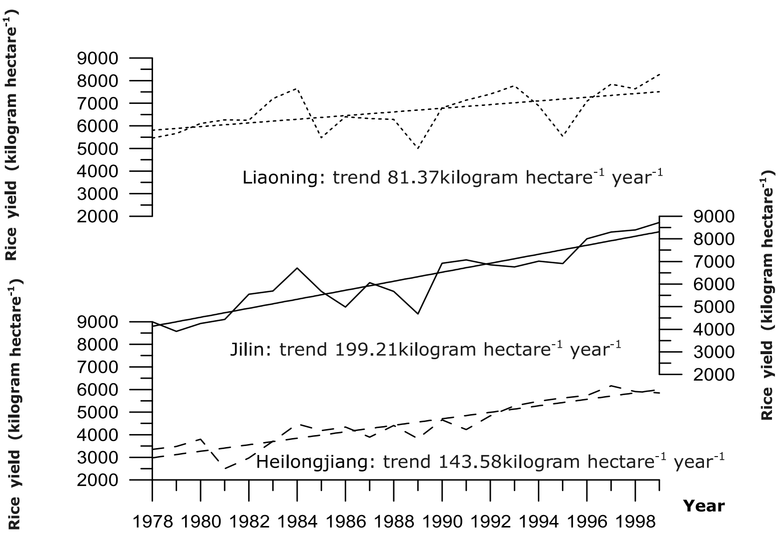

FIGURE 7

Chang of rice yield (kilogram hectare^{-1}) in the Northeast China (1978~1999) rice yield per unit area will decrease due to warming. This may be reflected in the lower increase in rice yield per unit area in Liaoning Province than the other two provinces. Climate warming has increasingly positive impacts on rice in Heilongjiang and Jilin provinces; however, these impacts are limited in Liaoning province.

2.3.2 Rice sown area and human adaptation

Human adaptation to climate warming includes not only changing the varieties of one kind of crop, but also adjusting the structure of planting. Major structural changes in planting crops can overcome adversity caused by climate change (Olesen and Bindi, 2002). The ratio of sown area is often applied to reflect the changes in the structure of planting. Rice has the largest income per unit area of grain crops. Therefore, as long as heat and irrigation satisfy rice demands, farmers will choose rice for a higher economic benefit.

Figure 8 shows that the ratio of rice sown area to main grain (rice, wheat, maize) sown area increased from 5.5 percent in 1978 to more than 30 percent in 1999 in Heilongjiang Province, and increased from 11.8 percent (1978) to 16.0 percent (1999) in Jilin Province. In Liaoning Province, the ratio of rice sown area to main grain (rice, wheat, maize) sown area increased a little in the 1980's, and declined in the 1990's.

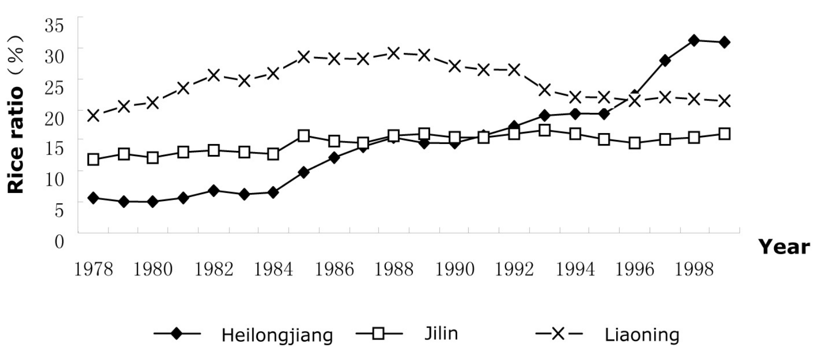

FIGURE 8

Ratio (%) of rice sown area to main grain (rice, wheat, maize) sown area in the Northeast China

In terms of the results of the model, the negative impacts of climate warming seem partly to induce the decrease in rice sown areas in Liaoning Province. The positive impacts of climate warming are likely to induce the growth of rice sown areas in Jilin Province and Heilongjiang Province. In Heilongjiang Province, rice sown areas expanded (Figure 8), where the north boundary of rice has shifted remarkably both northward and eastward.

3. Conclusion

Climate warming may produce positive or negative effects on agriculture, and this will require adaptation to new climatic conditions. In this paper, Northeast China is chosen as a case study to examine the effects and adaptations on rice crops when climate becomes warmer. A decision-making model was created to calculate the expected rice yield per unit area with accompanying heat resources. The model was used to assess the impact on rice production of changing suitable varieties under the new climate conditions. Comparing the results of model with the statistical data, it was found that increasing heat resources affected the rice yield per unit area trend in Northeast China, and that farmers can adjust their planting structure and rice varieties to adapt to climate warming. In sum, there are several conclusions.

1. Climate warming leads to an increase in the probability of extreme warm years and a decrease in the probability of extreme cold years. The increase in temperatures in the north is more remarkable than those in the south of Northeast China. Higher temperature variability appears in the southern part, and lower temperature variability appears in the northern part.
2. On the assumption that farmers ideally select the dominating rice variety that has a maximum expected yield to adapt to the climate of the period, pure impacts of climate warming will induce the rice variety that needs more heat to shift northward and eastward (if technological development is ignored). If farmers keep planting traditional rice varieties, the expected yield per unit area in Heilongjiang Province and Jilin Province will increase as warming provides more favorable temperatures for rice production. If farmers changed these rice varieties to adapt to a warmer climate, the expected yield per unit area will increase more. In a large part of Liaoning Province, the impact of climate warming to the expected yield of rice will be negative.

3. Real rice yield per unit area in Jilin Province and Heilongjiang Province increased higher than that in Liaoning Province in the past 20 years. Increasing heat resources affects the trend of rice yield per unit area. To avoid or reduce negative effects and exploit possible positive effects, farmers should expand rice sown areas in Heilongjiang Province and Jilin Province, but reduce rice sown areas in Liaoning Province. This fact demonstrates that humans can adjust planting structure to adapt to climate change.

This paper pays attention to heat resources and human adaptations. However, there are other factors that affect rice production in Northeast China. Some of these issues should be studied further such as the following.

1. A quadratic polynomial that approximates the relationship between temperature and yield per unit area is not the most precise model. More accurate data and models are needed to calculate the expected yield.
2. Other factors affect crop yield. Water resources are an important factor that affects rice yields. Although a serious drought took place after 1999 in the Northeast China (Xie an, 2003), and in the period (1960-1999) that was discussed in this paper, water was not the major limiting factor. The impact of water resources on rice production, however, could become more important in the future. In addition, human factors such as agricultural policies and technology are also important factors to be studied.
3. Human adaptation activities are also affected by other factors. In practice, farmers might select the variety for an extreme warm year or extreme cold year, instead of the average climate conditions. Price or the risk of a cool summer extreme often makes the farmer avoid the rice variety that has the maximum expected yield per unit area. Moreover, farmers often cannot take action in time. So the "adaptation lag" and the farmer's capacity to endure risk need to be studied.

4. Acknowledgements

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chapter VI

Energy, Infrastructure and Growth

16 paper

THE CHANGING CLIMATE AND COMMUNITY VULNERABILITIES TO DISASTERS

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ABSTRACT: Evidence from around the world indicates that the costs of weather related disasters are increasing over time. In many cases, these weather related disasters have resulted from the failure of our infrastructure and built environment to cope with extreme weather events, environmental degradation and the location of infrastructure in high risk locations. While debate still continues on whether or not climate variability and weather extremes have increased, other evidence suggests that vulnerabilities to climate events likely have increased. Reducing societal vulnerability to weather related disasters under current and changing climate conditions will require a diverse and interconnected range of adaptive actions. These actions include hazard identification and risk assessment, comprehensive disaster management, improved predictions of high impact weather, better land use planning, strategic environmental and ecosystem protection, continuously updated and improved climatic design values for disaster resistant infrastructure codes and standards, more enforcement of building codes and improved structural design methods and materials. Steps taken today to reduce the impacts of weather hazards will provide new opportunities to learn how to better face the challenges of the future. While several adaptation steps, both structural and non-structural, can be undertaken today to ensure that communities can withstand the climate of the future, other adaptation actions will be limited by considerable uncertainty in projections on future extremes and by the difficulties of retrofitting or changing the existing built environment.

Keywords: built environment, climate change, disaster, extreme weather, hazard, management, vulnerability.

1. Introduction

One of the most threatening aspects of global climate change is the likelihood that extreme weather events will become more variable, more intense and more frequent. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001a) states that:

> *"The key features of climate change for vulnerability and adaptability are those related to variability and extremes, not simply changed average conditions. Most sectors and regions are reasonably adaptable*

to changes in average conditions, particularly if they are gradual. However, these communities are more vulnerable and less adaptable to changes in the frequency and/or magnitude of conditions other than average, especially extremes". (Chapter 18, page 879)

International concern over extreme weather events has grown as the economic damages and human tolls from these events have increased. Since the decades of the 1950s, the annual direct losses from natural catastrophes have increased 14 times from the 1990s, increasing from US$3.9 billion to US$40 billion a year in 1999 dollars, as shown in Figure 1 (Munich Re, 2000; IPCC, 2001a). Most of these increases in losses have come from weather-related high impact events (Munich Re, 2000; IPCC, 2001a), with a significant proportion of these annual direct losses resulting from the failure of infrastructure or assets in the hazard-affected area to withstand extreme weather or anomalous climate events or from infrastructure and communities located in "harm's way". Of the annual total direct losses averaging $40 billion a year, approximately $9.6 billion of direct damage occurred as a result of damaged to infrastructure (Freeman and Warner, 2001).

While it is normal to expect large year-to-year variations in the number and intensity of natural hazards, it is not normal for the costs of natural hazards to continue rising over time. Several factors in addition to regional climate hazards have contributed to these rising trends in disaster losses (IPCC, 2001a), including:

- increasing populations;
- increasing urbanization and dependence on uninterrupted services in communities;
- increasing prosperity and insured property in developed countries;
- an increasing dependence in developed countries on high technology computer-based technologies and just-in-time delivery systems that are vulnerable to interruptions;
- infrastructure sited in higher risk locations;
- an aging infrastructure, changes to the design of infrastructure (e.g. performance based design) and a highly competitive construction industry;
- increasing poverty in lesser developed nations, ensuring that vulnerable populations remain unable to remove themselves from high risk locations;
- regional environmental degradation, which can transform a climatic hazard (e.g. heavy downpour) into a disaster;

- regional increases in frequencies or intensities of extreme events;
- failure to use best climatic design hazard information as well as best mitigation and engineering practice (including enforcement of codes and standards).

While natural hazards, including hurricanes, flash floods, severe winter storms, windstorms and earthquakes, are inevitable over time, community vulnerability to hazards can almost always be within control. When a natural hazard becomes a disaster and leads to disruptions of entire communities, the result is as much as function of the way that the community does business and adapts to the hazard as it is of the natural hazard itself. A natural hazard

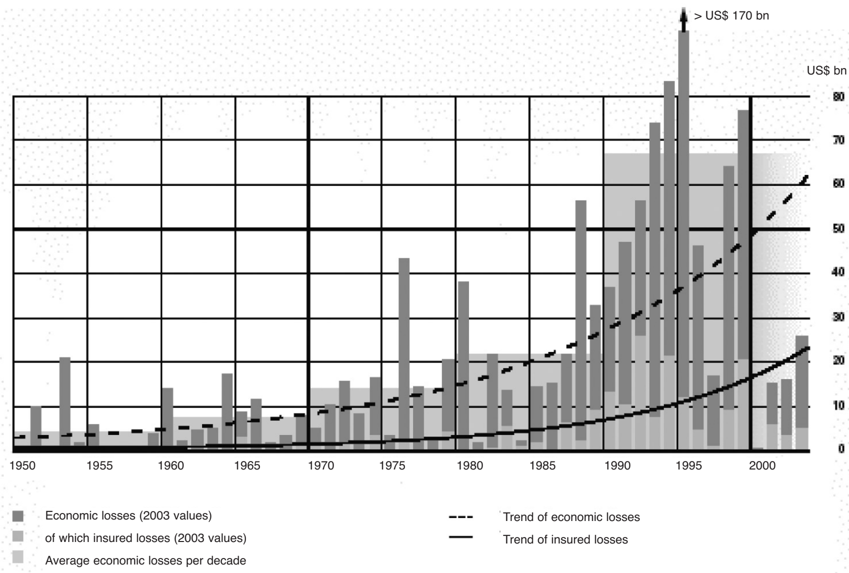

FIGURE 1

Losses from "great" natural disasters from 1950-2000 (US$), including trends in insured and other economic costs.

(From IPCC 2001a and Munich Re 2000). *The costs of catastrophic weather events have exhibited a notable upward trend in recent years. Yearly economic losses from these large disasters increased 10.3-fold from US$3.9 Billion in the 1950s to US$40 Billion per year un the 1990s (expressed in 1999 US$). Costs are larger by a factor of two when losses from relatively ordinary weather-related events are included. Population grew by one 2.4-fold during this period.*

does not need to become a disaster if the risks associated with the hazard are managed. In the built environment, natural hazards can be managed through proper land use, good engineering design and practice, and planned response to timely and accurate weather warnings (Freeman et al, 2003).

2. Managing Disaster Risks for Current and Future Climates

As temperatures warm globally and the climate changes, it is projected that direct losses from extreme weather will increase dramatically with the shifting of storm tracks and regionally increasing storm frequencies and intensities. According to the Intergovernmental Panel on Climate Change (IPCC, 2001a), extreme weather events may occur more frequently, with the potential to affect flooding, droughts and the frequency and severity of cyclonic systems (including hurricanes and tropical storms). Storm impacts in coastal areas will be further impacted by rising sea-levels that will magnify the impact of storm surges and wave action. As total direct damages increase globally, it is reasonable to expect that infrastructure damage as a portion of those overall losses will increase as well. According to a report by the United Nations Environment Programme's (UNEP) financial services initiative, the global cost of natural disasters is anticipated to top US$300 by the year 2050 (Berz, 2001) if the likely impacts of climate change are not countered with aggressive disaster reduction measures. The report calculates potential losses in such areas of energy, water, flood protection efforts, ecosystems vital for fish supplies, agriculture and forestry, construction, transportation, and tourism. In addition to the impacts of climate change, the risks posed by the increasing degradation of the environment, including deforestation, loss of biodiversity, reduced water quality and supply and desertification, can only add to future impacts.

There is a need for more comprehensive and integrated approaches to hazard risk management. These approaches need to accommodate both climate change adaptation requirements and community needs for risk management. All too often, the disaster management disciplines and the climate change disciplines do not communicate with each other, perhaps because the professionals working in these topic areas operate with different timescales and under different mandates. For example, while emergency coordinators focus on real-time disaster events and planning for emergency responses, the climate change scientists have a tendency to work with 50 to 100 year climate models that sometimes may bear little immediate relevance to the policy makers and fieldworks concerned with potential emergencies. The two sets of professionals need to interact more effectively and to better include the planning and development disciplines.

While adaptation actions are known and available today to reduce the risks of current and future natural disasters, many of these adaptation actions have yet to be applied to today's hazard problems for a number of reasons, including capacity and resources. As a first step to reducing climate change disaster risks, a "no regrets approach" that reduces vulnerability to near-term hazards is an effective strategy for reducing long-term risks. Approaches that address the potential impacts of climate change must be based on the current capacity to address existing climate variability and deficiencies in these capacities. Strategies to address existing risk scenarios have the advantage of being more feasible for mobilization of national and international political and financial resources than strategies that address a hypothetical future scenario. The adaptation lessons that are learned in the process of addressing current deficiencies will be needed as risks become more complex under the changing climate. Medium and long-term adaptation must start with efforts to improve current risk management and adaptation.

The first important step in reducing risks under the changed climate is to first seek to identify gaps in current capacity. The barriers to managing the risks associated with current climate variability are the same barriers that will inhibit regions and nations in addressing the future increases in the complexity and uncertainty of risk due to climate change. (UNDP, 2002). As a result, the adaptation lessons learned from current practices, along with a commitment to forensic studies and learning from failures, will constitute a critical component of climate change adaptation. Since many of the impacts of climate change will lie outside of existing experience and existing coping ranges, it is even more important that existing "adaptation deficits" (Burton, forthcoming) first be understood and filled.

3. Disaster Management

3.1 Disaster Management Strategies

Disaster management encompasses a variety of measures taken before, during and after disasters; it denotes the management of disaster risks as well as the consequences of disasters (Freeman et al, 2003). By definition, a hazard is an event or phenomenon that has the potential to cause harm or loss (Asian Disaster Preparedness Centre, 2000) and includes hurricanes, tornadoes, heavy rainfalls, severe ice storms, wind storms and similar events and well as technological accidents (often triggered by climate hazards). A risk is "the probability of harmful consequences, or expected loss resulting from interactions between natural hazards and vulnerable or capable conditions", and a disaster is understood as "the actual impact causing widespread losses which exceed the ability of the affected community/society to cope with such a situation using its own resources" (ISDR 2002). Disaster management then is the planned development and application of policies, strategies and practices to reduce disaster risk. Disaster management in essence tries to minimize the existing vulnerability and to prevent or to limit adverse impacts of hazards (mitigation and preparedness) with comprehensive plans to react to emergencies and act after disaster impacts (rehabilitation and reconstruction) (ISDR, 2002a). Disaster management is the most proactive and successful method for reducing the physical, financial, and emotional losses caused by disasters.

In most countries, natural hazard policies traditionally focus on establishing efficient disaster response. Although disaster response is important, it fails to address the causes of disaster losses. Those causes are rooted in the complex interaction of human settlement and the natural environment. Recurring natural events become disasters because populations exist in harm's way in structures inadequately prepared to withstand anticipated natural hazard events. To protect people and their assets, natural disaster policies must deal with a broad set of issues.

The most important element of a national disaster management plan is prevention. Prevention includes steps to reduce vulnerabilities that cause damages in the first place. Other elements of a disaster management plan include better early weather warnings of impending disasters that buy time to evacuate populations, reinforce infrastructure, reduce potential damages or prepare for emergency response. But, weather warnings are only effective if accompanied by more effective hazard and disaster response policies. In many countries, weather warning systems consist of an escalating series of messages intended to alert the public to impending weather hazards of various magnitude. Typically, these warning systems consist of advisories or watches for potential hazardous weather and then warnings issued as hazardous weather becomes more certain. In the UK, for example, a variety of weather warnings are issued, including early warnings for emergency authorities, motoring warnings for both emergency authorities and the public and warnings of severe weather and of exceptionally severe weather (http://www.met-office.gov.uk/weather/europe/uk/warnings.html). Advance warnings for emergency authorities and escalating warnings of exceptionally severe weather, particularly if linked to potential for infrastructure failure and emergency events, may be required under increasing disaster risks for optimal emergency response and preparedness.

A national disaster system requires the interaction of governments, institutions, financial mechanisms, regulations, and policies. Successful disaster reduction systems involve a wide variety of stakeholders. The most successful systems take advantage of the existing government structures and policies and involve all levels of government and other institutions (*ISDR, 2002a,* 2002b; ISDR, 2004). Above all, a disaster management plan needs to be appropriate for each country's circumstances and economy. The challenge in disaster management is to construct a program that is viewed as more desirable than the status quo by key parties. There also needs to be recognition that programs in place prior to a disaster may be greatly modified after a catastrophe occurs. (UNDP, 2004)

Finally, legislation increases the likelihood that a national disaster management plan will become sustainable. Legislation provides a formal basis for counter-disaster action, allocates major responsibilities in legal form, and provides a measure of protection for governments, organizations, and individuals by outlining the limited responsibilities of each in the disaster management process (Asian Urban Disaster Mitigation Program 2002). But, the best laws are useless if not effectively and impartially enforced.

Repeatedly, history shows that the prevention of natural disasters is closely tied to measures to protect the quality of environments and management of natural resources (German Committee for Disaster Prevention, 2002). At the same time, when disasters are not managed, the resources are often not there either to protect the environment or to ensure that a viable economy is in place. The natural environment can provide valuable environmental services that increase protection against disaster impacts. As a result, successful disaster reduction strategies need to enhance environmental quality, including protection of natural resources and open space, management of water run-off, and reduction of pollution. According to J. Abramovitz (2001), unhealthy ecosystems can exacerbate some hazards to the point where

> *"a growing share of the devastation triggered by 'natural' disasters stems from ecologically destructive practices and from putting ourselves in harm's way. Many ecosystems have been frayed to the point where they are no longer resilient and able to withstand natural disturbances, setting the stage for 'unnatural disasters' – those made more frequent or more severe due to human actions. By degrading forests, engineering rivers, filling in wetlands, and destabilizing the climate, we are unravelling the strands of a complex ecological safety net."*

3.2 Disaster Management Phases

There are two phases to disaster risk management: (1) actions required in the pre-disaster phase and (2) actions needed in the post-disaster period. The pre-disaster phase includes risk identification, risk mitigation, risk transfer, and preparedness; the post-disaster phase is devoted to emergency response and rehabilitation and reconstruction (Freeman et al, 2003).

3.2.1 Pre-Disaster Strategies

In disaster language, mitigation refers to policies and activities that reduce an area's vulnerability to damage from future disasters. These include structural and nonstructural measures that are put into place before a disaster occurs.

3.2.1a Structural Disaster Mitigation Measures

Structural disaster mitigation measures reduce the impact of hazards on people and buildings via engineering measures. Underground electrical transmission lines, for example, are protected from hurricane damage. Levees, dams, and channel diversions are all examples of structural flood mitigation. While structural mitigation projects can be very successful from a cost/benefit perspective, they also have the potential to provide short-term protection at the cost of long-term problems. In some areas, flood control systems have exacerbated rather than reduced the extent of flooding. In one case, sediment deposit in river channels as a result of flood control systems raised the height of river channels and strained dike systems, resulting in flood events of greater depth and bringing more damaging than in the past (Benson 1997). More generally, though, some structural mitigation projects have the potential to provide people with a false sense of security. The damages from the 1993 flooding of the Mississippi river in the United States were magnified because of misplaced confidence in structural mitigation measures that had encouraged development in high-risk areas (Mileti D., 1995; Platt R., 1999). To avoid this problem, structural mitigation projects should be accompanied by appropriate land-use planning and public awareness programs. However, the difficult reality is that land-use planning requires intense political support, particularly if it affects property values or involves the relocation of communities.

3.2.1b Non-Structural Disaster Mitigation Measures

Nonstructural disaster mitigation measures are non-engineered or institutional activities that reduce the intensity of hazards or vulnerability to hazards. Examples of nonstructural mitigation measures include land use management, zoning ordinances and enforcement of building codes, public education and training, and reforestation in coastal, upstream, and mountain areas. Nonstructural measures can be encouraged by government and private industry incentives, including measures such as preferential tax treatment or adjusted insurance premiums that reward private loss-reducing measures (Freeman et al, 2003). Nonstructural mitigation measures can be implemented by central authorities through legislating and enforcing building codes and zoning requirements or by NGOs or community groups initiating neighborhood loss-prevention programs.

The development of good engineering codes and standards will continue to be successful in preventing much harm to the built environment. Codes and standards are intended to represent minimum requirements for safe construction of structures and require the use of climatic and seismic design values. These climatic design values reflect an acceptable risk against the extremes of nature. Quantities like the 10, 30, or 100 year worst storm wind or rainfall are used and these values vary considerably from one location to another (Canadian Commission on Building and Fire Codes, 1995).

A drawback to such measures, however, is that even when they exist, there can be a tendency on the part of the private and public sectors to not properly enforce the regulations or standards on the books. For example, in Florida, insured property losses from Hurricane Andrew would have been reduced by 25 percent through building code compliance (Freeman et al, 2003). Studies have found that inspection personnel sometimes have insufficient knowledge of the hazard mitigation aspects of the building codes to enforce them effectively. The problem is compounded because of limited staffing so that even competent individuals cannot keep up with the demand for building inspections.

3.2.2 Post-Disaster Strategies

A tool for disaster reduction is *preparedness*, which involves the development of an emergency response and management capability long before a disaster occurs. Emergency response refers to actions taken immediately before, during, and after the onset of a major disaster or large-scale emergency to minimize the loss of life and harm to people and their property and enhance the effectiveness of recovery. Key disaster preparedness activities include hazard detection and warning, evacuation of threatened populations, shelter for victims, emergency medical care, search and rescue operations, security and protection of property, family assistance training programs for response personnel, exercises and drills of emergency plans, education programs to inform citizens, hazard detection and warning systems, identification of evacuation routes and shelters, maintenance of emergency supplies and communications systems, establishment of procedures for notifying and mobilizing key personnel, and individual household measures such as clearing attic space to make room for belongings in case of a flood. Other examples include the construction of temporary levees, closure of roads or bridges, provision of emergency water or power supplies, and response to secondary hazards such as fire or the release of hazardous materials.

The quality and timeliness of disaster response are typically functions of the planning and training done during pre-disaster preparedness. From decades of experience, it is clear that the best emergency response comes immediately and with sufficient resources to limit the loss of life and property. Experience in numerous disasters reveals the need for a strong, centralized system to mobilize emergency efforts and channel aid resources to victims (Red Cross, 2001).

In contrast with other elements of disaster management strategies that often operate at the national or large-scale regional level, preparedness projects tend to be oriented toward the actions of individuals and community organizations. Programs must therefore focus on the community level and a national system should include mechanisms to coordinate with preparedness projects. Disaster preparedness also requires significant political will. According to Smith (1996), "*it ties up facilities and people that are apparently doing nothing, other than waiting for an event that no one wants and many believe will never happen*" It is inherently difficult to maintain impetus for diverting resources into preparedness projects if many years have passed since the last disaster event. Outdated plans and warning systems, however, have the potential of being worse than no provisions at all (Freeman et al., 2003).

3.3 Assessing Vulnerabilities: An Effective Adaptation Strategy

A very critical part of a disaster reduction strategy is the completion of a Vulnerability Assessment. Vulnerability is defined as:

> *The extent to which a community, structure, service, or geographic area is likely to be damaged or disrupted by the impact of a particular disaster hazard, on account of their nature, construction, and proximity to hazardous terrain or a disaster prone area (ADPC 2000).*

Vulnerability assessments identify sources of hazards, vulnerable groups, risks likely and potential interventions. For example, vulnerability assessments identify weather and other types of hazards, identify critical infrastructure at risk to these weather hazards along with vulnerable groups and then develops potential adaptation and prevention interventions.

The identification and prioritization of hazards requires documentation and studies on the probable location and severity of dangerous phenomena such as high impact weather as well as information on the likelihood of their occurring within a specific time period in a given area. These studies rely heavily on available scientific information, including climate and hydrological data and maps; topographic maps, aerial photographs, and satellite imagery. Forensic studies or other historical information, in the form of written reports and oral accounts from long-term residents, can also be used at the community level to help characterize potential hazardous events (Government of Ontario, 2003; Meteorological Service of Canada, 2004). To be most successful, hazard assessment requires sufficient and defensible analyses by experienced scientific teams. Physical vulnerability studies could, for example, analyze impacts on local buildings, infrastructure, and agriculture.

4. International Strategy for Disaster Reduction

In recognition of growing concerns over the rising numbers of natural disasters worldwide, the United Nations is developing an International Strategy for Disaster Reduction (UN ISDR). The Strategy will follow from the recommendations of the 1990s International Decade for Disaster Reduction (1994) and the Plan for the Implementation of the World Summit on Sustainable Development in Johannesburg in 2002. The Strategy will identify specific activities on vulnerability, risk assessment and disaster management. As part of the review process leading to the UNISDR, the ISDR Secretariat and the United Nations Development Program (UNDP) have developed a *Framework for Monitoring and Guiding Disaster Reduction*. The framework contains the following goals (ISDR 2002; ISDR 2004):

1. Ensure that disaster risk reduction is a national/regional priority (e.g. legislation, empowering of communities)
2. Identify, assess and monitor risks and enhance early warning (e.g. hazard and risk mapping, climate change trends, weather and early warning systems, risk assessments, disaster information systems).
3. Use knowledge and education to build a culture of resilience (e.g. disseminated information on disaster risks, training for communities, communication technology).
4. Reduce the underlying risk factors (e.g. urban disaster risk assessments, climate variability and change adaptation, protection of critical infrastructure).
5. Strengthen disaster preparedness, contingency planning and community involvement in risk reduction (e.g. update disaster preparedness plans, cooperation between emergency management and disaster risk reduction programs).

5. Implementing a Disaster Management Strategy: A Case Study for Ontario, Canada

The province of Ontario, located in central Canada, passed provincial legislation in April, 2003 requiring that all municipal and regional governments adopt disaster management planning by the end of 2006. The requirements of this legislation meet many of the goals of the International Strategy for Disaster Management. For example, the legislation requires that municipalities identify and assess the various hazards and risks to public safety that could give rise to emergencies in their communities and develop a prioritized emergency response plan, including the identification of the facilities and other elements of the infrastructure that are at risk of being affected by emergencies. In the subsequent two years, these municipalities must develop comprehensive plans to reduce prioritizes risks. This includes the development of a municipal disaster mitigation strategy, planning for high risks, the development of an emergency recovery plan, implementation of guidelines for risk-based land use planning and development of public education programs (Government of Ontario 2003). In support of these measures, Emergency Management Ontario has provided vulnerability assessment training to emergency coordinators while the Meteorological Service of Canada has prepared hazards documentation.

The Meteorological Service of Canada has developed an atmospheric hazards publication and web site that allows municipalities to access climatological information, customize atmospheric hazards maps for their localities and to overlay regional combinations of hazards maps (Meteorological Service of Canada, 2004). The web site includes documentation and a collection of atmospheric hazards maps on a wide range of weather hazards. These maps also include weather hazards maps (e.g. severe ice storms, heat, tornadoes, heavy rainfalls) as well as information on extreme air quality events to help health units develop plans to protect the most health vulnerable members of society. The software on the site allows various hazards maps to be overlain with customized screening criteria applied to each map (see Figure 2). This co-recognition software is helpful in assessing cumulative hazards. Plans are in place to augment the hazards web site with web-based studies on climate change trends, along with information on their potential impacts and implications for future disasters. The site should eventually include displays of customized weather data and weather warning status information, forensic meteorological studies as well as atmospheric risk assessment studies, as appropriate.

FIGURE 2

Composite mapping of two hazards fields: High Hail Frequencies for all locations in Ontario and High Tornado Frequencies. (From http://www.hazards.ca).

6. Conclusions

Since their first appearance on the planet, humans have been adapting to changing climate conditions and to extreme events. But, the growing increases in disasters and losses from climate related hazards indicates that existing adaptation measures have either not been implemented or are failing. These vulnerability and loss trends, combined with new risk factors such as climate change and globalization, all suggest continued increases in losses in the future if deliberate, co-ordinated and conscientious disaster management actions are not taken in the short and medium terms.

There is a growing awareness of the need for linkages between disaster management and climate change. Addressing and managing climate risk in the here and now for current extreme events and impacts is the most appropriate way of strengthening adaptation capacities to deal with changing climate of the future (UNDP, 2002). The adaptation and disaster management options in the here and now must include early warning systems, more accurate forecasting and better uptake of warning information, improved land-use planning and zoning; continuously updated building codes and infrastructure standards; better disaster mitigation planning strategies (including floodplain and other hazard mapping); inventories of resources (such as water) and the use of water-saving devices and watershed management; the inclusion of traditional knowledge; and the integration of climate change considerations into the management decisions for all sectors.

The inappropriate use of natural resources, environmental degradation and haphazard development of human communities are significant contributory factors to natural disasters. Environmental degradation can increase the intensity of natural hazards, or transform a climate hazard into a disaster. The resilience of communities to climate and other hazards can be increased through practices such as the sustainable and integrated management of natural resources, including reforestation schemes, proper land use and good management of rivers and coastal areas (ISDR, 2003). In the end, "secure societies are those that have learned to live with their land as well as from it. Disaster reduction strategies will have succeeded when governments and citizens understand that a natural disaster is a failure of foresight and evidence of their own neglected responsibility rather than an act of God." (ISDR, 2002b).

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17 paper

CLIMATE CHANGE AND EXTREME CLIMATE EVENTS:
VULNERABILITY AND ADAPTATION OF THE CANADIAN ENERGY SECTOR

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ABSTRACT: There are two specific "reasons for concern" for the stakeholders of the Canadian energy sector about the seriousness of climate change impacts. They are the relationships between the global mean temperature increase and the distribution of impacts; and the probability of extreme weather events. Energy production, supply and demand are sensitive to climatic variability and change and sea level rise in Canada. Power generation, transmission and distribution components of the energy sector are presently vulnerable to extreme weather events. Power output loss due to low lake levels in 1964 was estimated at 4.4 million megawatt hours. During the ice storm of 1998, power transmission and distribution suffered a total insured loss estimated at CAN$3 billion. The damage to high voltage transmission towers, distribution systems and transformers raised serious questions about the robustness of the power distribution systems in Ontario and Québec. In general, the measures to cope with the situations were found to be inadequate. In the future, there are possibilities of more heat waves, ice storms and drought conditions in Canada due to climate change. Therefore the energy sector may become more vulnerable unless adequate adaptation measures are designed and implemented.

Keywords: climate change, adaptation, energy, water levels, ice storm

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) indicated about possible changes in climate and increases in extreme weather events in the future (IPCC, 2001). The sensitivity of the Canadian energy sector to future changes in climate and climate extremes may be more pronounced. Mirza (2004) discussed the major impacts of climate variability and change on various components of the Canadian energy sector. Energy production, supply and demand are sensitive to climatic variability and change, and sea level rise. With changes in precipitation and lake levels, hydro-electric power generation may be affected across Canada.

Available assessments show that future warming will reduce heating energy demands in the winter. On the other hand, cooling energy use in the summer will increase. A rise in sea level and possible increases in the number of extreme weather events (such as high winds and storm surges) may cause adverse effects on the offshore oil industry in terms of damage to platforms and riskier investments. Increased winter storms may cause serious damage to transmission and distribution of electrical energy. Coastal energy supply infrastructure may also be impacted as a result of storm surge and sea-level rise. Changes in permafrost in northern Canada will cause stability problems for fossil fuel transmission pipelines. High summer temperatures may reduce transmission capabilities although the magnitude of such a reduction is not known. Extreme events such as severe winter or summer storms can cause extensive damage to power transmission lines and other infrastructure.

The future vulnerability of the Canadian energy sector to changes in climate and extremes is highly dependent on its present state. It is therefore necessary to assess the present vulnerability and performance of the measures to adapt to climate change and climate extremes. It is also necessary to examine potential adaptation measures that will help reduce vulnerability. This paper addresses these in two steps. First, two extreme climate events are selected and vulnerability of the energy sector and the adequacy of adaptation measures are analyzed. Second, a range of adaptation options are suggested to reduce the sensitivity of key assets to changes in climate and extremes, designing resilience and flexibility into the energy infrastructure on appropriate time scales, and managing energy systems and institutions in a climate-resilient manner.

2. Extreme Weather Events and Vulnerability of the Canadian Energy Sector: Two Case Studies

2.1 Case Study: Ice Storm 1998

Eastern Canada (Québec, Ontario and the Maritimes) is susceptible to ice storms – the result of the ice formation process greatly influenced by general weather patterns. The ice storm which hit eastern Canada in 1998 was the worst in recent history. Three previous storms are well documented During the ice storm of February, 1961, the Montreal area was without power for several days, and the estimated damage was CAN$41 million in 1998 dollars (CAN$7 million in 1961) (Mahaffy, 1961). The March, 1972 ice storm affected the Ottawa Valley and the Laurentian foothills (Chaîné, 1973). Damage was estimated at CAN$6 million (CAN$1.5 million in 1972 dollars) and included 900 fallen wooden hydro poles (Chaine and Skates, 1974; Bergeron et al., 1997). During the December, 1983 ice storm, southwestern Québec was plunged into darkness. The ice storm deprived half a million Montreal residents of power for a period of at least 36 hours (Bergeron et al., 1997).

Milton and Bourque (1999) analyzed precipitation data to identify areas in Canada susceptible to freezing precipitation (see Table 1). The analysis shows the highest days of freezing precipitation occur in Newfoundland followed by Québec. In the case of Newfoundland, this is due to the formation of freezing drizzle initiated by frequent contact of cold air masses with the Atlantic Ocean (Phillips, 1990). Western Canada is only moderately susceptible to freezing precipitation.

The 1998 ice storm inflicted heavy damage to the transmission and distribution infrastructure of the power sector in the Canadian provinces of Québec, Ontario, New Brunswick and Nova Scotia. Table 2 demonstrates the damage that occurred during the ice storm.

Table 1 Average annual number of days with freezing precipitation for the period 1961-1990.

CITY	MEAN ANNUAL NUMBER OF DAYS
Gander, Newfoundland	51
St. John's, Newfoundland	36
Halifax, Nova Scotia	19
Ottawa, Ontario	17
Vald'Or, Québec	16
Québec City, Québec	15
Montreal/Dorval, Québec	13
Bagotville, Québec	13
Saint-Hubert, Québec	12
Shefferville, Québec	12
Winnipeg, Manitoba	12
Sherbrooke, Québec	10
Toronto, Ontario	10
Sept-Îles, Québec	9
Mont-Joli, Québec	8
Edmonton, Alberta	8
Vancouver, British, Columbia	1

Source: Milton and Bourque, 1999.

Table 2 Damage caused to transmission and distribution lines of Hydro-Québec

VOLTAGE CLASS KILO VOLTS (KV)	NUMBER OF DAMAGED LINES	NUMBER OF COLLAPSED STRUCTURES
Transmission		
735	10	150
315	12	60
230	13	300
120	67	1,100
49	14	1,500
Total	116	3,110
Distribution		
25	350	16,000

Source: Hydro-Québec, 1998a

It appears that much of the damage was caused to the main transmission lines. Out of eleven 735 kilo Volt lines, 10 were completely damaged (91%). Lines of smaller voltage class were also damaged significantly. Comparatively, damage of distribution lines was only 12 percent. A disproportionate collapse of high voltage towers might have been due to under-designing for ice load. The highest number of collapsed structures belonged to distribution lines.

There are several factors leading to the vulnerability to ice storms of the energy sector infrastructure in Quebec including the spatial location of power lines; the overdependence on electricity as an energy source; the long distance lines that transmit energy; the design criteria of their transmission lines; the availability of climatological data; the reliance on single line transmission and; and the use of overhead transmission lines. Each factor will be addressed briefly.

In terms of the spatial location of power lines, historical losses from freezing rain and ice storm events across Canada and the United States of America occur in a band of territory that stretches from northern Texas, USA to Newfoundland, Canada. The Hydro-Québec transmission lines are a powerful high voltage network covering long distances, parts of which lie in these areas prone to heavy icing (Hydro-Québec, 1998a).

In terms of overdependence on electricity, the abundance of natural waterways and the pursuit of a 30-year-old policy of promoting electricity over other forms of energy have left Québec overly dependent on hydro-electric power (Environment Index, 2000). Québec is also close to being the most electricity-dependent jurisdiction in the world. Electricity provides over 40 percent of Québec's energy needs compared with 23 percent in other Canadian provinces. As many as 75 percent of the homes and more than 90 percent of newly built residence-depend on electric heat in Québec. Natural gas and oil, more widely used in other Canadian provinces, cannot compete against Hydro-Québec's subsidized rates.

In terms of long distance transmission lines, Hydro-Québec supplies power to Montreal, the most densely populated area in Québec, from generating stations in James Bay and Churchill Falls located as far away as 1,600 kilometers. This is not typical for North American urban centres which get most of their power from local generating facilities (Environment Index, 2000). In order to maintain required power efficiencies over such lengthy distances, Hydro-Québec operates its transmission lines at a high voltage of 735 kilo Volts. As a comparison other utilities such as Ontario Hydro operates at 500 kilo Volts, and both New England and New York operate at 345 kilo Volts. In fact, only 2 other utilities in all of the United States and Canada use the 735 kilo Volts lines and not nearly to the same extent as Hydro Québec (Environment Index, 2000). This requires heavier, more expensive cables, higher transmission towers and more space between transmission lines.

Hydro-Québec made a complete review of its design criteria for the entire province following the 1969 and 1973 major line failures caused by in-cloud icing on the Manic-Churchill lines. The ice carrying capacity of the lines was raised from 35 to 45 millimeters of radial ice (Canadian standard was 12 millimeters). In addition to radial ice, the process of transmission line failure is accelerated by high wind speeds. Design wind speed specifications for the Hydro-Québec are not known; however, Ontario Hydro uses 100 kilometers per hour for its main transmission lines (Street et al., 2002). The vast majority of energy transmission lines built in Quebec after 1976 include modified design features to help its carrying capacity. The 1998 ice storm raised several questions regarding climatalogical data such as the gathering of historical data on atmospheric icing, the reliability of the instruments used for measurement of ice accumulation, the models applied for transforming ice accumulation data into radial ice thickness, the method of producing iso-line contour maps, and the applicability of such data for line design (Hydro-Québec, 1998a). Data from Hydro-Québec and Environment Canada are of different types. Whereas Hydro Québec's ice measurements are converted into equivalent radial ice thickness, Environment Canada's measurements are expressed in equivalent liquid precipitation. While the information from both sources regarding location and geometry of the storm is consistent, these two sets of data are difficult to reconcile with respect to ice thickness.

Some regions of Québec, including urban areas, rely on a single transmission line for its electrical energy source. For example, the South Shore region along the St. Lawrence River in Quebec is served by a single line which, if put out of commission by natural processes or emergencies, will not be able to deliver electricity to these areas (*Kerry et al., 1999*). The South Shore area was severely affected when the single feeding line was lost during the 1998 ice storm.

Over 90 percent of Hydro-Québec's distribution system is not buried underground, but is overhead. This makes the power distribution system very vulnerable to natural disasters such as ice storms and tornadoes. The weight of ice accumulation on the cables could add 15 to 30 kilograms per meter to the wire.

2.2 Case Study: Low Lake Levels

The Great Lakes are the world's largest body of fresh water comprised of five lakes: Superior, Michigan, Huron, Erie, Ontario and their outlet rivers. Their water levels are of concern to hydropower, navigation, coastal landowners, and environmental interest groups. Over 820 billion kilowatt hours of hydropower are produced annually at the outlets of Lakes Superior, Erie and Ontario (Beranek, 2000). In 1964, water levels in the Great Lakes dropped to extremely low levels. This caused significant impacts on hydropower generation in Canada and the USA. In Canada, total generation in the Niagara Falls and St. Lawrence River dropped by 20 percent.

Periods of low or high water levels in the Great Lakes occur over several years (Brotton, 1995). However, strong evidence shows a yearly high-to-low cycle; and a second, larger cycle with deeper peaks and depths occurring roughly every thirty years. Low water levels were recorded in 1934, and 1964 but not 1994. A third theory is extremely deep low Great Lakes levels arriving every 150 years (MSU, 2002).

Annual or seasonal variations in water levels are based mainly on changes in precipitation, evaporation and runoff to the Great Lakes. Generally, the lowest levels occur in winter when much of the precipitation is locked up in ice and snow on land, and dry winter air masses pass over the lakes enhancing evaporation. Levels are highest in summer after the spring thaw when runoff increases. However, low precipitation in winter together with higher evaporation and temperatures can cause lower water levels, which occurred in 1964, 1997, 1998, 1999, 2000 and 2001 (GLERL, 2000). Wind and atmospheric pressure may also cause temporary changes in the surface levels of the Great Lakes (Koshida, 1989). An example of water levels at one of the Great Lakes - Lake Ontario - are presented in Figure 1 for the period 1900-2000.

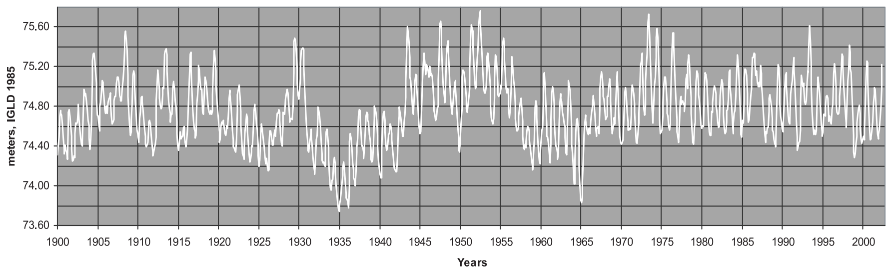

FIGURE 1

Lake Ontario water levels, 1900-2002. *Source: Environment Canada, 2003.*

Correlations of hydro-meteorological variables - runoff, overlake precipitation, evaporation, temperature, outflow and net basin supply - with lake levels have were conducted and are presented in Table 3. Runoff shows strong correlation with lake levels for Lake Huron and Lake St. Clair; while a low negative correlation is found for Lake Superior. Overlake precipitation is found to be important for Lake Ontario and Lake Superior with negative correlations for Lake Huron and Lake St. Clair. Temperature and outflow show positive correlation with water levels which needs further investigation. Net basin supply demonstrates the strongest correlation for Lake Superior and an almost similar level of correlation for Lake Ontario and Huron.

Table 3 Correlation between lake levels and various hydro-meteorological variables

HYDRO-METEOROLOGICAL VARIABLES	ERIE	HURON	ONTARIO	SUPERIOR	ST. CLAIR
Runoff	0.44	0.68	0.52	-0.25	0.98
Overlake Precipitation	0.36	-0.04	0.58	0.75	-0.15
Evaporation	0.15	0.06	0.24	-0.07	-0.18
Temperature	0.35	0.30	0.57	-0.23	0.56
Outflow	0.92	0.91	0.67	0.62	0.46
Net basin supply	0.39	0.55	0.59	0.8	0.44

In the 1960s Ontario Hydro had major power development capacities on the Great Lakes system at Niagara and on the St. Lawrence River. The installed capacity was of the magnitude of 3,000 Mega watts and the total investment was in the range of CAN$3-4 billion (in 1964 dollars). Driven by low water levels in the Great Lakes, power generation in 1964 was one of the worst years on record. The Hydro-Electric Power Commission of Ontario (1964) compared the power output of 1963 with that of the average of 100 years. Table 4 illustrates the effects of the low water event for power production.

Table 4 Power output at Niagara Falls and on the St. Lawrence River

ITEMS	AVERAGE 100 YEARS	1963	1964
Power output (million megawatt-hours)	19.64	16.16	15.24
Loss in output (million megawatt-hours)		3.48	4 .40
Equivalent volume of coal needed for replacement (million tonnes)		1.40	1.76
Value of replacement power (million dollars in 1994 prices)		55.80	82.50

Sources: Boyer, R.J. 1964. Hydro-Electric Power Commission of Ontario, 1964; Statistics Canada, 1995.

Hydropower generation is dependent on lake levels which is broadly dependent on the amount of precipitation that falls in a region. It is also sensitive to variations in temperature and wind. Ontario Hydro assumes that decreases in hydropower generation due to inadequate precipitation are not expected to occur more than 2% of the time (Lawford, 1977). The implication of such probability is that the generation station may be below capacity for six months every 25 years or for two years every century. While historical streamflow data are used in the design of each station, the length of record at many stations precludes a consideration of the effects of a five- to ten-year drought. A drought can also cause broader regional impacts; it can affect a number of hydraulic stations in a region simultaneously. Therefore, it becomes impossible for the regional generation stations to satisfy the demands without tapping alternative power sources or importation of electricity from elsewhere (Lawford, 1977). Both options lead to increases in the cost of electricity (Brotton, 1995).

Great Lakes' water is also used for cooling and steam condensing purposes; its temperature is increased a small amount as a result. Any interruption to the supply of this fresh water will result in the curtailment or interruption of delivery of power (McKeran, 1964). It is believed that certain severe wind conditions, coupled with existing low levels, could create conditions that would interrupt water supplies (McKeran, 1964).

2.3 Adaptation Measures and Policies

2.3.1 Case Study: The Ice Storm 1998

Southern Canada has a long history of ice storms and records are available from 1942. Economic damages due to ice storms since that time are significant. The storms also caused human sufferings in terms of power disruption, relocation, and physical and mental trauma. Records demonstrate that the pattern of historical damage is similar to the 1998 storm. However, the magnitude of the earlier ice storms were not as large.

Hydro-Québec's claims that its transmission system has been designed and developed over the years according to reliability criteria that generally exceed recognized standards in North America. Exceedences in standards were made because of the exceptional climatic conditions and great importance of electricity in Québec. However, a commission examining the 1998 ice storm in Quebec disagreed with this claim. Expert analysis by the Nicolet Commission (1999) has revealed that Hydro-Québec had designed, constructed, operated and maintained an unstable and unreliable system. The power grid might have saved money in construction and maintenance, but only at the cost of reliability when tested by conditions that could have been reasonably expected (Young, 1999). The Nicolet Commission reported that: "…transmission and subtransmission lines collapsed at vertical load levels that were below their theoretical design ice-load limit. In fact, since the winds at the time could be classified as no more than moderate, the commission's experts, in their evaluation, termed these raptures premature." (Nicolet, 1999).

Hydro-Québec did not introduce uniform design criteria for all transmission lines. For example, old steel tower lines built prior to 1974 were designed in accordance with the Canadian Standard Association criteria of their time. Variable performance was observed in the recently built transmission lines during the storm. These lines are supported on anti-cascading towers which limit the effect of a collapse in series to 10 towers at the most. During the storm, some new lines even seem to have performed better than expected (Hydro-Québec, 1998a). In terms of performance, wooden poles were the worst. However, wooden poles are chosen for transmission purposes due to economics (Hydro-Québec, 1998a).

The choice of a Gumbel distribution by Hydro-Québec for extreme value analysis of the climate data was criticised by the Nicolet Commission. The Commission was of the opinion that application of the Gumbel method may lead to an underestimation of the amount of freezing rain for long periods of return (Hydro-Québec, 1998b). However, Hydro-Québec disagreed with the Commission's view. Hydro-Québec explained that it used pooled data from stations to form a triad and doing so, the Gumbel distribution fit appeared to be very satisfactory with the adjustment of error by 10 to 15 percent (Hydro-Québec, 1998b). Reliability of the model used for converting ice data to radial values was also questioned after the 1998 ice storm. In addition to this, there is a procedural difference in terms of climatological data collection, transformation and interpretation between Hydro-Québec and Environment Canada (Hydro-Québec, 1998a).

De-icing of power transmission lines can save millions of dollars in repair costs and can reduce risk of collapse of the lines and resultant power outages (*McCurdy et al.,* 2001). Ice-melting is the process of placing a short circuit at one end of a sub-transmission line, essentially turning the line into a heating element which melts the ice. Generally, the temperature on the line is raised to just a few degrees above freezing. Hydro-Québec does not use the de-icing method at all. Exceedence of international standards for capacity, voltage level and design criteria prevented Hydro-Québec to apply the deicing technology.

Considering the magnitude of the damage caused by the 1998 ice storm to the power transmission and distribution systems in Québec, Ontario and the Maritimes, the concerned authorities and field workers worked day and night to restore power supply. However, the restoration process unveiled a number of problems faced especially by Hydro-Québec and Ontario Hydro in terms of human and material resources. Over 220 lineman arrived from British Columbia and Manitoba to help rebuild Québec's power grid (Lecomte et al., 1999). While this kind of cooperation is useful, it has risks too. If a storm would affect vulnerable provinces with the magnitude similar to Québec, this kind of manpower help may not be available.

Supply of hardware materials also experienced a shortfall. On January 27, 1998, Hydro-Québec announced that in just three weeks, it had exhausted its normal five-year supply of materials (Lacomte et al., 1999). In a normal month, as many as 150 truckloads of supplies arrive at Hydro-Québec's complex in Saint-Hyacinthe. During the ice storm and after, more than 2000 trucks carrying goods from all over North America to repair Hydro-Québec's downed power network had rolled into the complex's yard (North, 1998).

When the power system collapsed providing emergency power supplies to hospitals, water utilities and gas stations became a difficult problem to handle. Power supply authorities did not have enough high power generators. On January 9, 1998, power supply was cut to the water filtration plant of Montreal and the water supply was almost depleted. Hydro-Québec shifted power to the water supply system. This system had no back up generators (Environmental Index, 2000).

During the months of January, February, and March 1998, the Citizens Utility Company transported 64, 507 Mwh of Hydro-Québec power across its transmission system under its Open Access Transmission Tariff. These deliveries were made to alleviate transmission outages in the province of Québec resulting from the severe ice storm. No costs were reported with these ice storm deliveries since Hydro-Québec was both the supplier and recipient of this power (DOE, 2000). Hydro-Québec also imported some electricity from the Vermont Electric Transmission Company, Inc. Tripping of two 735 kV lines, which supply electricity to Des Cantons substation, caused a setback for Hydro-Québec in importing electricity from the USA during the ice storm.

Underground lines constitute only 10% of the distribution lines in Québec. Although the underground lines are considered to be safer and robust, they also pose a significant risk of failure too. After the 1998 ice storm, Hydro-Québec constituted a Task Force to look at the technical and economic aspects of underground cables (Hydro-Québec, 1998b). It also carried out an economic comparison of a German design and its own design. The German design was found to be half the cost of the Hydro-Québec underground design for that type of new installation. The principal reasons for such differences were attributed to: years of experience with undergrounding, network configurations, different voltages, direct-buried cables, standardization, quality control of equipment and installation, costs of cables and coordination of joint use of trenches (Hydro- Québec, 1998a).

2.3.2 ***Case Study: Low Lake Levels***

In the low lake levels on the Great Lakes in 1964, Ontario Hydro required 1.4 million tons of coal to compensate the lost output of electrical power due to low lake levels (Boyer, 1964). In another episode of low lake levels, Ontario Hydro was forced to use more expensive methods (e.g. fossil fuel) of generating electricity in many areas of north-western Ontario during the fall of 1976 and winter of 1976/1977. Flows over and above the normal regulated outflow were discharged in 1964 from Lake Superior to improve extremely low level situation downstream in Lakes Huron-Michigan. This additional inflow assisted in preventing a further decline in the level of these lakes and maintained the inflow into Lake Erie (Hydro-Electric Power Commission of Ontario, 1964).

Other measures that have been suggested but not applied to address low water levels on the Great lakes include cloud seeding to initiate rainfall on specific areas of deficient lakes (Hydro-Electric Power Commission of Ontario, 1964); diversion of additional water flow into the drainage basin but this is enormously expensive; and the construction of regulating structures at the outlets of Lake Huron and Lake Erie to permit all of the Great Lakes to be regulated. However, such a plan would be very complex as all interests are not compatible. For example, too great a compression of the storage range of the lakes for the benefit of riparian interests would reduce the great natural storage effect and would damage other interests such as power (Hydro-Electric Power Commission of Ontario, 1964).

2.4 Climate Change and Future Adaptation

In the past, the effects of climate variability varied from component to component of the energy sector. Responses resulted in the introduction of measures to reduce or eliminate the negative effects, usually in the context that the changes in climate and their effects were short term and both would in most of the cases return to "normal" following the perturbation. In the case of the projected changes in climate associated with an enhanced greenhouse effect, existing coping measures may not be effective and specific adaptation measures and policies will need to be designed, evaluated and implemented to reduce vulnerabilities of the energy sector.

The nature of future impacts is anticipated to be broadly similar to current conditions but the magnitude and frequency are likely to be greater than at present. It is difficult to predict the exact adaptation measures, which will need to be developed and incorporated in various components of the energy sector. Table 5 presents some adaptation measures for the Canadian energy industry. However, adaptation measures that should be implemented at various levels of the energy sector from generation to consumer. The measures have been classified according to the definition of Burton et al., 1993 (see Table 6). They would also vary from region to region depending on climate, socio-economic structure, resources, technology and policy formulation and implementation strengths.

Table 5 Major adaptation measures for the Canadian energy sector

MEASURE	IMPACT ADDRESSED	TYPE OF ADAPTATION	COMMENTS
I. Energy Generation/Supply Change in approach to water management vis-a-vis hydroelectric generation	Loss of hydroelectric generation capacity	Loss sharing/use change	Reductions in or changes in patterns of lake/river or stream flows may require changes in approach of water management
Increase energy production in the fossil fuel powered stations	Loss of hydroelectric generation capacity	Loss sharing/use change	This may increase in greenhouse gas emissions. Clean coal technology may be useful.
Operate hydro-plants at different locations	Decommissioning effects; temporary loss of power generation	Change location/Loss sharing	Construction of new plants may cause environmental effects and cost.
Invest in water storage	Potential for secured power supply	Prevent effects	Construction of new storage and creation of capacities in existing storage may cause environmental effects and cost.
Increase number of vessels to maintain level of coal supply for the fossil fuel powered generation units in Ontario	Reduction in power generation due to navigation problem in the Great Lakes caused by falling lake levels	Threat modification	Per unit cost of electricity generation may increase that will have to be shared by the consumers eventually
Buying energy from other sources	May reduce power shortage		Risks involved if the suppliers unable to secure the supply
II. Energy Transmission High-temperature super conducting material can be used to prevent power loss due to increases in temperature	Power loss in the transmission lines due to increase in temperature	Threat modification	Investment in power transmission will increase considerably
Strengthening of transmission structure of the long-distance power lines	Damage of transmission structures and lines during an extreme event (e.g., storms)	Threat modification	Investment in power transmission will increase significantly

Table 5 Major adaptation measures for the Canadian energy sector *...continued*

MEASURE	IMPACT ADDRESSED	TYPE OF ADAPTATION	COMMENTS
III. Energy Use Increase efficiency of air conditioning equipment	Increased cooling electricity cost	Threat modification	Increased air conditioning efficiency will reduce electricity expenditures, but will make initial costs higher. The measure will also reduce greenhouse gas emissions.
Thermal shell standards	Increased cooling costs	Threat modification	Increased insulation is often the most cost-effective measure.
Information Dissemination programmes	Increased space cooling costs	Threat modification	Energy sector agencies can provide information about energy efficiency measures that can save energy use and reduce energy costs.
Voluntary conservation programme	Energy saving possibility	Education/behaviour al change	Must be a part of the long-term planning process. Might take a long-time period to yield any result

Sources: Modified from Stern, 1998; Smit, 1993; and Scott and Gupta, 2001.

Table 6 Types of Adaptation

Burton et al. (1993) grouped adaptation types into the following eight categories.

(i) *Bear losses.* Bearing loss occurs when a sector or a person affected has no capacity to respond in any other ways or where the costs of adaptation measures are considered to be high in relation to the risk or the expected damage.

(ii) *Share losses.* This type of adaptation response involves sharing the losses among a wider community.

(iii) *Modify threats.* For some risks, it is possible to exercise a degree of control over the environmental threat itself.

(iv) *Prevent effects.* A frequently used set of adaptation measures involves steps to prevent the effects of climate variability and change.

(v) *Change use.* Where the threat of climate change makes the continuation of an economic activity impossible or extremely risky, consideration can be given to changing the use.

(vi) *Change location.* A more extreme response is to change the location of economic activities.

(vii) *Research.* The process of adaptation can also be advanced by research into new technologies and new methods of adaptation.

(viii) *Educate, inform, and encourage behavioural change.* Another type of adaptation is the dissemination of knowledge through education and public information campaigns, leading to behavioural change.

3. Concluding Remarks

Damage that occurred during the 1998 ice storm to electricity transmission and distribution systems in eastern Canada demonstrates the vulnerability of these systems to extreme weather events. Extensive damaged caused to Hydro-Québec was due mainly to the exceptional nature of the storm. In many areas the combination of ice loads and wind speeds exceeded the recommended design standards. Vulnerability also increased due to the presence of high voltage towers in a region susceptible to ice storms, long transmission lines, and the short length of climatic records.

Although Hydro-Québec worked very hard mobilizing all of its resources, in many cases, the adaptation measures in place were found to be inadequate. As a result, the Nicolet Commission recommended reinforcement of the power network, improvement of network structural features and adapting the energy policy and securing electricity supplies. The commission also recommended an improved emergency preparedness program and that the government considers public control over good design practices. Initiatives have been taken by Hydro-Québec to strengthen their network structural system.

Hydropower generation is also vulnerable to low lakes levels in the Great Lakes. This may result in a drop in hydropower generation in the Niagara Falls and St. Lawrence River by as much as 20%. Low precipitation, high evaporation and high temperatures cause lower water levels. But, their correlation with water levels is not well studied. This is important for avoiding any setback in hydropower generation that is dependent on the Great Lakes water levels. During the 1964 extreme low lake levels a number of adaptation measures were suggested, but none of them were found to be economically viable, especially regulation of the Great Lakes water levels.

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18 paper

ENERGY EFFICIENCY AND ENERGY FROM RENEWABLES:
BRINGING MITIGATION AND ADAPTATION TOGETHER

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ABSTRACT: The production and consumption of energy, particularly fossil fuels, is the root cause of humankind's most significant environmental challenge, global climate change. By definition, how society changes its use of energy applies both to mitigation and adaptation strategies. It is unique in this sense, since many actions that address climate change are categorized as either mitigation or adaptation, and rarely as an integrated response. This paper explores the important role that producing and using energy in a more sustainable manner can act as an effective integrated response to climate change, specifically the role of energy efficiency and energy from renewables. It draws upon secondary and primary research and highlights similarities and differences in Canada and China.

Keywords: adaptation, energy efficiency, integrated response, mitigation, renewable energy

1. Introduction

The production and consumption of energy, particularly fossil fuels, is the root cause of humankind's most significant environmental challenge, global climate change. By definition, how society modifies its use of energy can apply to both mitigation and adaptation strategies. It is unique in this sense, since many actions that address climate change are typically categorized in the climate change impacts literature, in policy development, and even in the practice of stakeholder engagement, as either mitigation or adaptation, and rarely considered as an integrated or dual function response. While there are undoubtedly valid reasons for this separation, the establishment of "stovepipes" or "silos" around these actions may actually inhibit the development and implementation of a more integrated and effective response to climate change, particularly at the community or local level.

Generally, adaptation has taken a back seat to mitigation in the policy discourse on climate change, despite the fact that the former is also cited in the United Nations Framework Convention on Climate Change (Article 4.1) and the Kyoto Protocol (Article 10). Arguably, the climate change impacts literature has adopted a somewhat defensive tone, treating adaptation in isolation of mitigation, or at best presenting it as a necessary addition to measures to reduce emissions of greenhouse gases (e.g. Maxwell et al., 1997; Smith et al., 2001). Efforts to broaden the treatment of climate change adaptation have also ventured into the field of sustainable development (e.g. Cohen et al, 1998; Venema and Cisse, 2004), but its overlap and integration with mitigation measures remains the exception rather than the norm. Energy production and use is a good illustration of this dichotomy which needs to be redressed because a better integration of mitigation and adaptation measures could lead to a more effective and sustainable use of scarce resources. Renewable energy, for example, is more likely to be considered as a mitigation response to climate change and yet a combination of renewable sources may be more resilient than conventional large-scale centralized systems, especially to extreme weather events. However, this separation and lack of understanding regarding the dual benefits of some climate change measures is not restricted to energy. Indeed, a thorough inventory and assessment of measures that address both mitigation and adaptation has yet to be published, whether on a sectoral, regional or country basis.

This paper outlines how the more effective production and use of energy can play an important role as a sustainable and integrated response to climate change. At best, this paper is exploratory in nature, focusing on the role of energy efficiency and energy from renewables. It draws upon secondary and primary research and highlights similarities and differences in China and Canada, and in the latter case with special reference to the province of Ontario. The discussion begins by briefly outlining how mitigation and adaptation can and should be brought together through the example of energy. Issues such as greater energy security, reduced vulnerability of the electricity generation and distribution system, improved air quality and health, and an increase in rural employment, among others, are examined vis-à-vis energy efficiency and renewable energy. The next section describes the energy situation (especially electricity) in each country, in terms of its temporal and spatial dynamics, as well as the economic and political forces influencing supply and demand for current conditions and future scenarios. The environmental and health consequences associated with conventional energy sources and business-as-usual practices are then highlighted for both Canada and China. It also examines the economic, social and environmental co-benefits that could be achieved by adopting an alternative pathway of energy efficiency and low impact renewables. The discussion concludes by proposing a blueprint for energy efficiency and renewable energy in Canada, and discusses its applicability to the situation in China.

2. Mitigation and Adaptation

While the Kyoto Protocol is an important first step in reducing GHG emissions, the meeting of these targets by all signatories to the agreement will only slow down a doubling of carbon dioxide (CO_2) in the atmosphere by approximately 6 years. It is almost certain that some degree of climate change is inevitable, unless more significant emissions reductions occur. According to the IPCC Third Assessment Report, the stabilization of atmospheric CO_2 at concentrations around 500 ppmv, below what is considered currently to cause dangerous interference with human and natural systems, requires global anthropogenic emissions of GHG to be reduced by about 50 percent relative to current levels (Houghton et al, 2001). From a policy perspective this leads to two clear conclusions: 1. adaptation to climate change will be necessary; and 2. further reductions in GHG emissions beyond the Kyoto targets are needed.

Despite the fact that both mitigation and adaptation are required to deal effectively with climate change, each type of response tends to be treated separately at the national, regional and local level. Exceptions for an integrated approach include the broadening of mitigation actions to consider the co-benefits from improved air quality for environment and health, and the incorporation of adaptation measures into principles of sustainable development. The former is based on the fact that fossil fuel combustion generates emissions of air pollutants that cause a suite of atmospheric concerns, including climate change, acid deposition, hazardous airborne pollutants, and smog. Not surprisingly the co-benefits for environment and health from taking actions to reduce emissions of greenhouse gases plus other pollutants is a prominent feature in the climate change policy discourse, especially in areas where coal-fired plants are a significant contributor to regional air pollution and pose a serious health problem. The health benefits from improved air quality alone arising from GHG emission reductions of 10 and 15 percent below 1990 levels for developing and developed countries respectively could reach over 700,000 avoided premature deaths annually on a global basis (Lee Davis et al, 1997).

The integration of mitigation and adaptation measures however is less prevalent in the literature, especially in climate change impact assessments. In some cases the issues are presented jointly, but even then climate change science and the need for mitigation actions serve more as the context to address adaptation rather than presented as part of an integrated response (e.g. Smith et al, 2001; Standing Senate Committee on Agriculture and Forestry, 2003). Even the three IPCC Assessments have generally presented climate change in this manner (e.g. Smit and Pilifosova, 2001; Toth and Mwandosya, 2001). As a result, decision-makers are frequently left with little guidance in terms of developing an integrated response to climate change or evaluating mitigation measures vis-à-vis their contribution as an adaptation response and vice versa. The need for an integrated response may be most acute at the local level, where, in Canada for example, municipalities are directly and indirectly responsible for fifty percent of greenhouse gas emissions, and where there is limited knowledge about impacts and adaptive capacity. There is evidence, however, to suggest that tentative steps forward are beginning to be taken to address the integration gap. Just recently an integrated, collaborative approach to climate change adaptation has been initiated in the Regional Municipality of Halifax, with the intent of helping municipalities develop management and planning tools to adapt to climate change and reduce greenhouse gas emissions (Government of Canada, 2004).

In terms of the energy sector, the preponderance of research and policy initiatives has been directed at mitigation, with much less attention on impacts and adaptive capacity. This disproportionate attention towards preventing climate change from occurring may have been necessary to gain global commitment for mitigation targets, but now that the Kyoto Protocol is ready to be activated, the consequences of ignoring the vulnerability of the energy sector to climate change impacts needs to be assessed carefully. Such an imbalance is ill advised for energy planners and decision-makers, since there is growing evidence that the impacts of climate change on the energy sector can be significant, not only for exploration and resource extraction, but also for electricity generation, transmission/distribution, and demand (Street et al, 2002; Mirza, 2004). Furthermore, the focus on one type of response overlooks the potential for identifying and implementing actions that address both mitigation and adaptation needs. This could lead to the inefficient use of scarce resources, and missed opportunities to capture a wide range of co-benefits.

The linkage of adaptation to mitigation issues has been addressed in some cases, specifically in the context of how various emission reduction policies (to both climate change and air quality) and population/economic growth scenarios may affect the future energy mix, which in turn could be impacted by climate change (Lin et al, 2004). The latter research effort, which has focused on energy supply, generation, transmission and use at the regional scale, has engaged stakeholders through surveys, interviews and numerous workshops. It has advanced an integrated approach recognizing that the future energy mix will be determined more by emission reduction policy considerations rather than by climate change impacts. However, it still falls short of providing a comprehensive assessment of conventional (nuclear, fossil fuel, and large-scale hydro) and low-impact renewable energy options vis-à-vis their dual mitigation and adaptation functions.

3. Energy Systems and Challenges – China and Canada

China and Canada have significant differences in population size, economic output and energy resource distribution; however, both face substantial challenges for energy production and use. Most of these challenges, whether shaped by geography, economic, political, social and environmental factors, are unique to China and Canada, but many are also common to both countries. Both China and Canada, in the latter context especially the province of Ontario, are facing energy and electricity shortages, requiring greater consideration of energy efficiency measures and the expansion of renewable energy.

3.1 China

Energy plays a crucial role in any economy, and is key to China's continuing rapid economic growth and efforts to alleviate poverty. Although blessed with a wealth of natural resources, China is typically considered to be "energy poor", given its expanding economy, population size, and low per capita energy consumption. In recent years the Chinese economy has been growing by approximately 9 percent annually, while its population is reaching 1.3 billion and is increasing at about 10 million each year. Although per capita energy consumption is about one-sixth that of OECD countries, China ranks as the second largest energy consumer and producer in the world, behind only the United States.

From 1980 to 1996 the centrepiece of each of China's 5-year economic plan has been the expansion of energy production, in part responding to more than a doubling in primary energy use over this period. While energy use declined slightly from 1996 – 2000 during the Asian economic recession, since 2000, energy use has increased again and is expected to grow by over 3 percent annually between 2005 to 2015 (Asia Research Centre, 2001). Increases in the standard of living, rising incomes and the continued exodus of rural-to-urban migration are expected to drive much of the demand for electricity. In 1990, net electricity consumption in China was 551 Terra Watt-hours (TWh), rising to 1,312 Terra Watt-hours by 2001 (EIA, 2003). Given the complex dimensions of the factors determining energy supply and demand, it is difficult to forecast future scenarios accurately, especially for a rapidly emerging economic giant such as China. There is little dispute, however, regarding the overall direction and general magnitude of future conditions. Assuming an average annual percent change of 4.3, for example, net electricity consumption is projected to reach almost 3,600 Terra Watt-hours by 2025, representing more than a 6-fold increase from 1990.

China relies heavily upon conventional sources of power for its energy and electricity needs. More than 60 percent of China's primary energy consumption is derived from coal, and the country has sufficient reserves to meet demand at current levels past 2100. Domestic oil reserves have been declining since the mid-1990's, resulting in an increase in imports and some substitution with natural gas. In the latter case, residential use has been increasing steadily, especially in large urban centres, in an effort to reduce harmful emissions causing air pollution. While electricity use has been increasing substantially, approximately two-thirds is generated by coal-fired power stations, with hydropower generating about one-quarter and the rest from oil and nuclear. At best, China's economy can be described as a highly inefficient user of energy, especially in the heavy industry sector. In the late 1970s, specific economic and conservation policies were introduced to improve energy efficiency, which led to significant energy savings. By 2000, China had reduced its energy use per unit of GDP to half of what it consumed in 1980; however, the room for improvement continues to be large. In order for its industrial sectors to meet international energy efficiency standards, China needs to further reduce energy use by 30 to 50 percent (IEA, 2000). Although energy efficiency can go a long way towards reducing GHG emissions, with economic development expected to continue at a fast pace, efficiency measures alone will be insufficient to control GHG emissions from the energy sector (Metz et al, 2001).

With the world's fourth largest land mass of 9,596,960 square kilometers, geography plays a significant role in China's energy production and use, particularly in terms of resource distribution and distance to markets (McCreary et al., 1996). A majority of fossil fuels are found in northern areas, yet much of China's rapid economic growth has occurred in the south and along its eastern coastal regions. Significant energy transportation problems exist in terms of inadequate support infrastructure and limited rail freight capacity. The latter has been especially problematic for coal, resulting in the higher production and use of more accessible but extremely low-grade deposits in the south, compared to the less accessible but higher-grade deposits in the north. China has the world's largest hydropower generating potential in the world, estimated at 379 Gigawatts (GW); however, much of this potential is at sites located within the Himalayan mountain ranges in the southwest, which are also far from major centres of population and economic activity. Even if all exploitable hydropower resources were developed, while more than 1,900 Terra Watt-hours could be generated, an amount three times the electricity China produced in 1990, this amount would still represent only about one third of projected capacity for the year 2015. Nuclear power capacity is about 2 Gigawatts, which amounts to only 1 percent of China's current total electricity use. New plants under construction could quadruple nuclear output by 2010, but this will still likely only contribute a small fraction of total electrical generating capacity. In 2001, renewable energy (geothermal, solar, wind, and wood and waste) generated 1.9 Terra Watt-hours, a negligible amount of China's net electricity generation (EIA, 2002). Generation capacity from windfarms was less than 400 Megawatts (MW).

Due to its relative abundance, coal is expected to feed the growth of electricity generating capacity for many years. This dependency on coal, however, has come at a significant environmental and social cost. China is the world's largest producer of sulphur dioxide emissions, and the second largest emitter of carbon dioxide. A report released in 1998 by the World Health Organization noted that seven of the ten most polluted cities in the world are in China, due largely to emissions of sulphur dioxide and particulate matter from coal combustion (WHO, 1998). The report also estimated that acid deposition falls on 30 percent of China's total land area. Further, the impacts of air pollution on agricultural production and human health may be so severe that up to 10 percent of China's gross domestic product may be lost each year (Johnson et al, 1997).

Despite the challenge of providing energy for a growing economy and the associated costs of burning coal, there are positive signals that the Chinese government is prepared to take action towards cleaning up the environment. In their tenth five year plan (2001-2005), for example, the Government of China emphasized clean energy, technological upgrading of the energy industries, and energy efficiency over the more traditional structural adjustment of expanding energy production. China's energy priorities seem to be moving towards clean coal, natural gas, nuclear and to a lesser extent renewables. Furthermore, in July 2004, the Chinese State Council (akin to cabinet) approved a draft of China's Energy Development program for 2004-2020, with energy conservation and efficiency as its top priority. Continued rapid economic growth and one of the most serious periods of energy shortages since the 1980s is placing an urgent emphasis on the potential for energy efficient measures.

In recent years the electricity sector has also undergone considerable reform, moving from a state-owned centrally controlled system to a more deregulated, decentralized and market oriented system. Under the previous system, the coal industry enjoyed a history of being heavily subsidized, and energy reforms are considered a necessity to create a market in which renewable energy can become more competitive. However, the wind power and renewables industry tends to be much more controlled by government than other sectors of the economy. The potential of renewable energy resources for electricity is substantial in China, with wind power, for example, capable of achieving 250 Gigawatts of installed generation capacity (Brown, 2002).

3.2 Canada

In Canada, energy also plays a key role in the national economy, and contributed to over 6 percent of GDP in 2002. Despite having a comparatively small population of just less than 32 million in 2001, Canada is an energy intensive country, with one of the highest per capita consumption rates in the world (National Energy Board, 2003). Canada has abundant energy supplies, including the oil sands. Approximately 50 percent of the natural gas produced in Canada is exported to the United States. On a national basis, electricity generation is dominated by hydro. With an installed capacity of 67,000 Megawatts, Canada is a world leader in its use. Approximately 60 percent of Canada's electricity is generated by large-scale hydro, with coal, nuclear, natural gas and oil contributing 18, 13, 4 and 3 percent respectively.

Small-scale hydro and other renewables contributes less than 3 percent. Barely 440 Megawatts is currently generated by wind power in Canada.

Net electricity consumption was 435 Terra Watt-hours in 1990, reaching 504 Terra Watt-hours by 2001 (EIA, 2003). Assuming a business-as-usual average annual change of 1.9 percent, electricity consumption is expected to rise to almost 800 Terra Watt-hours by 2025, reaching a level just below double from 1990. Electricity production and use varies considerably across Canada, as both resources and technologies are unevenly distributed. Some provinces, such as Quebec and Manitoba, rely principally upon hydro, while others such as Nova Scotia, Saskatchewan and Alberta rely primarily upon coal. Ontario is perhaps unique in this regard since electricity generation is distributed across nuclear (36 percent), hydro (25 percent), coal (25 percent), and oil and gas (14 percent). Renewable energy (wind power) contributes only 0.2 percent of the provincial electricity capacity.

Ontario presents a significant energy and electricity challenge for many reasons. The province is one of two (the other is Alberta) in Canada that has recently introduced reforms in the electricity sector, moving away from a monopoly run system towards an open market. Price volatility is now the norm, for both electricity and natural gas, which is raising some concerns regarding economic competitiveness and affordability. Ontario has the largest population in the country, and contains Canada's industrial heartland. Although the provincial electricity system has its roots in hydropower, since the early 1970s it has become increasingly dominated by a pro-nuclear and pro-coal culture. There is growing concern about costly price overruns on refurbishing ageing nuclear facilities, and increasing environmental and health concerns around coal-fired power plants. In the latter context, electricity generation from coal is a major source of sulphur dioxide, nitrogen oxides, and other air toxics such as mercury, contributing to acid deposition, smog and emissions of hazardous air pollutants. Their contribution to local air pollution has attracted considerable attention from environmental groups and the public health community, which have been campaigning vigorously to have them phased out. A recent report has estimated that air pollution from all sources is responsible for 1,700 premature deaths and 6,000 hospital admissions annually just in the City of Toronto (Campbell et al, 2004). Another study has estimated the economic and social costs for Ontario to be about $1 billion per year (Ontario Medical Association, 2000). Coal-fired plants are also a major source of GHG emissions, and their phase out would make a substantial contribution to Canada's Kyoto target of 6 percent below 1990 levels by 2010. The current government has promised to phase out coal generation by 2007.

Existing installed generation in Ontario is about 30,500 Megawatts, although in practice normal weather peak demands rarely exceeds 24,000 Megawatts. Even at this amount, however, there is limited excess capacity and the Independent Marketing Organization often has to import power from other provinces and the U.S. during periods of peak demand. Without significant conservation efforts, energy consumption is forecast to grow from about 156 Terra Watt-hours in 2005 to about 169 Terra Watt-hours in 2014, based on an average annual growth rate of 0.9 percent (IMO, 2004). Summer peak demands are projected to exceed 26,600 Megawatts by 2014. If coal is phased out by 2007 and nuclear facilities are retired by the end of the next decade, Ontario could be facing a significant shortfall between electricity supply and demand. Even if proposed generation projects are completed in a timely manner, which would add about 6,000 Megawatts of new supply mostly from natural gas, aggressive conservation measures will be required, as well as additional generation capacity from new supply or refurbished generation. While electricity could be imported from hydro sources in Quebec and Manitoba, this would require substantial investments to expand the transmission infrastructure. For long-term reliability, planning would have to include higher construction standards to minimize projected climate change impacts on the grid (Mirza, 2004).

An opportunity therefore exists for considerable expansion of renewable energy and energy efficiency measures. The provincial government has recently announced renewable targets of about 1,350 Megawatts by 2007 and 2,700 Megawatts by 2010. A recent RFP (request for proposals) issued by the provincial government for 300 Megawatts from renewables attracted forty final proposals that would, if constructed, collectively add more than 1,100 Megawatts of electricity capacity by 2010. But there is the potential for much more in the future. The theoretical potential for Canada's green power resources is at least 340 Terra Watt-hours, or more than half of the current annual electricity generated in Canada (Pollution Probe and Summerhill Group, 2004). In terms of energy efficiency measures, Winfield et al (2004) have estimated that the adoption of best practices throughout the economy could result in electricity use dropping by 40 percent below business-as-usual forecast for 2020. Such a target may be achievable given Canada's historical performance. Energy productivity gains in Canada from 1970 – 1998 were greater than increases in primary energy use in all sectors (Torrie et al, 2002). Between 1990 – 2002 alone, improvements in energy efficiency saved 880.7 Petajoules of energy and 49.9 Mt of GHG emissions (Office of Energy Efficiency, 2004).

4. Potential and Benefits of Energy Efficiency and Energy from Renewables

While adopting energy efficiency measures and increasing the amount of energy and electricity from renewable power have obvious mitigation implications, their adoption also has considerable co-benefit potential for environment and human health. The analysis of co-benefits has received considerable attention in the climate change literature, and while most studies are not intended to defend or justify GHG mitigation actions on this basis, they do illustrate the additional benefits that could be realized if appropriate actions are taken. Among the various mitigation options, electricity generation and energy efficiency in residential and commercial buildings have been identified as two key areas where considerable co-benefits could be realized (Chiotti and Urquizo, 1999). A preliminary assessment of air quality co-benefits from climate change mitigation actions conservatively estimated for Eastern Canada that a suite of measures, including reductions from coal-fired power plants, would lead to 92-150 avoided annual mortality by 2010, and reduced health care costs of $300 - $500 million (EHI, 2000).

Studies on the co-benefits from energy efficiency are less common. While such measures would also help reduce emissions of greenhouse gases and other air toxics, there is also the potential for more localized benefits to be realized, including strengthening adaptive capacity. For example, some cities are promoting the use of green roofs, in which gardens are installed on building rooftops as an integral part of the roofing system. The green roofs can help reduce the urban heat island effect, which can result in illness and even deaths, thereby contributing to the process of adapting to warmer summers. At the same time, green roofs can help reduce air conditioning use that results in a reduction in emissions of GHG's and other air pollutants from coal-fired power plants. Further, green roofs can help filter out air pollutants, act as a buffer in storm water management and offer other benefits such as providing wildlife habitat, offering new economic opportunities, and increasing property values (Bass and Baskaran, 2003). Other energy efficiency measures could also perform both a mitigation and adaptation function, while improving indoor air quality and human health. New homes modeled on R-2000 standards, for example, have been found to achieve significant energy savings (from 35 to 49 percent reductions in electricity, natural gas and oil consumption), while reducing GHG emissions associated with fuel consumption by an average of 39 percent (Lio and Associates, 2003). To address the need for ventilation in R2000 homes, due to the more air-tight construction used for greater energy efficiency, the homes use heat recovery ventilators that not only reduce the condensation associated with air-tight homes, but offer cleaner indoor air for a healthier environment. A recent study by Leetch et al. (2004) found that the occupants of new energy efficient homes (which met R-2000 standards) experienced lower incidence of throat irritation, coughing, fatigue and irritability.

While renewable energy is more likely to be considered as a mitigation response to climate change, it can also perform an adaptation function. A combination of renewable sources can often be more reliable and resilient than conventional large-scale centralized systems, and in the case of climate change a diversified system could be more adaptable to extreme weather conditions. The 1998 ice storm and the August 2003 blackout, for example, clearly demonstrated both the vulnerability and limited adaptive capacity of conventional generation and the transmission grid in North America. In the case of China, an added consideration may be the impact of renewable energy expansion on employment and rural development. An established wind turbine manufacturing industry, for example, creates about 40 percent more employment compared to coal per dollar of investment. In the U.S., a recent study has estimated that strategic investments in clean energy and efficiency would create 3.3 million new, high-wage jobs (Institute for America's Future and The Center on Wisconsin Strategy, 2004). The expansion of renewables into rural China, such as household biogas digesters, could also help replace the use of traditionally burned coal in unvented firepits, which is known to increase the risk of lung cancer (Lan et al, 2002), and has other hygiene and agricultural productivity benefits. The most significant co-benefits, however, could be realized in polluted urban centres. In Shanghai, for example, a combination of improved energy efficiency and the introduction of natural gas could lead to 647 – 5,472 PM_{10} related avoided deaths by 2010, and 1,265 – 11,130 by 2020 (Gielen and Changhong, 2001; Changhong et al, 2001).

The broader implications of shifting energy supply from conventional sources to less polluting alternatives are perhaps best defined in the context of developing countries and decentralized renewable energy. Venema and Cisse (2004) propose that decentralized renewable energy projects should be a fundamental priority of sustainable development and also represent an example of an integrated mitigative and adaptive response to climate change. The link to adaptation extends well beyond the energy sector, suggesting that more equitable access to energy supplies will help stabilize the social and ecological determinants of climate change vulnerability. This implies that some energy measures may not in themselves be considered as a direct climate change adaptation strategy, but can nonetheless indirectly function as an essential prerequisite for building adaptive capacity. In the case of decentralized renewable energy, while their adoption may serve a mitigation function, they will also contribute to a number of positive sustainable development outcomes, such as:

- assisting the sound and equitable management of biodiversity and ecosystems;
- improving access to safe water and sanitation services;
- improving air quality and limiting exposure to toxic chemicals; and
- reducing and mitigating natural disasters and resource-based conflict.

Adopting environmentally sound energy systems can also help alleviate poverty, reduce child mortality and promote gender equity (Reddy et al, 1997). Improved access to energy services, especially high quality fuels and cooking technology, has a direct impact on the health of children. For example, in many rural communities chronic exposure to harmful airborne pollutants often occurs at the household level among women and children, due to biomass combustion using primitive, inefficient stoves indoors (Smith, 1993). Energy efficiency measures can be described in a similar manner, enabling society to live better, pollute less and deplete fewer resources, create income and jobs, multiply the use of scarce capital, and increase security (Van Weizsacer et al, 1997). When done properly, energy efficiency measures applied in residential and commercial buildings can also help improve indoor air quality, and subsequently lead to improved human health and well being.

5. Towards a More Sustainable Energy Future

This paper has attempted to demonstrate how the more effective and environmentally sensitive production and use of energy, specifically renewable power and energy efficiency, can play an important role as a sustainable and integrated response to climate change. Renewable power in both countries are not merely a niche market, and combined with energy efficiency can help address regional and global environmental challenges, while still meeting domestic economic needs. In the absence of a fully developed and comprehensive integrated energy strategy in the climate change literature, however, it may be prudent to look elsewhere for direction and guidance in terms of moving forward towards a more sustainable energy future. In this case *A Green Power Vision and Strategy for Canada* may be a good place to start (Pollution Probe and Summerhill Group, 2004). A thorough assessment of renewable energy options and energy efficiency measures in terms of their applicability as mitigation and/or adaptation actions is needed. This would require consideration of a broader range of benefits that have been identified for green power (see Figure 1). Enhanced adaptive capacity would likely contribute to energy security, electric power grid stability, rural development, and job creation, among others. Energy efficiency would also contribute to most of these categories.

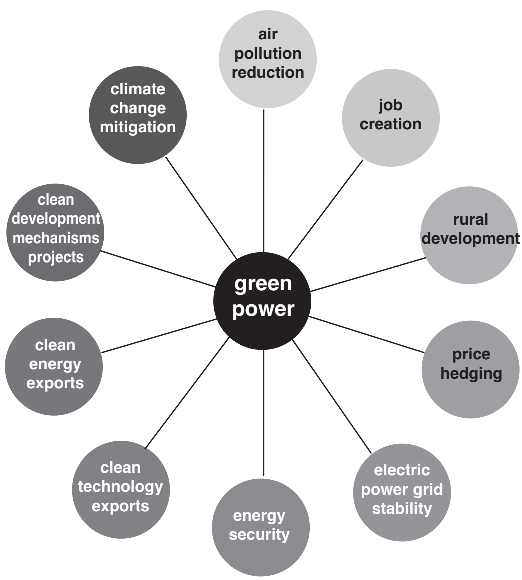

FIGURE 1

Green Power Benefits

From a policy perspective, it will be important to focus on three priority areas if progress is to be made on guiding and accelerating the development of renewable energy and energy efficiency. First, it will be necessary to level the playing field, which currently favours the conventional centralized energy systems for electricity generation. Historically, billions of dollars have been invested to develop oil, gas and nuclear power to ensure reliable and low-cost supplies of electricity – it is time to invest in renewable energy sources in the same way. It will be necessary to invest in innovative technologies for renewable energy and energy efficiency to ensure future market readiness for emerging technologies. Support for such innovative technologies could also enhance each country's potential to develop expertise in these areas and market the knowledge and technologies worldwide. Long-term opportunities for renewable energy both domestically and abroad look promising as the capital stock of the global energy system is expected to turn over at least twice by 2100 (Painuly, 2001). Whereas Canada is facing the need to replace aging conventional generating stations, China's rapid economic growth presents them with the opportunity to adopt cleaner green technologies from the outset. Lastly, it will be necessary to engage a wide range of decision-makers and the public in achieving this vision, particularly at the community level. While community engagement is considered an essential piece of the Canadian strategy, its application to China may be more problematic. As Brown (2002) notes, how quickly energy from renewables penetrate energy markets in China will depend in part on consumer pressure but more so on government policy and regulatory support, which depends on broader energy, industrial and environmental objectives.

In the case of China, the solution may be to build on the trend of decoupling economic growth from energy consumption and adopt a normative approach to energy production and use, that accepts economic growth as a necessary but not a sufficient condition. As Goldemberg et al. (1988) suggest, the fundamental goals of society should be equity, economic efficiency, environmental harmony, long-term viability, self-reliance, and peace. Energy production and use should be compatible with these societal goals, which applies to both developing and industrialized countries, as well as having implications for the relationship between them and within the global community. China's efforts and success to reduce energy use and emissions of air pollutants is not only a domestic concern, but also a key factor in international environmental relations. With continued economic growth and the world's largest population, China will soon surpass the United States as the world's largest emitter of CO_2 emissions. It is therefore in Canada's interest not only to support China's efforts to develop a more sustainable energy system, but also to lead by example by taking action on a vision and strategy that promises a more sustainable domestic electricity future through energy efficiency and energy from renewables. By doing so, both countries will not only help reduce harmful emissions of GHG's and other pollutants, but also strengthen their adaptive capacity to climate change impacts.

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19 paper

CITIES AND COMMUNITIES:
THE CHANGING CLIMATE AND INCREASING VULNERABILITY OF INFRASTRUCTURE

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ABSTRACT: Climate change will impact infrastructure through gradual changes in weather patterns and through increasing variability and potential increases in extremes. Climate change will affect the safety of existing structures, potential for weather disasters, design criteria and engineering of future structures and potential for premature weathering of all structures. Because infrastructure built in current times is intended to survive for decades to come, it is critically important that adaptation options to climate change be developed today and implemented as soon as possible.The climate change adaptation actions that will likely be required in future will be significant and numerous, ranging from updated or increased climatic design values, improved building codes and infrastructure standards, better disaster management planning as a result of changed risks, enhanced climate monitoring and weather warning programs, more rigorous land use planning, structural maintenance standards, new structural materials, changed insurance and financial risk management through to relocation of structures and replacement of unreliable or unsafe structures. At the same time, infrastructure will also be required to contribute to climate change mitigation actions. The first step will be to identify gaps in current capacity for addressing climate variability and extremes. Such "no regrets" adaptation actions are available today and include measures such as enforcement of engineering codes and standards, efforts to reduce uncertainties in climatic design values and to update calculations, maintenance of the quality and length of climate data records and networks, consistent forensic analyses of infrastructure failures, regular maintenance of existing infrastructure and community disaster management planning. Where updated information is not available, the implementation of a Climate Adaptation Factor may provide an option to address deficiencies in existing design criteria conditions and to allow for projected trends in future climate conditions. Where the impacts of the future climate lie outside of existing experience and the coping ranges of infrastructure, adaptation options will need to be developed over time through "adaptation learning", along with better pre-disaster planning. Climate change adaptation will require that planners, their agencies, the engineering community and community decision-makers consider timeframes beyond statutory requirements and even beyond the lifetime of most individuals. Improved understanding of climate change impacts and the need for adaptation must be combined with "tough" actions that include better risk assessment of community climate change impacts and vulnerability, the identification and avoidance of development in vulnerable areas and ongoing incorporation of adaptation strategies into land use planning and community disaster management planning. Such actions will entail significant costs, disruptions to communities and require political commitment and cooperation between all levels of government.

Keywords: infrastructure, climate change, built environment, disaster, hazard, vulnerability, adaptation, codes, standards, extreme weather, climatic design values, risk.

1. Introduction

Infrastructure is critically important to individuals and to communities. The purpose of infrastructure is to protect the life, health, psychological and social welfare of all of its inhabitants from the weather elements, to host economic activities and to sustain aesthetic and cultural values. Infrastructure—including houses, hospitals, schools, factories, roads, bridges, communications structures, power distribution networks, water structures—supports communities and economic activities, provides important life services for individuals and families, and protects society's cultural heritage. When infrastructure fails under extreme weather conditions and can no longer provide services to communities, the result is often a natural disaster (Freeman and Warner, 2001). As the climate changes, it is likely that risks for infrastructure failure will increase worldwide as weather patterns shift and extreme weather conditions become more variable and regionally more intense. Because infrastructure underpins so many of the economic activities of societies, these impacts will be significant and will require a variety of adaptation actions (Dalgliesh, 1998; Holm, 2003; Lowe, 2003).

Compared to the decade of the 1950s, the annual direct losses from large or globally significant natural catastrophes in the 1990s increased over 10 times1, rising from US$3.9 billion to US$40 billion a year in 1999 dollars (Munich Re, 2000; IPCC, 2001a), while population grew only by 2.4-fold. Most of the increases in losses were the result of weather-related high impact events. Of total losses averaging $40 billion a year, approximately $9.6 billion of direct damage occurred as a result of infrastructure losses (Freeman and Warner, 2001). In the case of flood losses, some estimates indicate that infrastructure failure and loss accounted for 65% of all flood losses (Swiss Re, 1997a). While total disaster losses can vary considerably from year-to-year, notable losses were reported in 1995 when, based on historical data, infrastructure losses alone totalled some $33 billion (Munich Re 1999). For example, studies undertaken by the Norwegian Building Research Institute (Ingvaldsen, 1994; Liso et al, 2003) indicate that the cost of repairing damages to structures in Norway from storm events is estimated at about 5% of the annual investment costs for new construction, amounting to NOK $4 billion

1These costs are larger by a factor of two when losses from relatively ordinary weather-related events are included.

annually in Norway alone. Although an increase in the number and intensity of storms regionally may play a role in these disasters, there is no question that a significant portion of the increasing costs are also the result of increased vulnerability (Pielke and Downton, 2000; Auld and MacIver, 2004).

One of the most threatening aspects of global climate change is the likelihood that extreme weather events will become more variable, more intense or more frequent, leading to catastrophic losses. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001a) states that:

> "The key features of climate change for vulnerability and adaptability are those related to variability and extremes, not simply changed average conditions. Most sectors and regions are reasonably adaptable to changes in average conditions, particularly if they are gradual. However, these communities are more vulnerable and less adaptable to changes in the frequency and/or magnitude of conditions other than average, especially extremes". (Chapter 18, page 879)

According to the Intergovernmental Panel on Climate Change (IPCC, 2001a), extreme weather events may occur more frequently, at least regionally, with the potential to affect flooding, droughts and the frequency and severity of cyclonic systems (including hurricanes). Factors such as changing winds or storm tracks might offset this effect at the local level. In all cases, changes in climate will require changes to the criteria for the design of infrastructure, as well as larger societal and sectoral changes. The structures built in earlier times will remain robust under current and future conditions if extremes decrease, while those designed for earlier and lower extremes will come under greater risk of collapse if extremes increase. Overall, it is reasonable to expect that infrastructure damage will increase exponentially as a portion of total losses with changing extremes. According to a report by the United Nations Environment Programme's (UNEP), the global costs of natural disasters are anticipated to increase significantly and to top US$300 Billion by the year 2050 if the likely impact of climate change is not countered with aggressive disaster reduction measures (Berz, 2001; UNEP, 2001). Infrastructure's share of this annual total could reach at least 25% of the total or about $80 billion each year (Freeman and Warner, 2001).

2. Infrastructure and Climate Adaptation Requirements

Because the Building, Construction and Property Services Sector is claimed to be the world's largest sector, at least for industrialized countries (Holm, 2003), any increase in extreme events will have significant economic and social impacts. In developing countries, changes in extreme events have the potential to cause even greater disruption to communities and to significantly impact future development.

The impacts of climate change on infrastructure and the built environment will require unique adaptation options due to the complexities associated with the construction sector and the uncertainties in the climate change information needed to inform adaptation decisions. For example, adaptation options will need to consider the following realities:

- Infrastructure typically has long lifetimes, with many structures expected to be still standing at the end of this century. Buildings, for example, are often designed with the intention that they remain stable for 50-60 years (Steemers, 2003a);
- The robustness of the existing stock of infrastructure is variable, with structures constructed to withstand varied extreme climate and weather conditions, depending on the age and type of structure, its maintenance record and the "margins of safety" used;
- Structures and their materials are aging and in many regions, infrastructure has not been replaced or maintained at sustainable rates. As a result, the proportion of the infrastructure that is vulnerable to extremes and to "weathering" processes is increasing. Regionally, infrastructure is also deteriorating prematurely or at accelerating rates due to the changing physical and chemical atmosphere (Holm, 2003);
- Many existing buildings and communities are located in vulnerable locations, including exposed coastal zones and river flood plains, and more rigorous disaster management planning will be required;
- The construction industry, building codes and standards and land use planning all have historically remained slow to change;
- Land use and building materials decisions are often dominated by short-term commercial interests rather than long-term risk requirements.

Current understanding of the potential impacts of climate change on infrastructure is still very limited and further research and development will be required to support decision-making. While a few studies are emerging from a handful of countries, most of these studies are based on generalities and on broad large-scale analyses. Among the challenges, there is a critical need for research to fill in the gaps between regional climate impacts and the requirements for designing infrastructure to withstand the climates of today and the future. More specific information is needed to determine which types of infrastructure and which regions are likely to experience the greatest losses in future and to develop climatic design information that minimizes additional risks for structures long into the future.

3. Weather Extremes and Designing Against Infrastructure Damage

As the climate changes, it is expected that small increases in weather and climate extremes will have the potential to bring large increases in damages to existing infrastructure. Studies indicate that damage from extreme weather events tends to increase dramatically above critical thresholds, even though the high impact storms associated with these damages may not be much more severe than the type of storm intensity that occurs regularly each year (Munich Re., 1997; Swiss Re., 1997a; Coleman, 2002). In many cases, it is likely that the critical thresholds reflect storm intensities that exceed average design conditions for a variety of infrastructure of varying ages and condition. An investigation of claims by the Insurance Australia Group (IAG), as shown in Figure 1, indicates that a 25% increase in peak wind gust strength can generate a 650% increase in building claims (Coleman, 2002). Similar studies indicate that once wind gusts reach or exceed a certain level, entire roof sections of buildings often are blown off, or additional damages are caused by falling trees. Typically, minimal damages are reported below this threshold (Munich Re., 1997; Swiss Re., 1997a; Freeman and Warner, 2001; Coleman, 2002).

The quality of construction and the maintenance of structures will strongly influence the damages and extent of claims. Figure 2 shows typical vulnerability curves for various quality of construction, where mean marginal damage from windstorms increases exponentially with local peak wind gust velocities (Swiss Re, 1997a). The curves reflect substandard quality, standard quality and high quality construction (bottom curve), respectively. Hence, as shown in Figure 2, moving from a wind speed of 40 meters per second to a speed of 60 meters per second increases marginal damage from about 2 to 10 percent (standard construction). For buildings of substandard quality, an

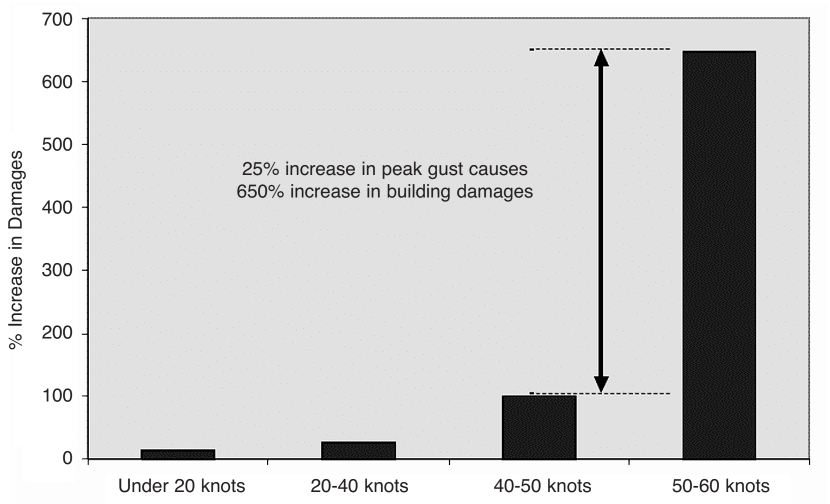

FIGURE 1

IAG Building claims as a function of peak gust speed. *Source: (Coleman, 2002)*

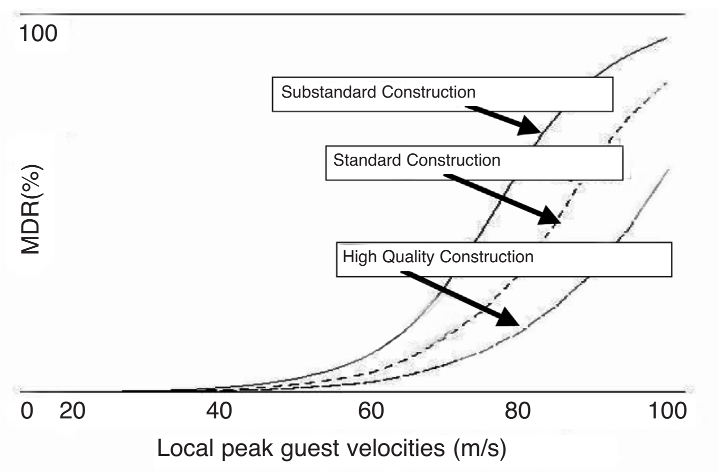

FIGURE 2

Relative mean marginal building damages (%) as a function of peak wind gust velocities for varying quality of construction. The results indicate, for example, that a 20 meter per second increase in wind speed can increase damages by 65%. *Source: (Swiss Re, 1997a)* increase in wind speed from 60 meters per second to 80 meters per second increases losses from 10 percent to 75 percent (Swiss Re, 1997a). As wind speed increases, minor changes in velocity can drive up damage significantly. It is obvious that lower quality construction or poor maintenance over time rapidly worsens marginal damage.

Similar results have been obtained for flood and hailstone damages. For example, hailstones below a certain size have been found to not damage car panels whereas above this critical size, damage increases abruptly (Freeman and Warner, 2001). Likewise, similar damage curves exist for flood damage events (Munich Re 1997; Swiss Re 1998), indicating that a small increase in flood levels may vastly increase flood damage as incremental flood levels overwhelm existing infrastructure and flood protection systems. In general, flooding, ice storm and wind storm events tend to result in the most widespread, costly and direct impacts to infrastructure such as buildings, bridges, roads, communications, electricity generation and water systems.

Globally, droughts are one of the most costly of all disasters worldwide, capable of bringing massive economic losses, destruction of ecological resources, food shortages and starvation for millions of people in developing nations (IPCC, 2001a). Climate change projections of more frequent and intense drought conditions will affect demands on water distribution infrastructure and impact soil stability for other types of infrastructure. For example, more frequent and intense droughts will likely increase incidences of soil and infrastructure subsidence, requiring more adaptation actions in the form of widespread structural underpinning, tree removals near building foundations, deeper foundations for new structures and redesign of foundations with increased stiffness (Sanders and Phillipson, 2003).

3.1 Climate Change and Engineering Codes and Standards

In many countries, structures are designed using national building codes and infrastructure standards. These codes and standards depend on a set of climatic and seismic design values, where values can vary considerably from one location to another. Almost all of today's infrastructure has been designed using climatic design values calculated from historical climate data under the assumption that the average and extreme conditions of the past will represent conditions over the future lifespan of the structure. While this assumption has worked in the past, it will no longer hold as the climate changes. Until the uncertainty in climate change scenarios are reduced, it will become critically important that climatic design values be regularly updated to reflect the changing climate and that deficiencies in existing climatic design values be improved, with uncertainties reduced as soon as possible.

Typically, decisions on how to build structures are primarily driven by the need to build both safely and economically. The appropriate balance must be struck between safety and required strength and serviceability over the life of the structure and over initial and maintenance costs. This balance can only be achieved using realistic estimates of future climatic design loads. While structures can always be "over-designed" to protect against natural hazards, the economic costs to societies can prove prohibitive.

Climatic design values include quantities like the 10, 50, or 100 year return period “worst storm” wind speed, rainfall or weight of snowpack conditions that are typically derived from historical climate data. Other climatic design quantities include percentile cold, hot or humid temperature or humidity conditions return period ice accretion loads and average degree day quantities. A given return period storm does not mean that the design storm only occurs once in the named time frame but refers to the risk of an event being reached or exceeded in a period. A 50 year return period wind storm speed, for example, refers to a one chance in 50 wind speed that can be expected to be reached or exceeded in any year. On average, a 50 year return period storm has a 64 percent chance of being reported at least once in a given 50-year period, a 26 percent chance of occurring twice and an 8 percent chance of at least three occurrences in a 50-year time period (Cook, 1985). In essence, there is about a one in twelve chance of at least three storms with wind speeds equal to or greater than the 50-year design speed occurring within a given 50 year period.

Structural failures can result when climate extremes approach their design values and the engineering performance of the structure encroaches or exceed design uncertainty limits. The design of structures requires an appreciation of the variability and uncertainty of the engineering technology. For critical post-disaster buildings such as schools and hospitals, basic engineering loads are augmented by greater safety factors that account for uncertainties in strengths of materials and uncertainties in other engineering technologies (Canadian Commission on Building and Fire Codes, 1995). However, safety or uncertainty factors are not necessarily assigned to the climatic design values, with the implicit assumption being that these values are relatively stable. In reality, climatic design values derived from extreme climate statistics can be subject to considerable uncertainty due to data and other constraints, as discussed in Section 6.

The choice of safety factor used depends upon the intended occupancy or use of the structure. The greater the number of people expected to use or be impacted by the structure, the safer the design must be. Transmission lines, for example, are designed with lower safety factors since their failures are considered to bring economic losses rather than losses of lives while critical post disaster buildings, such as hospitals or schools, are designed with higher safety factors. However, with increasing trends towards electronic and "just in time" delivery economies, the losses from interruptions in power now include large economic costs as well as losses of lives. The severe Ice Storm of January, 1998, that caused failures and interruptions to electricity distribution systems in eastern Canada and the northeastern U.S. also led to loss of lives from ice hazards, exposure, an inability to heat buildings, road accidents and poisoning from use of temporary heaters. It seems likely that, as societies become increasingly dependent on critical infrastructure services and increasingly vulnerable to interruptions created by weather and climate extremes, the safety factors in use in codes and standards will need to be assessed and potentially revised. This assessment will be particularly important for the more critical infrastructure components.

Until the uncertainties associated with the directions and magnitudes of changes in climate extremes are known and can be incorporated into climatic design values able to consider current and future climate conditions, the safety factors used in codes and standards may need to be increased to reflect the growing uncertainties in climatic conditions over the lifespan of the structure. Since uncertainty is well accepted as a part of construction codes and standards and the regulatory process, it should be possible to deal with the growing uncertainty of future climate design values through measures such as increasing safety factors (Dalgliesh, 1998; Sanders and Phillipson, 2003). While regulators and the construction industry will undoubtedly be reluctant to include significant improvements and resultant increases in the costs of construction, the reality is that engineering and regulation are already based on statistical analyses of risk. Uncertainty over the future climate is one more source of variance or uncertainty that can be quantified by various methodologies (e.g. variances from different climate models). Improvements in downscaling methodologies and the development of climate change analyses techniques more appropriate for climate extremes (e.g. statistical map typing methodologies, decision modelling) will also improve confidence in projections of climate change impacts and their implications for climatic design values.

Under current processes, building codes and other infrastructure standards are typically slow to change, particularly since industry stakeholders often resist new changes that add to the costs of structures. Because new or replaced infrastructure will come to play an increasingly important role in building adaptive capacity, particularly when compared to the cost of retrofitting existing infrastructure, it is important to ensure that infrastructure is optimally adapted as soon as possible for existing and future climate conditions. An alternative that allows for early adaptation and complements the eventual changes that will be needed and reflected in codes and standards would be the introduction of a "Climate Change Adaptation Factor" (CCAF) into engineering practices. The "Climate Change Adaptation Factor" would ensure more timely and optimal adaptation of infrastructure and could incorporate two components, as needed. The first component would explicitly allow updating of existing climatic design values (Acurrent) while the second component would consider expected climate change increases in climatic design values (Aclimate change) similar to adjustments proposed by the Association of British Insurers (2003).

Using a Climate Change Adaptation Factor, the user could undertake a risk assessment to determine whether to apply this Factor to design requirements, given that components are tabulated for geographical areas and include different climate model scenarios. For example, the factor could be applied when updated design values are needed and/or when the risks to specific infrastructure from climate change are likely to increase over time. While this approach has the advantage of being relatively easy to update as new climate data and climate change scenario information become available, it could have the disadvantage of being difficult for users and inspection personnel to understand initially and could carry the risk of being ignored unless backed by legislative or other authoritative action.

4. Premature Weathering of Infrastructure

In contrast to extreme events where the damage is done in minutes or days, premature failure caused by weathering or deterioration from the weather elements usually takes months or years to become evident. Similar to the natural environment, man-made structures are also subject to erosion caused by the slower day-to-day processes of wind-driven rain, by freeze-thaw cycles, frost depth penetration, wetting and drying, by abrasive materials, by the action of broad spectrum solar radiation and ultraviolet (UV) radiation, and by chemical breakdown in the presence of water, oxygen and assorted pollutants.

Buildings, for example, are particularly vulnerable to weathering impacts that compromise their durability and resilience to extremes over time. Uncontrolled moisture accumulation in structural materials can reduce the structural integrity of building components through mechanical, chemical and biological degradation. It is the function of the building envelope, which includes the exterior walls, foundations, roof, windows, insulation, connectors, and doors that enclose the indoor environment, to separate the indoor from the outdoor environments (Bomberg and Brown, 1993). To maintain its durability over time, the building envelope needs to prevent weather elements from entering the structure and becoming trapped inside the walls, which can cause wall components to continue to decay. Durability of the building envelope and provision of the desired service life more or less assures protection of building occupants from all weather elements and systems contained within it, along with the contents. If the building envelope fails during a storm, damage to contents typically raises the total loss by a factor of 2 to 9 over the cost of repairing the building itself (Sparks et al, 1994). Following Hurricane Andrew in August 1992, for example, building codes in the two counties affected in the Miami area were changed to require the building envelope to remain in place and capable of protecting contents during the design extreme wind event (Minor, 1994). Other publicized cases of moisture damages from envelope failures in North America include the Vancouver condos, North Carolina housing units, and Seattle leaky homes. Another study by the Norwegian Building Research Institute estimates that three-quarters of all building damages registered in Norway resulted from water and moisture infiltration and the health costs associated with problems from moulds, etc (Liso, 2001). These results, in effect, impose a requirement for durability over the service life of the building, where any loss of function over the service life of a structure may result in health costs (e.g. moulds) as well as infrastructure no longer able to resist extreme events.

Exacerbating concerns over the premature deterioration of infrastructure are issues related to aging and overextended infrastructure. Spending on public infrastructure has been declining steadily, when rated as a share of economic activity (IPCC, 2001a). In North America, for example, public spending on a broad range of new infrastructure projects represented almost 3.5% of GDP in the early 1960s, but had declined to less than 2% in the 1990s (Statistics Canada, 1999; USBEA, 1999). This reduced rate of spending on replacement and expansion of infrastructure to meet growing population and urbanization demands has resulted in a significant proportion of aging, "overextended" infrastructure that is increasingly vulnerable to selected climatic hazards (IPCC, 2001a). The American Society of Civil Engineers, for example, has warned that many dams in the United States have exceeded their intended lifespans (Plate and Duckstein, 1998). More than 9,000 regulated dams have been identified as being at high risk of failing, with the result that there may be significant loss of life and property from future failures.

Premature weathering or deterioration of structural materials is becoming a growing concern in many regions, perhaps related to the changing physical and chemical atmosphere. For example, in parts of North America, concerns are growing over the premature deterioration of materials such as clay bricks, reinforced concrete and pavement (Auld, 1999; Haas et al, 1999). In northern latitudes, there is evidence that recent warmer winters in traditionally colder winter climates are resulting in more frequent freeze-thaw cycles, leading to potentially greater weathering of infrastructure materials such as concrete and pavement (Auld, 1999; Stutzman, 1999; Green et al, 2003). Increasing freeze-thaw cycles in cold regions are also under suspicion for enhancing susceptibility to building roof ice damming and moisture damages (Magnuson et al, 2000; Baker, 1967). If this rate of deterioration of infrastructure is not slowed through adaptation actions, existing structures may become more vulnerable to the changing climate of the future.

5. Adaptation Options and Actions Supporting Infrastructure

Because infrastructure built in current times is intended to survive for decades to come, it is critically important that adaptation options to climate change be developed today and implemented as soon as possible. In many cases, it is likely that the impacts of future climate change will lie outside of existing experience and coping ranges of infrastructure and adaptation options will need to be developed over time through "adaptation learning" and more effective pre-disaster planning. As much as possible, it is important that adaptation lessons be learned from current practices, with continuing emphasis on the need for post-storm forensic studies and learning from failures.

The many implications of the changing climate will require a structured approach for the reinforcement and retrofit of existing infrastructure, planning for redundancy of critical infrastructure and the updating of infrastructure codes and standards. Underlying these activities will be an ongoing need for careful monitoring of regional climate conditions and prioritization of adaptation actions, as described below.

Infrastructure adaptation actions needed to help communities and decision-makers cope with the changing climate include:

(i) ***Updated and Regularly Revised Structural Codes and Standards, Climatic Design Values and Engineering Practices (Section 6)***

- Update codes and standards and their climatic design values, according to the following requirements:
  - Regularly assess and update climatic design values;
  - Consider changing safety factors (or other measures) to reflect growing uncertainties and risks under climate change;
  - Develop analytical techniques to incorporate climate change and socio-economic scenarios into climatic design values.
- Incorporate Climate Change Adaptation Factors for immediate updated adaptation requirements
- Ensure sufficient density, data quality and record length of climate networks
- Enforce compliance to infrastructure codes and standards
- Assess engineering practices in light of the changing climate
- Reduce premature deterioration rates for infrastructure

(ii) ***Prioritized Adaptation Actions for Critical Infrastructure and Vulnerable Regions (Section 7)***

- Prioritize and develop adaptation options for the most critical infrastructure
- Prioritize and develop adaptation options for the most critical regions
- Incorporate infrastructure adaptation into the planning cycle

(iii) Enhanced Community Disaster Management (Section 8)

- Provide accurate early Weather Warnings of hazards
- Phase in avoidance of vulnerable regions
- Encourage energy efficiency and self-sufficiency
- Support multi-disciplinary forensic studies (adaptation learning) and risk reduction learning
- Require community pre-disaster and post-disaster management planning (through regulation).

(iv) Education and Outreach of Engineering and Planning Communities and Public (Section 9)

- Create awareness of community risks and vulnerabilities
- Encourage closer collaboration between planning and engineering communities and climate community
- Include topics of disaster resistant construction and climate change adaptation in curriculum for engineering and planning professions.

6. Structural Codes and Standards, Climatic Design Values and Engineering Practices

"No regrets" adaptation options are available in the here and now that can reduce the vulnerability of infrastructure to existing climate variability and help with future climate change. In Canada, and likely elsewhere in the world, current long-standing gaps and deficiencies in the determination of climatic design values prevent optimum decisions from being made on infrastructure reliability and safety. Structures designed using climatic design values that are based on poor climatic data, sparse data or previously short dataset records are particularly vulnerable. It is important that such uncertainties and deficiencies in climatic design values be addressed on a priority basis to ensure effective adaptation to current climate variability. A better understanding of these uncertainties is needed to determine whether and by how much structures can tolerate slight increases in loads. For example, the climatic design values used in any given building code or infrastructure standard vary considerably by locality and region, by the date of its calculation and on whether design values have been regularly updated. The uncertainties in climatic design values will depend strongly on the complexity of the climate in a locality, the density of climate stations, quality and length of the climate data used for the estimation of climatic design values, the frequency of the extreme climate event, statistical approaches used and spatial and temporal interpolation approaches applied for estimation at a location (Canadian Commission on Building and Fire Codes, 1995). In the near future, it will become even more important that climate station record lengths and quality be enhanced or at least maintained to allow adequate calculation and interpolation of climatic design values and that climate networks be enhanced or maintained in areas of sizable populations, near critical infrastructure and in the regions most vulnerable to climate change.

The impact of uncertainties in the estimation of historical climatic design values need to be understood and reduced in order to update and optimize the safety and economy of future climatic design values. For example, conservative assumptions that were applied regionally in past can result in additional "margins of safety" or over-design in existing climatic design values. In other cases, due to climate data shortfalls not considered in data treatments or due to regional trends towards increasing climate loads, some existing climatic design values may already be at risk under current climate conditions and not be able to accommodate any further increases in loads.

Once the uncertainties in existing climatic design values are minimized, it is important that climatic design values be regularly updated over time. Where adaptation urgency is important and codes and standards cannot be changed soon enough, a Climate Change Adaptation Factor may need to be applied. Climatic design values for codes and standards need to reflect the changing climate conditions and be assessed against regional climate trends to determine whether existing "margins of safety" have any remaining tolerance to accommodate increases in loadings. Localities and regions where climate trends are encroaching on tolerance limits require, on a priority basis, increases in climatic design values for new structures and potential structural reinforcement for existing "at risk" structures.

Methodologies are needed that allow climate change scenario information to be incorporated into design of infrastructure. Such studies and methodologies are rare. A study by the Meteorological Service of Canada, for example, on the potentially changing risks of severe ice storms has shown that several complementary analyses should always be considered when projecting the implications of extreme weather under changing climate conditions (Klaassen et al, 2003a; Cheng et al, 2004). The study, which identified regions of increasing risks under initial winter warming, indicated that considerable potential exists for the use of statistical synoptic map typing procedures in identifying trends in large scale or synoptic, regional and local scale weather patterns for severe ice storms. Statistical map typing methodologies also have considerable potential as a technique to downscale projections from global and regional climate models using fields more reliably handled by the global climate models. Other complementary analyses used in the study (Klaassen et al, 2003a) included storm tracking, assessment of threshold synoptic storm components for the most extreme ice storms affecting eastern North America, assessment of climate impact thresholds, and spatial or analogue approaches that correlate conditions and impacts in adjacent regions during the most severe storms.

Existing infrastructure failures are often shown to result from inadequate compliance to codes and standards. As a result, compliance and the development of institutional capacity to implement building standards and codes of practice will become increasingly important in future. Several studies have documented widespread damages as a result of the construction industry not complying and building inspections not detecting the violations. For example, the hurricane that hit Northwest Norway in 1992 caused damage to buildings in the order of NOK $1.3 billion, with total damages to structures in general amounting to approximately NOK $2 billion (Liso et al, 2003). The bulk of the damage to buildings was incurred on roofs and roofing and could have been avoided had the existing Building Regulations and Codes of Practice been followed (Liso et al, 2003). In the UK, analysis of claims and weather data have shown that a large percentage of wind-related damage takes place at wind speeds lower than those to which buildings are nominally designed and are caused by failures to apply existing codes of practice (Buller, 1993).

Because of the varying safety factors used for each type of infrastructure, it is theoretically possible that some structures designed for longer return period extremes, such as hospitals, may be able to withstand more extreme atmospheric hazards with much longer return periods while others structures with minimal safety factors, such as electrical distribution lines, may readily encroach on the limits of their load tolerances. Where existing safety factors are relatively high or conservative, adaptation actions may not be required immediately to ensure structural safety. In other cases, a Climate Change

Adaptation Factor may be needed to ensure timely adaptation actions. Further study is needed to determine whether and when structures will become vulnerable to the increasing uncertainty of climate design values and to assess the impact of changing engineering practices and codes and standards on the ability of structures to withstand surprises in extreme weather loads. In prioritizing adaptation requirements, studies are needed to identify which types of structures are most vulnerable to the impacts of climate change (e.g. electrical distribution lines, sewers). Such studies will also help to determine to what extent tendencies towards standardized cost-effective structures today may have compromised robustness or adaptability of structures. Alternatively, a review of generic building typologies that have survived over centuries may reveal characteristics that make these structures particularly adaptable to climate variations and changes (Steemers, 2003b). The learning from such a review would serve to highlight adaptative attributes and sound building practices that historically may have been better adapted for local climatic conditions and also reveal current practices that are contrary to effective adaptation.

Finally, the relationship between atmospheric weathering processes, building materials, maintenance schedules and structures is complex and in need of further study. The understanding of how degradation and damage can best be reduced economically is of growing importance for the design and construction of structures. In many areas, future building materials, structures and building enclosures, will need to withstand greater climatic impacts than they do today. When designing building enclosures to resist wind actions, materials and engineering practices will need to ensure the integrity of the envelope so that moisture does not enter the structure (Holm, 2003). A particular challenge will be the identification of weathering processes of greatest importance in order to develop appropriate adaptation responses. For instance, the duration of excessive precipitation may prove of greater importance for certain types of building facades, while the intensity of driving rain may be the most important element for other types of external walls. Freezing and thawing cycles may prove significant in winter climates for performance of masonry and concrete construction while polymer materials may be more affected by the sum of ultraviolet radiation (Holm, 2003). Adaptation actions could take the form of different formulations for materials (e.g. concrete, clay brick) or different engineering practices to ensure greater durability and requirements in standards for preventative maintenance.

7. Prioritize Adaptation Actions for Critical Infrastructure and Vulnerable Regions

Critical infrastructure is defined in Canada as "those physical and information technology facilities, networks, and assets whose disruption or destruction would have serious impact on the health, safety, security, and economic well-being of Canadians or on the effective functioning of governments in Canada" (Grenier, 2001). Enhanced design of the most critical infrastructure (such as communications structures, power supply and distribution systems and emergency shelters) and built-in redundancies may improve the likelihood of continuous operation during extreme weather events, as well as improve response and recovery following disasters and generally reduce the vulnerabilities to regionally increasing extremes. The survival or failure of housing has also been claimed to be a key factor determining the severity of a natural disaster and the ability of a community to recover, indicating the importance of proper design and construction of housing (Davenport, 1999).

Although the damages from the eastern North American Ice Storm of January 1998 were initiated by a particularly severe ice storm, the event quickly turned into a technological disaster because of cascading impacts from power outages. Due to a whole chain of events, affected communities experienced a major malfunction of some of their other most critical infrastructures such as telecommunications, transportation, banking and financial systems, drinking-water supplies and, of course, energy infrastructures. The January 1998 Ice Storm emphasized that all components of critical infrastructure are inter-linked today, particularly given the nature of today's electronic and "just-in-time delivery" economies, industries and communities.

While particular types of infrastructure will require priority adaptation action, particular regions may also require priority adaptation actions for enhanced design of new infrastructure and protection of existing infrastructure. Some of the greatest impacts of climate change on infrastructure will likely be noticed in exposed coastal zones, flood plain regions, heavily urbanized areas and permafrost regions. Adaptation options will require a suite of actions ranging from avoidance of the most vulnerable sites to expensive protection structures.

Melting of permafrost in northern regions will require expensive monitoring of buildings, road-beds, pipelines, utility lines, dams and water diversion channels. The net result likely will be extensive repairs and modifications of existing structures, and changed techniques for new construction. While tested adaptation solutions are available, given warning of changes, reliable local information, and funding, the costs will be expensive. Proven methods of supporting roads, airports, and buildings can prevent settlement under permafrost thawing while expensive maintenance can protect facilities built on permafrost (University of Alaska Anchorage, 2000). New structures in permafrost regions can be built over gravelly "thaw-stable" permafrost to avoid the worst consequences, but more costly up-front actions will be required to select the most reliable and least vulnerable sites as the permafrost thaws.

Many structures and communities in coastal zones and flood plains will face significant risks from the changing climate as a result of sea level rise, increases in storm surges, increases in water and air temperature, more extreme rainfall and storm intensity, and resulting land erosion and inundation from the sea. These impacts will likely lead to increased susceptibility of buildings and structures to damages in vulnerable locations and to more frequent disruptions to services (Planning Institute of Australia, 2004). All of these impacts could affect the future design and location of development. The more risky coastal locations that contain high cultural, environmental or financial value may require construction of expensive structures for protection against inundation, such as barriers and dykes and reinforcement of buildings and other infrastructure, along with measures to reduce premature weathering of materials, including enhanced maintenance.

It is expected that climate change will affect the costs and timelines for planning, upgrading and maintaining infrastructure. Prioritization of required adaptation and mitigation actions will need to account for the variable lifecycles of structures and replacement cycles, including infrastructure maintenance and upgrade cycles. Table 1 indicates the expected lifecycle activities for the various types of infrastructure. As the Table indicates, planning decisions are being made about buildings and other infrastructure today that have a very high probability of being affected by the direct impacts of climate change in the future.

The design life of a structure becomes important in determining what climate change impacts can be expected over its lifetime. On the adaptation side, structures with a design life of 30 to 50 years will need to consider different future climate conditions than others with a longer design life of 100 years. Short-lived assets and components, such as heating, ventilation and cooling systems, tend to be replaced at various times during the lifespan of a building, offering opportunities for adaptation or "phasing in" of systems to the changing climate. Other medium-life assets such as industrial plants, oil and gas pipelines, and conventional power stations that need to be modernized to take advantage of competitive technologies are also likely to be replaced or relocated over shorter time scales than other infrastructure and can become adaptable, particularly through upgrades and relocation. For structures not as likely to be relocated or replaced, such as housing, the challenges of adapting basic structural components will be more difficult. Due the varied ages and replacement life of structures in the built environment, it will take time to change structures, institutions and other policies to cope with climate change realities.

The changing climate will, in effect, shorten the lifespan of existing structures in many regions. Where extremes increase, the impact will be a reduction in the "effective" return period event that existing structures were built to withstand. For example, Kharin and Zwiers (2000) analyzed changes in daily precipitation extremes under climate change using output from an ensemble of transient climate model simulations and concluded that the return period of extreme rainfall events may, on average, be reduced by a factor of two. This means that, under a changed climate, a current 20-year rainfall event could occur every 10 years. As the effective return periods of extreme events change with the climate, weather extremes will tend to exceed the design specifications for structures more frequently, decreasing the durability and resilience of the structure. Repeated extreme event loads (fatigue loads) cause deterioration of materials and can lead to eventual failure of the structure.

In the timeframe of climate change impacts, it is evident that new infrastructure will play an increasingly important role in building adaptive capacity as older structures are replaced over time. For example, within the next 50 years and assuming a replacement rate of 1% to 1.5% for buildings, it is likely that roughly half of existing buildings will need to be demolished and replaced (Fernandez, 2002). Hence, within the timeframes for climate change impacts, new buildings will accumulatively account for an equal or greater fraction of the building stock and need to be designed to enable adaptation to climate change as soon as possible (e.g. through continuously updated building codes, increased safety factors and incorporation of climate change scenarios).

The adoption of practices supporting the "diversified lifetime" of a building may also become a powerful adaptation option (Steemers, 2003a). This will require that buildings and other structures become "designed for disassembly, separation technologies, materials reclamation and recycling, loose-fit detailing, lightly-treading foundations and other technologies that allow use to change over time" (Fernandez, 2002). The concept behind the "diversified lifetime" is that a structure be designed using a number of different parts with different design lives. As a result, uncertainty about a

Table 1 Infrastructure Lifecycle Timeframes (Adapted from Planning Institute of Australia, 2004)

STRUCTURE	PHASE	TYPICAL EXPECTED LIFECYCLE
Commercial Buildings	Retrofit Demolition	20 years 50-100 years
Housing	Additions and Alterations Demolition	15-20 years 60-100 years
Roads	Maintenance Resurface Reconstruction/Major Upgrade	Yearly 5-10 years 20-30 years
Bridges	Maintenance Resurface concrete Reconstruction/Major Upgrade	Yearly 20-25 years 60-100 years
Rail	Major refurbishment Reconstruction/Major Upgrade	10-20 years 50-100 years
Airports	Major refurbishment Reconstruction/Major Upgrade	10-20 years 50 years
Seaports	Major refurbishment Reconstruction/Major Upgrade	10-20 years 50-100 years
Dams/Water Supply	Major refurbishment Reconstruction/Major Upgrade	20-30 years 50 years
Waste Management	Upgrade Major Refurbishment	5-10 years 20-30 years
Sewers	Reconstruction/Major Upgrade	50 years

building's long-term use or environmental conditions can be reflected by reduced investment in some of its construction or components, with an inherent potential to adapt spatially and functionally to change. In the case of climate change, the objective would be to anticipate changing climate conditions (or even market conditions) and where there is certainty, to consider whether it is worth investing for the longer term. For the buildings sector, this could involve investing in a strategy for the key long-term parts of the building that will need to be able to cope with predicted climate change and allowing the short-term components of the buildings or structure to be designed for minimal climatic change and maximum flexibility.

8. Improved Community Disaster Management

Concerns over the impacts of weather-related hazards on vulnerable populations are growing, due to increasing risk factors such as population growth and urbanization, a rising proportion of poor living in vulnerable locations and the changing climate. Actions to reduce exposure to weather hazards or disaster management are necessary and will need to include adaptation actions such as planned responses to timely and accurate weather warnings, proper land use planning, good engineering design and practice, good maintenance of structures and efficiency and self-sufficiency in use of energy and services (Freeman et al, 2002; Planning Institute of Australia, 2004).

A very critical part of a disaster management strategy is the completion of a Vulnerability or Risk Assessment. Vulnerability is defined as:

> *"The extent to which a community, structure, service, or geographic area is likely to be damaged or disrupted by the impact of a particular disaster hazard, on account of their nature, construction, and proximity to hazardous terrain or a disaster prone area." (ADPC 2000).*

Vulnerability assessments identify sources of hazards, vulnerable groups, likely risks and potential interventions. For example, vulnerability assessments identify weather and other types of hazards, identify critical infrastructure at risk to these weather hazards along with vulnerable groups and then develop potential adaptation and prevention interventions. As illustration, the province of Ontario, Canada, recently passed its Emergency Management Act (Government of Ontario, 2003) mandating that all municipal and regional governments adopt disaster management planning. The legislation requires that municipalities identify and assess the various hazards and risks to public safety that could give rise to emergencies in their communities and develop a prioritized emergency response plan, including the identification of infrastructure at risk. The Act also requires that municipalities develop comprehensive plans to reduce and prioritize risks, including development of a municipal disaster mitigation strategy, planning for high risk events, development of an emergency recovery plan, implementation of guidelines for risk-based land use planning and development of public education programs (Government of Ontario 2003). In support of these measures, the Meteorological Service of Canada (Auld and MacIver, 2004; Meteorological Service of Canada, 2004) recently released a web site and publication on atmospheric hazards that allows emergency managers to access climatological hazards information, customize atmospheric maps for their localities and to overlay regional combinations of hazards maps.

The successful application of early warnings is another effective measure for disaster reduction. Effective warnings of impending events allow people to take actions that save lives, reduce damage, reduce human suffering, and speed recovery. In essence, accurate and timely weather warnings play a critical role in buying the time needed to evacuate populations, reinforce infrastructure and prepare for emergency response. While scientists and emergency managers are improving capabilities to warn for more weather and related environmental hazards and to increase warning accuracy, greater improvements are needed in measures to deliver warnings in a timely manner and to those people and regions mainly at risk. Improvements are also required for better coordination among warning providers, for better education of those at risk, and in building partnerships among the many public and private groups involved in response.

In many countries, weather warning systems consist of an escalating series of messages intended to alert the public and emergency responders to impending weather hazards of various magnitudes. Typically, these warning systems consist of advisories or watches for potential hazardous weather, with warnings issued as hazardous weather becomes more certain. As risks increase regionally under climate change, improved and expanded weather warning programs, such as specialized warnings for emergency responders, may be needed along with increased lead time. For example, the U.K.

Meteorological Office currently provides Early Warnings of potentially disastrous weather events to emergency responders up to five days in advance so they can be prepared to respond to the effects of high impact weather. Because prediction of severe weather at this range, especially in any detail, is difficult, these Early Warnings are expressed in terms of probabilities, with warnings issued when the probability of disruption due to severe weather somewhere in the UK is 60% or more (U.K. Meteorological Office, 2004). Other expanded weather warning programs could include escalated warnings of potential community disasters that are based on infrastructure damage thresholds, as discussed in Section 3. These weather-infrastructure warnings could include warnings of extreme ice loads or wind loads with the potential to disrupt transportation and to cause widespread failure of electrical power distribution networks (Cheng et al, 2004) or alerts of extreme snow loads giving increased risks for building collapses (DeGaetano and Wilks, 1999). Similarly, expanded weather-health warnings and response systems for potentially "dangerous" environmental conditions could include community Heat Alert systems for vulnerable populations, waterborne disease outbreak and beach water quality alert systems for water managers (Auld et al, 2004) as well as other health emergency alert systems. The Meteorological Services of several countries, including Canada, currently provide Heat Alert prediction systems for selected pilot cities when risks of elevated mortalities from heat wave events reach regional threshold levels. The U.K. Meteorological Office also supports health-related weather services aimed at assisting in more effective public healthcare planning and delivery. By building high-quality weather information into the decision-making process, public health officials, healthcare providers, researchers and others are able to plan emergency health care operations and activities with greater confidence, manage workload more effectively and make the best use of limited healthcare resources (UK Meteorological Office, 2004). While emergency disaster response is important, climate change adaptation options for infrastructure and communities will ultimately require more intervention by land use planning authorities.

Land-use planning is a powerful tool to help reduce the loss of life and property. One study that indirectly illustrates this concept compared impacts from flooding storm events in Michigan and neighbouring Ontario (Brown et al., 1997) and found that nonagricultural flood damage from a set of storms moving through Michigan exceeded that of southwestern Ontario by a factor of about 900, even though the flood yields in Ontario were greater than those in Michigan. Their analysis ascribed the cause as greater development in flood-prone areas in Michigan. The storms generally exceeded land-use design thresholds in Michigan, whereas in Ontario they did not.

Many of the following disaster management planning measures will need to be considered in future to better deal with the increasing risks to communities (Planning Institute of Australia 2004), but will not likely be "welcomed". These measures include:

- More intensive and efficient use of land in areas less exposed to climate change risks. This may mean encouraging greater urban consolidation and avoiding development in high-risk areas (e.g. flood plains and coastal zones subject to sea level rise and storm surges);
- Locating new development in areas not vulnerable to the impacts of climate;
- Planned retreat or a focus on systematic abandonment of land, ecosystems and structures in vulnerable areas;
- Identification of high risk areas of high cultural, environmental, strategic or financial value for consideration of adaptation options such as constructing works to protect against sea level rise and flooding events;
- Enhanced building design for continued occupation of vulnerable regions (e.g. exposed coastal zones and flood plains).

Forensic disaster investigations likely will become increasingly important for adaptation learning. The performance of structures during extreme events needs to be monitored to confirm and to further fine-tune engineering design practices, as well as to assess climatic design values. As an example, many lessons were learned from the detailed investigations of how structures responded to the Barrie and Grand Valley tornadoes in southern Ontario, Canada in 1985. The studies of damages following the tornado outbreak indicated that occupants of houses that were destroyed by the tornadoes survived in buildings when the walls of their homes were properly secured to the foundations (Allen, 1986). As a result of these and other studies, the 1995 National Building Code of Canada increased requirements for anchoring of walls to foundations for tornado prone areas (Canadian Commission on Building and Fire Codes, 1995). Similar adaptation lessons have been learned worldwide from forensic investigations of damages following hurricane landfalls and flooding events. As illustration, the massive destruction of

Hurricane Andrew ($26 to 30 Billion), which struck the southeastern US in 1992, brought issues of construction, mitigation and the insurance industry into sharp focus (International Hurricane Centre, 1999). The recommendations from the Committee that investigated the damages had an impact on the South Florida Building Code and construction regulations. Changes were introduced for new product approval test criteria for building components that included impact and fatigue tests able to simulate flying debris. The Committee also determined that the most significant hurricane damages resulted from the loss of "integrity of the building envelope" and that the breaching of the exterior of a structure set off a chain of events that led to more severe damage (e.g. shutters can significantly reduce the net damage that a building sustains in a hurricane).

Forensic investigations of flooding events often yield valuable insights. For example, the Meteorological Service of Canada, in partnership with the province of Ontario, several regional watershed management Conservation Authorities and the Ontario Flood Forecasting and Warning Committee, undertook a series of forensic studies of seven high impact rainfall storms and flooding events in Ontario, Canada for the year 2000. From these studies (Klaassen et al, 2003b), several adaptation recommendations were jointly developed by all of the study partners and have widespread applicability for government jurisdictions, decision-makers, meteorological services and planners. Some of these adaptation recommendations to reduce risks from flooding events included:

- Regular forensic reporting and studies are beneficial to the public and yield valuable adaptation lessons. The studies need to include an assessment of the meteorology, technology, weather prediction and warning improvements, impacts, historical climatological conditions, climatic design information and engineering requirements and be undertaken by multi-disciplinary teams.
- For heavy rainfall events, weather warnings and their threshold criteria need to consider antecedent or accumulated rainfall conditions.
- The quality and amount of weather and climate data are critical for the detection and warning of an extreme rainfall event and for determination of updated engineering design values.
- Coordinated efforts are needed to ensure that data networks remain sufficiently dense to capture events, provide guidance for early and accurate weather warnings, allow for updating of climatic design

information and assist improvements to weather radar and other forecasting tools.

Adaptation measures that decrease the energy requirements of buildings and ensure more disaster-resistant energy service systems (e.g. renewable sources) can reduce losses from business interruptions and damages to property, while helping to mitigate increases in the greenhouse gases driving climate change. For example, energy efficient buildings are of value when backup power systems are needed during times of power outages. In the North American ice storm of 1998, the costs of perished foods in residential freezers lost as a result of power outages was one of the larger costs faced by homeowner insurers. Likewise, more energy efficient windows, including those with retrofit films, can reduce energy losses by half while increasing their resistance to breakage from flying debris in windstorms. Studies, for example, have indicated that double-glazed windows with one low e-coating take three to four times longer to break than ordinary double-glazed windows (Anderberg, 1985; Mills, 2003). Similarly, some improved building envelopes (i.e. insulated concrete form construction) tend to be more resistant to flying debris than standard timberframe construction (Farnsworth, 2000). Insulating water pipes or insulating cold spaces where water pipes run can also save energy and reduce risks of frozen water pipes and water damage since insulated pipes cool and freeze less readily. The US insurance industry estimates that claims from frozen pipes have cost US$4.2 Billion over 10 years (IBHS and SBA, 1999).

9. Education and Outreach of Engineering and Planning Communities and Public

The implementation of cost effective climate change adaptation measures to protect communities will require greater knowledge and understanding of climate change impacts in the public and private sectors. In particular, the planning and engineering communities will need to work closely with the climate community in order to become knowledgeable on regional climate change impacts for infrastructure and to identify and implement regional adaptation options. Consequently, an important step in promoting safe building construction in vulnerable regions will be the requirement to create awareness and appreciation of levels of risks within communities and within relevant professions. Since planning is a future oriented profession, adaptation to climate change is a challenge that this profession must accept and act upon as soon as possible. At the same time, professionals coming out of engineering and architectural programs as well as practicing professionals will need to have greater exposure in their curriculum to disaster resistant construction and awareness of climate change impacts and the need for adaptation.

10. Conclusions

Climate change will impact infrastructure through gradual changes in weather patterns and increasing vulnerability to extreme events. Because infrastructure built in current times is intended to survive for decades to come, it is critically important that climate change adaptation options be developed today and implemented as soon as possible. The many implications of the changing climate will require a structured approach for the updating of climate design values, codes and infrastructure standards, for reinforcement and retrofit of existing infrastructure and for planning redundancy of critical infrastructure. Underlying these activities will be an ongoing need for careful monitoring of regional climate conditions and prioritization of adaptation actions.

The first important step in reducing risks to infrastructure is to seek to identify gaps in current capacity for addressing climate variability and extremes. "No regrets" adaptation actions are available in the here and now to reduce the vulnerability of infrastructure. These "no regrets" actions include measures such to reduce uncertainties in climatic design values and to update calculations, enforcement of engineering codes and standards, safeguarding the quality and length of climate data records and networks, regular maintenance of existing infrastructure, consistent forensic analyses of infrastructure failures and community disaster management planning. In other cases, it is likely that the impacts of future climate change will lie outside of existing experience and coping ranges of infrastructure, requiring that adaptation options be developed over time through "adaptation learning".

In all cases, adaptation to climate change will require that planners, their agencies, the engineering community and community decision-makers consider timeframes beyond statutory requirements and even beyond the lifetime of most individuals. Improved understanding of climate change impacts and the need for adaptation must be combined with better risk assessment of community climate change impacts and vulnerability, the identification and avoidance of development in vulnerable areas and ongoing incorporation of adaptation strategies into land use planning and community disaster management planning. In essence, adaptation options for infrastructure will require "tough" actions such as the location of new development in areas less vulnerable to the changing climate, the abandonment of land, structures and ecosystems in vulnerable areas, location of greenbelts in residential areas, altered building design and retrofits of existing structures and defence of vulnerable areas. Such actions will entail significant costs, disruptions to communities and require political commitment and cooperation between all levels of government.

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20 paper

IS SMART GROWTH A SMART ADAPTATION STRATEGY:

EXAMINING ONTARIO'S PROPOSED GROWTH MANAGEMENT STRATEGY UNDER CLIMATE CHANGE

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ABSTRACT: Scenarios of future climate change present vulnerabilities for urban environments in Ontario, Canada. Recent efforts for future land-use planning in Ontario have focused on the concept of Smart Growth. Smart Growth delimits areas where cities can expand and encourages higher densities of commercial and residential land use. This paper examines how Smart Growth strategies in Ontario, Canada influence the vulnerability of Ontario's urban environments to climate change through two specific impacts – increased storm water runoff, and warmer summers. The paper concludes that Ontario's Smart Growth strategies both increase and decrease the vulnerability of Ontario urban environments to climate change. It is shown that Ontario Smart Growth strategies can be modified by increasing the vegetative components of the urban environment using approaches such as green roofs that ensure a decrease in the vulnerability of urban environments to climate change.

Keywords: Smart growth, climate change, land-use planning, urbanization, green roofs, vegetation, population growth, urban sprawl, urban densities, urban heat island

1. Introduction

Urban planners and other municipal officials throughout North America, Europe and Australia have been grappling with the costs of urban sprawl. Amongst this community of professionals and others, the realization has dawned that urban sprawl has led to increased traffic congestion, with its attendant economic and health costs, loss of green space and impingement on watersheds, increased infrastructure requirements and costs and a loss of a unique sense of place that is found in the downtown neighbourhoods of most cities. There have been several responses such as fixed boundaries for urban areas and green spaces and new urbanism, but the 1990s witnessed the birth of a new movement in planning called Smart Growth. Smart Growth proposes a number if initiatives to reduce or stop urban sprawl, to reduce traffic congestion and to increase the economic viability of cities.

The most common element in Smart Growth plans is delimiting the areas where cities can expand and encouraging higher densities on commercial and residential land use. These measures are accompanied by mixed land use areas to put people closer to work and closer to commercial activities to reduce the reliance on the automobile and increase social capital; investments in public transit; development in proximity to public transit; and the protection of green space. It is hoped that these measures will lead to more vibrant, pedestrian friendly communities, reduce the cost of new infrastructure by concentrating growth in existing areas, reduce the number of private automobile trips and provide more affordable housing. To one degree or another, these elements are found in Portland, Oregon, USA; Sydney, Australia; and in the Canadian Province of Ontario's new growth management strategy (Ministry of Public Infrastructure Renewal, 2004).

Smart growth initiatives should not be viewed solely as an environmental strategy to preserve green space or a rural strategy to preserve farmland. The Province of Ontario considers it to be a crucial step in maintaining and increasing the competitiveness of the Golden Horseshoe Region, which is the economic engine of the province and the country. It is not only driven by the need to maintain competitiveness, but to accommodate the future projected growth in the region in a manner that protects the region's watersheds, valuable green space including two UNESCO Heritage sites, preserve farmland and reduce the growth in traffic congestion.

It should be noted that Smart Growth stands on an economic, environmental and social pillar, but the emphasis differs from region to region. Thus in Northern Ontario, the major concern is declining population and the recommendations to the Provincial Government focused on new ideas in regional development, such as industrial clusters, and community building to keep people in the North and to draw new migrants to the area (Ministry of Public Infrastructure Renewal, 2003). The Smart Growth Panels in Western and Eastern Ontario had a decidedly more rural flavour, although with cities such as Ottawa and London, they also reflected the land use concerns found in Central Ontario (Ministry of Public Infrastructure Renewal, 2003).

The benefits of Smart Growth initiatives are not being questioned in this chapter. The question posed in this chapter is whether a planning strategy that is supposed to lead to more compact development increases or decreases the vulnerability to climate change, particularly in Central Ontario? It will be argued that it both increases and decreases the vulnerability to climate change. If a Smart Growth policy does increase our vulnerability, it should not be dismissed, due to the potential benefits of curbing urban sprawl in Central Ontario. Those components of the growth management plan that decrease Central Ontario's vulnerability to climate change should be noted and strengthened if necessary.

2. How Smart Growth Reduces Vulnerability to Climate Change

Two specific impacts - increased storm water runoff and warmer summers - will be used as the focal point from which to assess the extent to which a Smart Growth strategy will decrease vulnerability to climate change and enhance adaptability to climate change in Central Ontario. An increase in runoff is expected to result from an increase in extreme precipitation events. It is expected that warmer summers will not be characterized so much by an increase in average temperature, but an increase in the severity, frequency and/or length of heat waves.

There are three objectives of Central Ontario's Smart Growth strategy, known as the Greater Golden Horseshoe Growth Plan that would appear to reduce our vulnerability to both of these impacts: protecting green space, reducing congestion and compact development. The designation of protected green spaces and the restrictions on expanding urban boundaries suggest that the growth in impermeable surfaces, the root anthropogenic determinant of runoff, will be reduced or halted. Thus rain falling on these areas would not be expected to contribute to the total regional runoff and would not increase the risk of flooding due to higher spring stream flow although this risk could be increased by other factors.

Reducing traffic congestion, particularly within the urban core areas, and more compact development, would appear to be good adaptations to a warmer summer. All machinery contributes waste heat to the atmosphere, increasing the urban temperatures. Reducing traffic congestion would reduce the waste heat generated by idling automobiles and should have some impact on summer temperatures, although how large an impact is not known. However, the severity of smog is also increased under warmer temperatures and traffic congestion. Reducing automobile emissions by reducing the use of automobiles would remove a source of pollutants for the formation of smog and is a logical adaptation to a warmer climate. Another benefit that might be expected from reducing the number of automobiles in the urban core is a decrease in traffic accidents, and their associated costs, due to inclement weather.

Compact development would also appear to reduce our vulnerability to warmer summers as it allows for an optimization of infrastructure, particularly new infrastructure for delivering alternatives to electricity from Ontario's power grid. For example, providing air conditioning through a district approach, such as deep water cooling from a body of water, is more feasible with higher densities. This would reduce the dependency and the drain on the grid during periods of peak summer demand. Even without an alternative source for cooling, compact development should provide more opportunities for optimizing HVAC infrastructure, which should result in some energy savings during peak demand. Protecting green space would also reduce the geographic expansion of the urban heat island, an increase in urban temperatures as vegetation is replaced by hard, impermeable surfaces, typical of urban development. These surfaces absorb most of the incoming solar radiation, converting it to heat. On vegetation, a significant amount of incoming solar radiation is used for evapotranspiration and is bound up in the water molecules that are transported into the atmosphere. Hence, vegetated areas are cooler than non-vegetated areas.

Compact development also reduces the amount of new infrastructure required for drainage and sewage, thus freeing up additional funds that would otherwise have to be spent on maintenance and replacement of infrastructure. Although developers are responsible for installing the infrastructure for new developments, once the construction is complete, the responsibility for maintenance and replacement is turned over to the municipality. Low-density development on undeveloped green fields requires new infrastructure, which does not optimize the use of existing infrastructure, and requires more metres of pipe than higher density developments.

There are other ways in which the proposed regional growth management plan may decrease vulnerability to climate change. The designation and protection of greenbelts will provide corridors for biodiversity, which may be important as ecosystems adapt to a different climate. If this includes farmland as well, although only the tender fruit lands receive specific notice, it could provide an additional measure of food security. The Greenbelt

Discussion paper also proposes to protect at least part of the urban forest, which is critical to reducing both runoff and the urban heat island (Ministry of Municipal Affairs and Housing, 2004). The proposed plan also includes protection of watersheds. Without knowing if water supplies will remain at the current levels over the next thirty years, these watersheds may become increasingly important for supplying water throughout the region and in maintaining the greenbelt around the Golden Horseshoe (Ministry of Municipal Affairs and Housing, 2004).

3. How Smart Growth Increases Vulnerability to Climate Change

Just as Smart Growth may decrease the Golden Horseshoe's vulnerability to climate change, it may also increase its vulnerability. As in the previous section, the discussion will be confined primarily to storm water runoff and warmer summer temperatures. In fact, many of the very features that were cited in the previous section are the very same features that have a deleterious effect on the region's ability to reduce the impacts of climate change.

Storm water runoff results from an inability of the surface to absorb the precipitation as it falls. Thus it runs overland, and in cities, into a drainage system. During a heavy precipitation event, the drainage system's capacity is often exceeded, which leads to other problems. In parts of the Golden Horseshoe region, the drainage and the sewage systems are combined. During a heavy rainfall event, the excess storm water is flushed through the sewage system, and without adequate storage, the sewage will be flushed out of the system before it can be treated, an event called combined sewer overflow (CSO). In other systems, and even in combined systems, the sheer amount of water leads to excess runoff and even floods.

In an urban environment, roads, sidewalks, driveways and parking lots generate a large amount of runoff, but a great deal is also generated by rooftops. One strategy for reducing storm water runoff is to reduce the amount of impermeable surface, and this is often done with vegetation. Typically, urban vegetation is reduced with higher commercial and residential densities. Thus higher densities will tend to increase storm water runoff, not only by squeezing out space for vegetation, but also by increasing the percentage of area in rooftops.

The argument that compacting urban growth reduces the impermeable surface on a regional level may not be relevant in the Golden Horseshoe. The region already features a large settlement area. The plan is to increase densities within this settlement envelope with no mention made about preserving a fixed amount of vegetation or reducing the impact of density on runoff. In fact, development will be allowed to proceed in areas within the settlement area that have already been designated, further reducing the amount of vegetation and replacing it with impermeable surfaces. In addition, the proposed growth plan does not prohibit future greenfield expansion. It will be allowed under certain conditions, and it will also be at higher densities, thus increasing the amount of impermeable surface, thus increasing the amount of storm water runoff. The protection of "municipal forests" is proposed solely in the context of recreation and culture (Ministry of Municipal Affairs and Housing, 2004). Furthermore, it is not clear whether it applies to those urban forests that are only part of a network of green spaces or all trees,

The proposed growth management plan for the Golden Horseshoe region will also increase the vulnerability to warmer summers and heat waves. Typically, because of a reduction in vegetation, dense urban areas are warmer than their suburban and ex-urban counterparts - the phenomenon known as the urban heat island. The urban heat island has many ancillary costs, in addition to a decrease in thermal comfort. Every one degree Celsius rise in temperature increases electricity demand by at least 3.8 percent (Liu, 2003), which is a provincial average and may be higher within the Golden Horseshoe. This increase in demand places additional strain on Ontario's power grid leading to more pollution from Ontario's or US coal-fired generators, although this would be reduced upon the phase-out of coal-fired power in Ontario, and an increase risk of brown or blackouts. The increased temperature also increases the risk of morbidity and mortality for vulnerable populations, the severity of smog episodes and increased strain on the health care system (Basur, 2000).

Increasing the density within the current settlement boundaries will increase the amount of surface area that creates waste heat. Further, high-density expansions beyond the envelope will only increase this surface area. Typically, an urban heat island may augment temperatures by 2 – 4 degrees Celsius, but in Toronto, urban heat islands of 6 and 10 degrees Celsius have been measured in transects from downtown Toronto through York Region (Koren, 1997). If the proposed growth management plan creates higher densities within the existing settlement boundaries as well as additional higher density development outside the current boundaries, with no plan for preserving vegetation or mitigating the urban heat island, then cities in the Golden Horseshoe will experience even higher temperatures than expected under any scenario of future climate change.

There are other vulnerabilities related to climate change that have not been addressed in the Growth Management Plan at this stage, and are typically not addressed in Smart Growth. The plan for the Golden Horseshoe has identified priority nodes for infrastructure investment that will serve as "anchors" or high-density residential and commercial development. As these areas tend to be urban centres, there are opportunities to optimize the use of infrastructure and minimize the costs of new infrastructure. However, the plan provides no further discussion as to whether the existing infrastructure is adequate to cope with additional storm water runoff. Some of these nodes will also require additional infrastructure to meet the water and sewage needs of the projected growth. As this plan will take the region through the 2030's, it is surprisingly silent on future water supplies in the region under climate change; adaptations to cope with future uncertainties in the regional water supply; and potential conflicts between industrial, municipal, agricultural, recreational, shipping and energy stakeholders.

Discussions in the natural hazards area have also suggested that concentrating population in urban areas tends to increase societal vulnerability to extreme weather events, albeit with the recognition that cities tend to be better equipped to respond to emergencies (Mileti, 1999). This vulnerability has been highlighted with the 1998 ice storm in Montreal and Ottawa and the 2004 summer floods in Edmonton and Peterborough. There are also concerns about the construction standards for infrastructure under climate change. For example, it is expected that climatic design values will require updating, perhaps more frequently than in the past fifty years in order to ensure that the margins of safety are adequate. The climate variables that are the most important are winds, snow loads or snow packs, rainfall intensities, accumulated or antecedent rainfalls, cold and warm temperatures, wet bulb temperatures or other humidity variables, accumulated temperatures, and combinations of these variables with daily outputs as a minimum (Auld, 2004). The uncertainties of most of these elements in a climate change scenario are still high and the uncertainty of all elements increases at smaller time steps.

4. Modifying Smart Growth with Green Roofs

Smart Growth has emerged as a response to a real problem and its antecedent costs. The proposed Growth Management Plan for Central Ontario has the potential to decrease and increase the region's vulnerability to climate change. The suggested modifications in this section provide the means to mitigate the increasing vulnerability by reducing the urban heat island and storm water runoff without requiring major changes to the plan or the Government's policy directions. The simplest modification to deal with both storm water runoff and warmer summers is to add an urban vegetation component to the plan. The benefits of vegetation in an urban environment have been widely recognized and include reducing the urban heat island and storm water runoff, but extend to increasing biodiversity and improving mental well being (Kaplan, 1995; McPherson, 1994; McPherson et al., 1989; Terjung and O'Rourk, 1981).

One of the most important vegetative features in the urban environment is a tree. Being the largest piece of vegetation, trees magnify most of the benefits associated with vegetation as well as providing shade for people, animals and buildings. Being the largest also requires the most space. This requirement is under threat in many urban areas in the Golden Horseshoe, due to zoning restrictions in some areas and building densities in other areas. Although we tend to expect to minimize tree cover in a commercial high-density area, in some communities, the zoning restrictions have reduced the space in low-residential areas by two-thirds and even moderate zoning restrictions have reduced the available space by 25-30 percent (Duffy, 1999: Vrecanak et al., 1989). Without any provisions for urban vegetation, we can reasonably expect that space for trees will be further reduced under a plan that will use a variety of incentives to encourage more compact development.

In addition to trees, parks are another important green space in urban environments. The demand at certain times of the day already taxes the existing supply in the GTA and exceeds it in the City of Toronto. For example, there are insufficient parks in downtown Toronto to support the enrolment in soccer leagues that is supported throughout the region. A recent survey of downtown residents in a University of Toronto married student residence highlighted the lack of recreational amenity space for families in the downtown core (Smirnakis, 2003). It does not appear that parkland will increase in downtown Toronto under a Smart Growth policy.

There are several ways the plan could be modified, without sacrificing the requisite densities, to incorporate vegetation. The plan already ties future expansion beyond the existing settlement boundaries to several criteria including the protection of natural heritage systems. The Greenbelt Taskforce Discussion Paper mentions the identification of existing and potential public parks and open spaces, and the task force is considering the protection of a network of public open spaces including municipal parks and forests. These could be strengthened to provide for parkland, but it is important not to restrict urban vegetation solely to parks, but incorporate it into all parts of the urban fabric to reap the full benefits. The City of Toronto's Wet Weather Flow Plan is also a model for incorporating storm water runoff reduction features into medium and higher density areas (Works and Emergency Services, 2003)

Incorporating spaces for full-grown, mature trees is difficult in high-density areas, but this has been done in other cities such as Portland, Oregon, USA. It requires recognition of the importance of trees; planning for trees; and designing roads and walkways to allow the requisite space. In some urban areas, this is no longer possible, but there are other options. Shrubs provide many of the same benefits as trees and require less space. Rooftops and walls provide another option. Although they are similar to desert environments and contribute to the urban heat island, this effect can be mitigated through covering these surfaces with vegetation.

Green roofs are a thriving industry in Germany and other European countries, often backed up by legislation that requires the conservation or restoration of vegetation in urban areas. Green roofs in particular have been shown to reduce the urban heat island and to reduce storm water runoff. Green roofs and walls reduce the urban heat island by utilizing incoming solar energy for evapotranspiration, thereby cooling rooftop temperatures from 60 degrees Celsius or more to as low as 25 degrees Celsius. Green roofs also provide additional shade and insulation to a building, which in combination with the evaporative cooling reduces the requirements for air conditioning, more so in smaller buildings than large, multi-story buildings. However, green walls can be designed to achieve significant reductions in summer electricity demand even on multi-storey buildings. Green roofs store water in the growth medium, but include a drainage layer to store excess water, thus providing means to store rainfall or at least delay its entry into the drainage system during a storm. They can be designed to minimize runoff with deeper drainage layers, increase depth of growing medium and broad, leafy plants that intercept most of the vegetation.

Green roofs can be designed to accommodate a variety of uses and building conditions and capacity for increased loading on the roof. For example, the residents of the aforementioned University of Toronto residence now have access to recreational green space on one of the roofs that is accessible from a Parent Drop-in Centre, a meeting room and the laundry room. It provides a safe and secure environment for children to play and ride tricycles. Green roofs can support a wide range of biodiversity or they can resemble other less-diverse landscapes, such as turf grass; they can support food production; and they can be designed to be used as parkland.

One element of the proposed growth management plan is the protection of employment lands in urban areas. Employment lands are often characterized by large, one-story buildings on large lots of land as the design is adaptable to changing use and access is often required for trucks. Protecting employment lands is a difficult task for municipalities and not a popular political issue. Yet, these are the very buildings that could benefit the most from, and are the most amenable to, green roofs, and in some areas they have enough space to support substantial tree growth. Thus the employment lands - which are difficult to defend given the increased demand for housing, their apparent negative environmental connotations and the fact that they often sit vacant for long periods of time - can become the environmental heart of an urban area by providing green space to cool the city; reducing the impact on the drainage grid perhaps using the roofs to recycle water; and providing an option for rooftop parkland.

There are other measures that can be used to cope with both increasing runoff and the urban heat island. The worst effects of runoff, flooding, could be dealt with reactively, using a series of low-cost barriers that can be wrapped around the lowest levels of buildings preventing some of the damage associated with high water levels. The polluting effects of combined sewer overflow can also be mitigated by building large storage tanks to hold the overflow until it can be treated, or separate sewage and drainage systems, both of which represent significant infrastructure investments. Inlet control devices can be installed over sewer grates. These act to delay the flow of runoff into the drainage system, turning the street into a storage tank, although the local residents have to adapt to what appears to be a small flood during each rain event, and the risk of local floods may be increased during severe storms. Even roof runoff can be contained by using roofs as storage reservoirs or using holding tanks within buildings.

The urban heat island can be reduced through the use of reflective or white surfaces, and various demand management strategies or technologies can be used to reduce the demand for electricity from the grid during peak demand times. However, urban vegetation provides a range of benefits, some of which cannot be easily replicated by other approaches. It is also the simplest and least-cost strategy to reduce the vulnerability to runoff and the urban heat island in Central Ontario while maintaining the benefits of Smart Growth. However, the other areas of climate change vulnerability, such as the uncertainty of future water supplies or the standards required for new infrastructure need to be addressed through other means.

Planning for urban expansion could also be conditioned on projected water supplies over the next 30 years. Although these future supplies cannot be predicted with certainty, the Growth Management Plan could be modified to include at least two climate scenarios in planning the expansion of any particular urban area in order to increase the certainty about future water supplies. The model for this is Bill 160, The Emergency Management Act, in Ontario that mandates that each municipality develop a plan for emergencies. Environment Canada currently provides climate information for municipalities to assess the risks of meteorological hazards on a website devoted to supporting this bill (Environment Canada, 2004). Environment Canada's Climate Impact Scenarios website could be used for the same purpose.

5. Conclusions

The Growth Management Plan for Central Ontario will increase and decrease vulnerability to climate change in different ways. At this point it is not clear which trend is stronger. However, a strategy to increase urban vegetation will confer many benefits that are currently inadequately addressed in the Growth Management and Greenbelt Taskforce Discussion Papers. An urban vegetation strategy will also reinforce those elements of the Growth Management Plan that reduce the region's vulnerability to climate change. Reducing energy consumption due to the urban heat island will increase the effectiveness of energy infrastructure that can take advantage of compact development and will reinforce the benefits of reducing traffic congestion.

Reducing the additional storm water runoff from increased roof area will reinforce the reductions of the potential regional runoff that would follow a business-as-usual development scenario.

The introduction of an urban vegetation strategy would complement the proposed Green Belt protection legislation and build on the specific proposal for protecting the municipal forests in the Green Belt Discussion paper. The Province of Ontario is currently reviewing the Planning Act, the Provincial Policy Statements and developing the Growth Management Strategy for the Greater Golden Horseshoe. These policy initiatives provide the vehicles for developing an urban vegetation strategy, and beyond. In addition, a policy that specified vegetation, including green roofs, could be used to increase the marketability of Growth Management Plan in Ontario, as demonstrated in several other case studies (Loder, 2004).

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chapter VII

Ecosystems and Biodiversity

21 paper

FOREST BIODIVERSITY:
ADAPTING TO A CHANGNING CLIMATE

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ABSTRACT. Atmospheric scientists, using global climate models, have developed scenarios of the future climate that far exceed the historical climate envelope and current forest management practices. Adaptation of forest biodiversity means taking into account a changing climate; improving our understanding of forest landscapes, ecosystems, species and genetics under climate change; adjusting the way we plan, plant, tend, protect and harvest our future forests; and conserving native forest biodiversity. Not all forests are alike, nor do they share the same multi-taxa, adaptive life-cycles, feedbacks and threats. Given the life cycle of most forest species, forest management systems will need to adjust their limits of knowledge and adaptive strategies radically to initiate, plan and enhance forest biodiversity in relative harmony with the future climate. Protected Areas (IUCN), Global Biosphere Reserves (UNESCO), Model Forests and Smithsonian Institution sites provide an effective community-based platform to monitor changes in forest species, ecosystems and biodiversity under changing climatic conditions.

Keywords: Forest biodiversity, forests, Smithsonian Institution, UNESCO, SI/MAB, Biosphere Reserves, adaptation, climate change, community-based monitoring

1. Introduction

Forest biodiversity is not single-species management but, instead, recognizes the functional ability or impairment of ecosystems to support many diverse species. Human population expansion, land-use conversions and atmospheric changes have dramatically altered ecosystems and species worldwide. For example, many northern latitude ecosystems are limited climatically and lack the species richness of more tropical climates. In particular, these countries can ill afford to lose even one species or ecosystem.

It was perhaps Sigmund Freud that provided some further insight into the scale and importance of emerging issues. Freud observed that "humanity has in the course of time had to endure from the hands of science two great outrages upon its naïve self love. The first when it realized that our earth was not the center of the universe but only a speck in a world system of magnitude barely conceivable and the second was when biological research robbed man of his particular privilege of having been specially created and relegated him to a descent from the animal world" (Gould, 1977). In hindcast, the degree of uncertainty, at the time, associated with each of these outrages might possibly be equated to the uncertainty of the climate change debate, today. But more importantly, what would be the consequences if climate change is, in fact, the "third outrage" on humanity?

The Intergovernmental Panel on Climate Change (Watson, 1996) concluded that "the balance of evidence… suggests a discernible human influence on global climate". The most recent IPCC assessment (2001) suggests "there is new and stronger evidence that most of the warming observed over the past 50 years is attributable to human activities". We know from past experiences that weather and climate have a powerful influence on biological and human environments and that today's forest biodiversity is the culmination of a long evolution within a climate envelope containing many natural fluctuations and extremes. The conclusion by the IPCC is alarming with the result that today's forests and their resident populations will be maladapted to future climate and its many variabilities and extremes. This projected magnitude of climate change, especially the anticipated rate of change because of human influences on the climate system, is beyond our current level of knowledge and adaptation mindset. This "outrage" imposed by humanity on the climate system will require a significant paradigm shift and new levels of knowledge for forest managers. However, knowing the anticipated future climate scenarios, continuing population demands, and emission increases, forest managers can begin an adaptation process to design the taxa targets to satisfy a multiplicity of needs, products and services.

Why should adaptation to climate change and variability be considered? Responses to global warming are considered mainly in terms of mitigation with the aim of reducing human generated greenhouse gas emissions. However, adaptation is also a main part of the response set. Pro-active adaptation actions, especially the many benefits, are needed for several reasons, principally because humaninduced climatic change appears unavoidable, regardless of the mitigation actions to slow the speed of global warming.

Characteristics of systems related to adaptation are identified in several literature streams, including disciplines in both the natural and socioeconomic sciences. These include concepts such as resilience, sensitivity, tolerance, thresholds, critical levels, susceptibility, vulnerability, adaptability, adaptive capacity, coping range, flexibility, size (individual or collective) and part of the forest ecosystem (e.g. human, plant, animal, water, soil, air). Several of these are described in Smithers and Smit (1997). Any new operative word will need to focus much more on enhancing the "resourcefulness" of the forest estate, especially through human management practices that build on the interlinkages among forest ecosystems, species and genetics and the changing atmosphere.

2. Challenges of Adaptation Science: understanding the process

Adaptation means taking into account a changing climate; improving our understanding of forest landscapes, ecosystems, species and genetics under climate change; adjusting the way we plan, plant, tend, protect and harvest our future forests; and conserving native forest biodiversity. A main challenge facing adaptation science is to improve our theoretical understanding and predictive capacity. The purpose of this is to guide adaptive forest management. Adaptive management serves to reduce vulnerabilities to, and enhance opportunities of, climate variability and change. Responses can be nonlinear and may not occur until a certain threshold has been reached as suggested by paleo-forest evidence where changes have been step-wise and abrupt. Forests serve as an excellent example of this latter case when the rates of change of the future climate far exceed the historical rates of forest migrations and disturbance losses from forest fires and other insects, diseases and where population and land-use changes are expected to significantly change, as well. For example, a 1 degree Celsius increase in mean global temperature will have significant impacts on forest ecosystems and species, especially where forest climates have little or no buffering capacity (MacIver, 1998). The anticipated change in global climate of 3 to 5 degree Celsius or more could be devastating, leading to significant maladaptations over the next rotation cycle of most tree species.

The process of adaptation to a changing climate occurs in a wide variety of ways and under many circumstances. The process depends on many factors, including who or what adapts, what they adapt to, how they adapt, what resources are used and how, and the effects of adaptation within and across forest ecosystems, species and genetic levels. These related themes are part of a model of an adaptation cycle (see Figure 1) that changes through time and space. This framework is designed to organize concepts regarding adaptation, to stimulate ideas, and to explore the linkages among parts of the adaptation cycle.

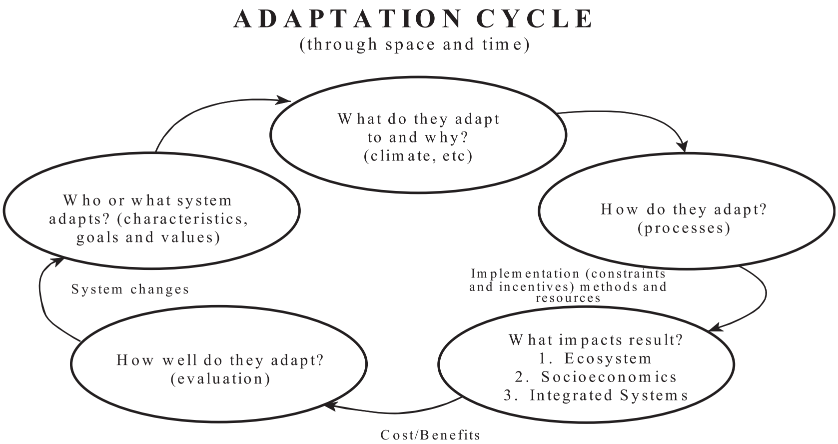

FIGURE 1

Adaptation cycle through space and time (Wheaton and MacIver, 1999)

The mainstreaming framework for the science of adaptation (see Figure 2) should address these questions with an overarching challenge to address: what is changing and why? Forest species have long rotation life cycles in the natural evolving world and species planted today are expected to thrive within the human induced climates of tomorrow. Hence, climate change adaptation should be a key part of today's decision making process, including the governance of the design and management of forests for the future. The design criteria for multi-taxa will be influenced by many factors, including lessons from past experiences, traditional forest knowledge in adaptation, adaptation technologies, risks, uncertainties, costs, benefits, social vulnerability and resilience, buffering capacities, impact assessments, data and information needs and knowledge of the forest climate.

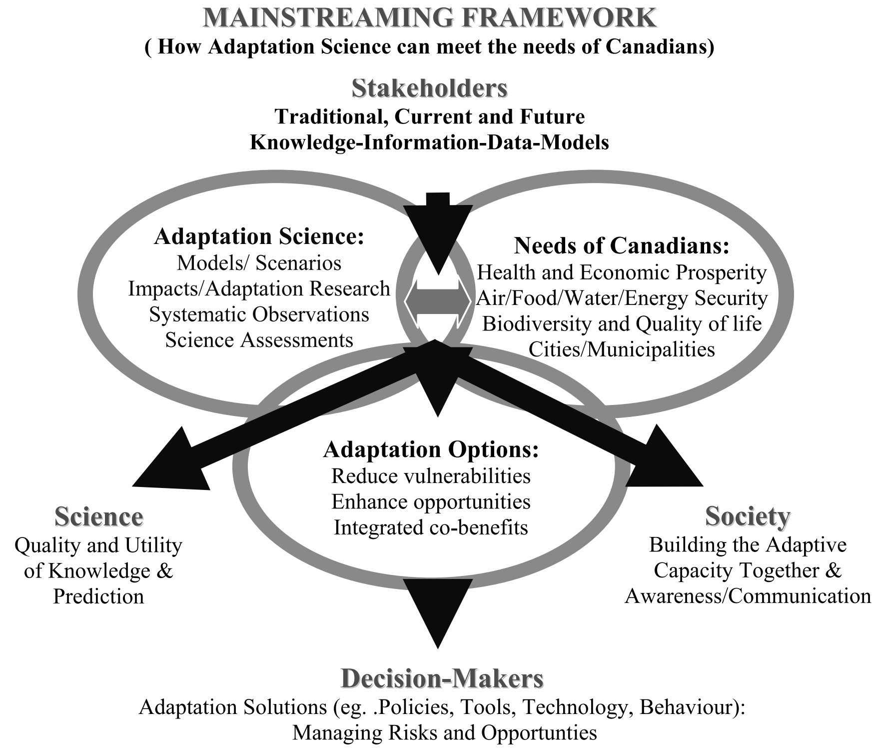

FIGURE 2

Adaptation Framework (Adapted from Wheaton and MacIver, 1999)

3. Challenges of Adaptive Management: reducing vulnerabilities through application of adaptation science

Adaptive management is the practice of adaptation science. There are many ways that adaptation processes can be managed. Figure 2 also depicts linkages of adaptation science with adaptive management and adaptation options.

When adaptive management first entered the vocabulary of forest management, it heralded a new way of thinking in which management policies were treated as experiments, learning from them and using them as a basis for changes and adjustments (Stankey, 2001). If we characterize current

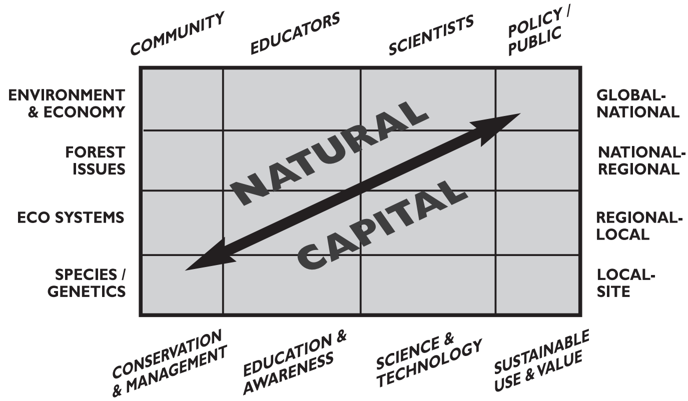

FIGURE 3

Natural Capital Framework

forest biodiversity management policies within the overarching theme of natural capital, then Figure 3 provides some insight into the multiplicity of goals, values and life services managed by many groups worldwide. Trees and forests are more than wood. In many communities they are the source of heat, food, shelter, and spiritual value. In others, they are the industrial forest, to others a habitat rich in biodiversity and to others a regulating influence on the atmosphere. The majority of forests worldwide continue to be natural and managed to varying degrees or not at all. But if we accept that humanity has created this third "outrage" on the world, then this graphical depiction quickly turns from a theme of viewing forests as natural capital to one of managed values for sustainability, by which all forests will be managed for a diversity of targets within the envelope of global climate change. This management of multi-taxa is the real challenge facing forest managers. Adaptive approaches offer hope for the successful management of natural-origin and planted forests for their multiplicity of values, but driven and defined at the local levels within a global climate change envelope.

4. Next Challenges: adaptation options

A preliminary framework to deal with adaptation options is presented in this paper and summarized in Figure 2. Adaptation options have been further subdivided into: reducing vulnerabilities; enhancing opportunities; and options assessments.

Our collective challenge, given the climate change scenarios, population increases, land-use changes and emissions, is a clear definition of our values, projected into the future and figuring out where we go from today. There is a need to reach agreement on a broad and descriptive vision of sustainable forests, woodlots and trees, shared by all. For example Figure 4, helps illustrate the many interlinkages that would allow for global and local target setting. In other words, a pro-active adaptation approach is needed to design future forests to survive and thrive in the future climate. Sounds simple, but the real challenge is taking the first step, tolerant of other competing values and yet managing tomorrow's forests and their many populations, now. For example, we know that forest migrations cannot keep pace with the expected rate of climate change. Forest ecosystems do not migrate en masse but species are resourceful in their continuing search for new development opportunities when the hospitality of the local landscape and environment are conducive for seed, pollen, habitat and growth processes. Without human intervention, it is expected that many forest reserves will become islands of declining habitat. Interconnecting corridors may help some forest populations but mass extinction of species is already underway. Humans have created this third great "outrage" and only humanity, not nature, can avoid expected maladaptations.

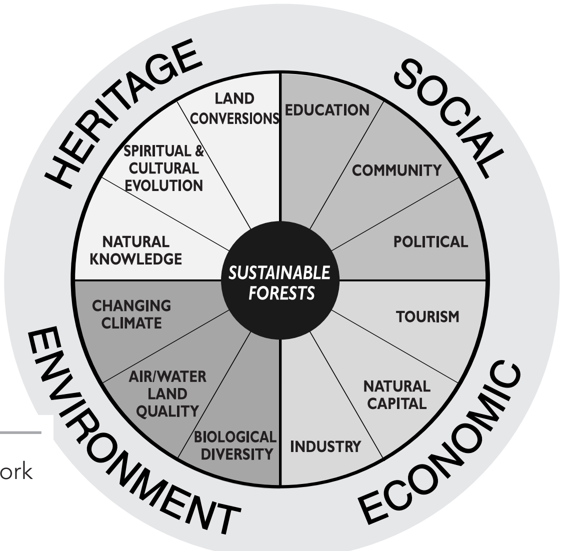

FIGURE 4

Sustainable Forests Framework

5. Global Adaptation Laboratories: Protected Areas, Biosphere Reserves and Smithsonian Biodiversity Sites

Knowing the future climate scenarios and increasing forest vulnerabilities, one of the key questions, simply stated, is how to we get from here to there? Convergence of major global efforts, such as Climate Change scenarios; Protected Areas (IUCN); the 400 World Biosphere Reserves (UNESCO), Smithsonian Biodiversity Sites and others (eg. ILTER sites and Model Forests) may provide some answers. The establishment of Smithsonian Forest Monitoring sites (SI/MAB), monitored by community groups using the same protocols and standards worldwide (Dallmeier, 1992), is particularly unique and noteworthy.

There are four general themes under which most forest biodiversity monitoring activities fall:

a. Monitoring based on species at risk
b. Monitoring based on population trends
c. Monitoring based on status and trends in habitat
d. Monitoring based on threats to biodiversity

It is important to remember that biodiversity monitoring is scale-dependent. For example, using these global protocols for forest biodiversity monitoring, there are now more than 80 SI/MAB sites in Canada, one-hectare in size, located across climate, chemical and ecological gradients (MacIver,1998). This also included the need for geo-spatial analysis based on Integrated Mapping Assessments (MacIver and Auld, 2000). In these ways, comparative biodiversity changes are assessed to better understand multi-taxa management approaches, especially in the managed versus the unmanaged forest. In addition, this includes the establishment of a climate change SI/MAB site within the urban heat island of Toronto, a city already experiencing equivalent climate change effects, to understand the performance of 23 forest species planted for today's and tomorrow's climate.

6. CONCLUSIONS

Tomorrow's forests and their many populations will need to be managed in a pro-active adaptive manner, given the anticipated threats of climate change. Lessons learned from past and current climate variabilities and extremes, future global climate scenarios and lessons derived from Protected Areas, Biospheres Reserves and Smithsonian Sites may help increase our collective understanding of adaptive forest biodiversity practices, especially human management options.

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22 paper

ADAPTING TO CLIMATE CHANGE IMPACTS ON HUMAN HEALTH

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ABSTRACT: This paper provides an examination of the potentially significant impacts of climate change on human health and well-being in Canada. Some key concerns include an increase in illness and premature deaths from temperature stress, air pollution, and increases in the emergence and persistence of infectious diseases. The effects of climate-related natural hazards and extreme events on both physical safety and mental health are another concern. Although there will likely be some benefits to climate change, such as a decrease in cold-weather mortality, negative impacts are expected to prevail. Adaptation will be necessary to reduce health-related vulnerabilities to climate change. Some adaptation initiatives include the development of vaccines for emerging diseases, public education programs aimed at reducing disease exposure and transmission, and improved disaster management plans. The implementation of early warning systems for extreme heat is another effective adaptation strategy. The paper concludes that successful adaptation to climate change will require coordinated efforts among different groups and the consideration of climate change in health care decision-making.

Keywords: climate change, adaptation, human health

1. Introduction

Good health, which requires physical, mental and social well-being, is a key determinant of quality of life. As a result, health and health services are extremely important to Canadians. The health care and social services sector employs more than 1.5 million Canadians, and over CAN$102 billion per year is spent on health services.(CIHI, 2002) This spending on health care accounts for about 9.3 percent of the total annual value of goods and services produced in Canada (Gross Domestic Product). This represents an average of approximately CAN$3,300 per person per year. At a very basic level, the relationship between health and climate in Canada is demonstrated by the strong seasonal variability in the incidence of infectious diseases (Li, 2000) and the persistent seasonal pattern in mortality (see Figure 1). The monthly number of deaths tends to reach a low in August, then rises to a peak in January and declines again during the spring and summer months. Many of the winter deaths result from pneumonia (Trudeau, 1997), suggesting that

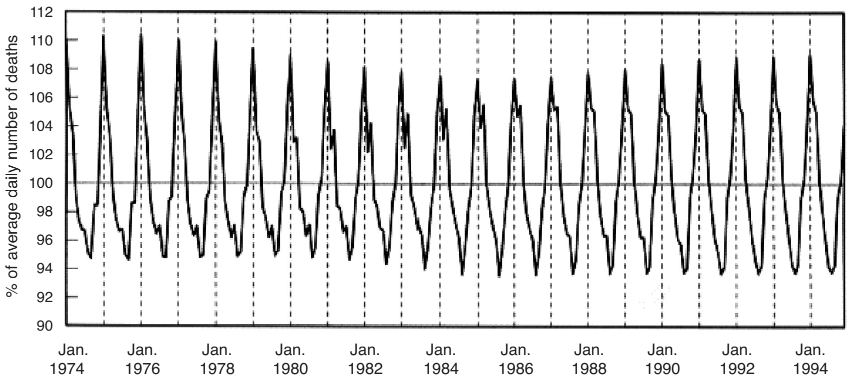

FIGURE 1

Seasonality of Deaths in Canada, 1974-1994. *Source: Statistics Canada, 1997.*

seasonal changes in weather and climatic conditions influence respiratory infections. Deaths from heart attacks and strokes likewise show strong seasonal fluctuations, with peaks in both summer and winter.

Another strong linkage between climate and human health is seen in the impacts of extreme climate events and weather disasters. Flooding, drought, severe storms and other climate-related natural hazards can damage health and social well-being by leading to an increased risk of injury, illness, stress-related disorders and death. In recent years, this has been dramatically demonstrated by the effects of the 1996 flood in the Saguenay region of Quebec (Brooks and Lawrence, 1998), the 1997 Red River flood in Manitoba (International Red River Basin Task Force, 2000), and the 1998 ice storm in eastern Ontario, southern Quebec and parts of the Maritime Provinces (Hartling et al., 1999; Slinger et al., 1999).

Trends in illnesses and deaths associated with air pollution, extreme weather events, allergies, respiratory diseases, and vector-, food- and water-borne diseases all illustrate that weather and climatic factors influence health and well-being. Therefore, there is concern that climate change of the magnitude projected for the present century by the Intergovernmental Panel on Climate Change (1.4–5.8°C increase in mean global temperature; reference 13) may have significant consequences for health and the health care sector in Canada.

Table 1 Possible health impacts from climate change and variability in Canada

HEALTH CONCERNS	EXAMPLES OF HEALTH VULNERABILITIES
Temperature-related morbidity and mortality	• Cold- and heat-related illnesses • Respiratory and cardiovascular illnesses • Increased occupational health risks
Health effects of extreme weather events	• Damaged public health infrastructure • Injuries and illnesses • Social and mental health stress due to disasters • Occupational health hazards • Population displacement
Health effects related to air pollution	• Changed exposure to outdoor and indoor air pollutants and allergens • Asthma and other respiratory diseases • Heart attacks, strokes and other cardiovascular diseases • Cancer
Health effects of water- and food-borne contamination	• Enteric diseases and poisoning caused by chemical and biological contaminants
Vector-borne and zoonotic diseases	• Changed patterns of diseases caused by bacteria, viruses and other pathogens carried by mosquitoes, ticks and other vectors
Health effects of exposure to ultraviolet rays	• Skin damage and skin cancer • Cataracts • Disturbed immune function
Population vulnerabilities in rural and urban communities	• Seniors • Children • Chronically ill people • Low-income and homeless people • Northern residents • Disabled people • People living off the land
Socio-economic impacts on community health and well-being	• Loss of income and productivity • Social disruption • Diminished quality of life • Increased costs to health care • Health effects of mitigation technologies • Lack of institutional capacity to deal with disasters

Indeed, results of climate modelling exercises, assessments of regional environmental and resource vulnerabilities, and climate abnormalities experienced across the country in recent years all indicate that changes in climate could make it more difficult to maintain our health and well-being in the future. The potential impacts of climate change are classified as either direct (e.g., changes in temperature-related morbidity and mortality) or indirect (e.g., shifts in vector- and rodent-borne diseases) (McMichael et al, 2001). Of particular concern are the effects on more vulnerable population groups, including the elderly, the infirm, the poor and children. Rural residents, who may have to travel farther for health care, and those relying directly on natural resources for their livelihood (e.g., some aboriginal communities), are also considered to be potentially more vulnerable. Overall, health effects will be a function of the nature of climatic changes, exposure to changes, and our ability to mitigate exposure. Although most of the literature focuses on the negative impacts of climate change on human health, certain benefits, such as decreases in illness and mortality related to extreme cold, are also expected (Duncan et al., 1997). Some of the key issues related to health and climate change in Canada are listed in Table 1.

This paper presents an overview of the major potential impacts of climate change on human health and well-being, and highlights some initiatives that have already been undertaken to better understand the impacts on Canadians and help provide information for the development of adaptation strategies.

2. Previous Canadian Studies on the Health Impacts of Climate Change

In their summary of research as part of the Canada Country Study, Duncan et al. (1997) identified a range of health-related climate change impacts, and discussed the role of potential adaptation strategies. Key concerns included the effects of climate change on heat- and cold-related mortality, a possible northward expansion of vector-borne diseases, an increase in food-borne diseases, changes in the amounts and quality of available water resources, and weaknesses in the public health infrastructure.

Particular attention was paid to the effects of high temperature combined with poor air quality in large southern Canadian cities. It was concluded that, in cities such as Toronto, Ottawa and Montréal, the degree of warming projected over the next few decades could lead to a significant increase in the number of deaths during severe heat waves, particularly among the elderly and the infirm.

The Canada Country Study also drew attention to potential increases in disease transmission and bacterial contamination due to climate change. For example, heavy rainfalls could increase outbreaks of infectious diseases such as cryptosporidiosis and giardiasis ('beaver fever'). Warmer temperatures would generally favour the survival of cholera bacteria, as well as the growth of certain algae that release toxins that can accumulate in fish or shellfish. A warmer environment resulting from climate change could also enhance the prevalence of food-borne diseases from enteric bacteria and viruses, favour the northward spread of mosquitoes and ticks capable of transmitting disease (e.g., dengue fever, yellow fever and malaria), and increase the number of disease-carrying rodents and their contact with humans.

Duncan et al. (1997) also discussed the need for both short- and long-term adaptations that would reduce the health impacts of climate change. Such adaptation measures include introducing weather-watch warning systems, assisting acclimatization to extreme heat, and improving public outreach and education. The need for increased research, including interdisciplinary studies, was also stressed.

3. The Health Effects of Climate Change and Climate Variability

Our health and well-being are strongly influenced by weather and extreme events. A changing climate would affect mortality and injury rates, illnesses and mental health. These impacts would result from changes in factors such as temperature extremes, air quality, water- and vector-borne diseases, and extreme weather events. The impacts would vary across the country, with different regions facing different priority issues.

3.1 Temperature Stress

Climate change is projected to cause milder winters and warmer summers. People will largely be able to adapt to gradual changes in average temperatures through normal acclimatization. However, higher air temperatures are also expected to increase the frequency and intensity of heat waves (McMichael et al, 2001). Heat waves can exceed the physiologic adaptive capacity of vulnerable groups, such as infants, the elderly and those with pre-existing health conditions. The impacts of heat waves tend to be greater in urban, rather than suburban or rural areas, likely owing to both the 'heat island' effect and higher levels of air pollution. Studies have suggested that an increase in the number of days of extreme heat (above 30°C) over this century, would result in greater heat-related mortality in some urban centres in southern Canada (Chiotti et al, 2002; Last and Chiotti, 2001). However, it should be noted that seasonal acclimatization and appropriate adaptation measures, such as access to air conditioning and necessary medical care, could reduce the number of deaths (Davis et al., 2002).

Research suggests that the timing and characteristics of heat waves may influence the degree of health impacts. For example, heat waves that occur earlier in the summer tend to result in more deaths than those that occur later in the season, as people have not yet acclimatized to warmer weather (Sheridan et al, 2002). In addition, current warming trends show that night-time minimum temperatures are increasing more rapidly than daytime maximum temperatures, and climate models suggest that this trend will continue (Dhakhwa and Campbell, 1998). This means that, during future heat waves, there would be less relief due to night-time cooling than there is at present, and this would further increase temperature stress (Epstein, 2000).

As well as affecting mortality rates, extreme high temperatures would also influence a range of heat-related illnesses. Direct impacts of extreme heat include heat fatigue, exhaustion, heat rash, cramps and edema, as well as heat stroke and sunstroke. Indirect impacts, such as pre-existing health conditions exacerbated by extreme heat, cover a wide range of circulatory, respiratory and nervous system problems (Thompson et al., 2001). Factors that increase the risk of heat-related illnesses include old age, medication use (especially anticholinergic and psychotropic medications), obesity, previous heat injury and skin disorders (Cooper, 1997). Heat-related illnesses place additional stress on health infrastructure and can cause significant economic costs. Studies suggest that, although heat-related health effects are reflected in hospital admissions, the relationship can be difficult to quantify because ambulance and hospital admission records are presently not designed to capture such data.

3.2 Air Pollution and Related Diseases

Air quality influences many respiratory ailments. Although the average concentrations of toxic air pollutants in Canada have generally been reduced to fairly low levels, relative to those experienced 50 years ago, the daily and seasonal rises in levels of air pollution are still closely followed by peaks in the number of people admitted to hospitals or dying of respiratory and circulatory diseases (Goldberg et al., 2001; Cakmak et al., 2002) Air pollution causes and exacerbates acute and chronic illnesses, such as lung disease, and results in increases in health care costs and premature deaths (Health Canada, 2001). Air quality is especially a concern in the most populous regions of Canada, including the Windsor to Québec corridor and the lower Fraser Valley of British Columbia, where summer air pollution levels often reach hazardous levels. Indeed, it is estimated that approximately two-thirds of Canadians live in regions that suffer from high smog levels in the summer (Maarouf and Chiotti, 2001). Children and the elderly are groups considered particularly susceptible to poor air quality.

Climate change could affect both average and peak air pollution levels (Chiotti et al, 2002). For example, background concentrations of ground-level ozone (a pollutant that irritates the lungs and makes breathing difficult) are expected to increase over mid-latitudes due, in part, to higher temperatures (McMichael et al, 2001), whereas intense smog episodes are projected to become more frequent during summer months as a result of climate change (Chiotti et al, 2002). Higher summer temperatures are also likely to increase energy consumption for cooling, thereby adding to pollution emissions (Maarouf and Chiotti, 2001).

Airborne particulates from natural sources, such as forest fires and wind erosion, also have the potential to increase as a result of climate change. During recent drought years, large forest fires have spread smoke across areas covering more than 200,000 square kilometres (Natural Resources Canada, 2003). In July 2002, smoke from large forest fires in Quebec caused New York to issue a statewide alert for people with respiratory and heart conditions to remain indoors. Particulates in forest fire smoke can irritate the respiratory tract when they are inhaled. Forest fires could increase in frequency and severity in some regions of Canada as a result of future climate change. An increase in drought could also lead to increased concentrations of dust in the air due to wind erosion of soils (Maarouf and Chiotti, 2001), particularly on the Canadian Prairies, where dust storms presently represent a significant natural hazard. Alkali dust emissions, resulting from wind erosion of dried salt lake beds, have caused nasal, throat, respiratory and eye problems for some rural residents on the southern Prairies and could become more common if climate change results in further drying of saline lakes in this region (Wolfe, 2001).

3.3 Waterborne Diseases

Heavier rainfall events and higher temperatures resulting from climate change may increase the occurrence of waterborne diseases, such as giardiasis and cryptosporidiosis. Although such diseases are generally not serious for most of the population, the very young, the elderly and those with compromised immune systems may be vulnerable. Heavy rainfall events and flooding can flush bacteria, sewage, fertilizers and other organic wastes into waterways and aquifers. If not properly treated, such events can lead to the direct contamination of drinking water supplies.

Recent examples of waterborne disease outbreaks related, at least in part, to climatic conditions include those caused by *E. coli* in Walkerton, Ontario (2000); *Cryptosporidium* in Collingwood, Ontario (1996); and Toxoplasma in the greater Victoria area, British Columbia (1995). In Walkerton, expert witnesses testified that the outbreak, which resulted in seven deaths and thousands of illnesses, could be partly attributed to an unusually heavy rainfall event, which followed a period of drought (Last and Chiotti, 2001). Such trends are receiving growing recognition; researchers have determined that more than 50 percent of waterborne disease outbreaks in the United States between 1948 and 1994 were preceded by extreme precipitation events (Curriero et al., 2001). A detailed discussion of the causes and history of infectious diseases associated with contaminated drinking water in Canada is provided by Krewski et al (2002).

Increases in temperature would also exacerbate water contamination, as higher temperatures encourage the growth and subsequent decay of algae, bacteria and other micro-organisms, causing odour and taste problems and, in extreme cases, even rendering the water toxic (Chevalier et al., 2002). In addition, higher water temperatures and storm water runoff, combined with greater use of beaches, have been associated with increases in infectious illnesses in people using recreational waters (City of Toronto, 2001)

3.4 Food-Borne Diseases

An increase in heavy rainfall events and higher temperatures may increase the occurrence of toxic algal outbreaks in marine environments (Weise et al., 2001). Toxic algal blooms can contaminate shellfish, which in turn pose a danger to human health through paralytic shellfish poisoning. Increased problems with contamination of both domestic and imported shellfish are possible. Food poisoning from contamination of other imported foods may also increase, as rising air temperatures allow microbes to multiply more quickly (Bentham and Langford, 1995).

3. 5 Vector- and Rodent-Borne Diseases

Vector-borne diseases are infections that are transmitted to humans and animals through bloodfeeding arthropods, such as mosquitoes, ticks and fleas. Insect- and tick-borne diseases, such as West Nile virus, Eastern and Western Equine Encephalitis (transmitted by mosquitoes), Lyme disease and Rocky Mountain Spotted Fever (transmitted by ticks),(Morshed, 1999; Morshed et al, 2000) already cause human health problems in some parts of Canada. Rodent-borne viruses, capable of causing illnesses and deaths in humans, are also present in much of southern Canada (Drebot et al., 2000). Hantaviruses, which can cause fatal infections (pulmonary syndrome), are of particular public health concern because the deer mice that carry hantaviruses tend to invade dwellings and are present across Canada as far north as the Yukon Territory and the Northwest Territories (Mills and Childs, 1998; Calisher et al., 1999). Rodents may also carry tick-borne diseases, such as Babesiosis (Jassoum et al., 2000).

There are concerns that future changes in climate could lead to conditions that are more favourable for the establishment and/or proliferation of vector and rodent-borne diseases (Chiotti et al., 2002). The impacts of climate change on these diseases are generally expected to result from the effects of changing temperature, rainfall and humidity on the vector species, although the development rates of the pathogens themselves may also be affected. For example, longer and warmer springs and summers resulting from climate change could increase mosquito reproduction and development, and also increase the tendency of mosquitoes to bite (Epstein, 2000). Mosquitoes would also benefit from warmer winters, as cold temperatures currently reduce mosquito populations by killing mosquito eggs, larvae and adults. Furthermore, increases in extreme weather events, especially those that trigger flooding, could increase breeding areas for mosquitoes by creating more shallow pools of stagnant water.

Observed trends in Lyme disease and West Nile virus illustrate how quickly new and emerging diseases can spread. For example, Lyme disease has extended its range significantly across the United States since the 1980s, and is now considered to be a major public health concern. Although the disease is still rare in Canada, warmer weather and the northward migration of animals and birds that carry infective ticks could further expand its range (Maarouf and Chiotti, 2001). The recent, extremely rapid spread of West Nile virus across the United States and Canada, although not due to climate change, is another example of how quickly and widely a newly introduced virus can expand its range. Conditions expected to result from climate change could further facilitate the spread of the virus northward.

Another potential future health concern in Canada is the re-emergence of malaria as a result of climate change, increased travel and immigration, and increased drug resistance (Martens, 1998a). Malaria-infected persons exposed to North American mosquitoes capable of transmitting the causative *Plasmodium* parasite can cause localized outbreaks of infections. In addition, new insect vectors, such as the 'tiger mosquito', which has spread across 25 states since its introduction to the US from Asia in 1987 (Moore and Mitchell, 1997), may extend their range to southern Canada if climate conditions become more favourable (Maarouf and Chiotti, 2001). Nevertheless, there remains considerable uncertainty regarding how climate change will affect vector lifecycle and disease incidence of malaria, especially in a North American context.

3.6 Allergens

Changes in temperature, precipitation and length of the growing season would all impact plant growth and pollen production, and ultimately human health by, for example, extending the allergy season (McMichael et al., 2001). Studies have also shown that elevated concentrations of atmospheric carbon dioxide can enhance the growth and pollen production of ragweed, a key allergy-inducing species (Ziska and Caulfield, 2000). Although not all species of allergen-producing plants will necessarily react in a positive manner to changed climate conditions, a more stormy climate may sweep more allergens into the air and lead to more frequent allergy outbreaks (Burch and Levitan, 2002). Stormy winds may also increase airborne concentrations of fungal spores, which have been shown to trigger asthma attacks.(Dales et al., 2003).

3.7 Ultraviolet (UV) Radiation

Exposure to ultraviolet (UV) radiation is expected to rise in future, leading to an increase in temporary skin damage (sunburn), eye damage (e.g., cataracts) and rates of skin cancer (Martens, 1998b; Walter et al., 1999). Increased UV exposure could result from a number of factors associated with climate change, including stratospheric ozone depletion due to increased concentrations of some greenhouse gases, and increased development of high-altitude clouds (Maarouf and Chiotti, 2001). Longer summer recreational seasons resulting from global warming may also contribute to increased population exposure to solar UV radiation.

3. 8 Effects on Human Behaviour

Climate also has an influence on mental health. This is particularly evident in the case of climate-related natural hazards, where property losses and displacement from residences can cause significant psychological stress, with long-lasting effects on anxiety levels and depression (Klaver et al., 2001). Social disruptions resulting from family and community dislocations due to extreme weather events pose a special stress for children and those of lower socio-economic status. Increased levels of anxiety and depression were seen among farmers experiencing crop failures (Klaver et al., 2001) due to drought and among victims of the 1997 Red River flood (International Red River Basin Task Force, 2000).

Temperature also appears to influence human behaviour. In the Montréal area, researchers found that the number crimes per day tended to increase with daily maximum temperature up to about 30°C (Ouimet and Blais, 2001). Another study found that higher summer temperatures are linked to increases in human aggression (Anderson, 2001). Linkages may also exist between extreme climate events, aggression and crime rates. For instance, increased aggression could result from crowding of disoriented and distressed people in temporary emergency shelters. A recent study examined how the ice storm of 1998 affected crime rates in three regions of Quebec.

4. Adaptation

Canadians escape many climate-related extremes by using a wide range of physical and social adaptation measures. Seasonal changes in our clothing and lifestyles, the design of our buildings and other structures, and behavioural, social and economic adaptations have allowed us to remain generally healthy and comfortable except under the most extreme weather and climate conditions. Nevertheless, the possibility that future climate changes will force Canadians to deal with conditions beyond the range of historical experience suggests that there will be new stresses on the health sector and that additional adaptation will be necessary.

To address population health risks resulting from climate change, a two-step process, in which the risks are managed in a systematic and comprehensive manner, has been recommended (Health Canada, 2000). First, there is a need to assess the vulnerabilities and adaptive capacities of different regions, communities and population groups. The next step would involve identification and selection of the most appropriate response strategies. The linkage between climate change mitigation and adaptation actions is particularly strong in the health sector because of the health benefits derived from reducing greenhouse gas emissions. Assessments must take into account not only the possible impacts of climate change on the health sector, but also the capacity to adapt to those impacts. This process is well suited to being examined as part of an integrated risk-management framework.
Work has also already started on developing vaccines against several viruses and protozoa responsible for emerging infectious diseases prevalent in the tropics, including malaria and West Nile virus (Marshall, 2000; Taubes, 2000). These new vaccines may help to limit the future spread of emerging viral diseases. Monitoring for emerging diseases, and public education programs that provide information on reducing the risk of exposure and transmission, will also serve to limit the threat of infectious diseases. For example, satellite measurements could be used to determine linkages between environmental conditions and the spread of some pathogen vectors (Estrada-Pena, 1998).

As noted previously, health impacts related to an increased frequency of extreme climate events and climate-related natural disasters are a key area of concern. Although many Canadian municipalities have emergency management plans in place, their emergency management capacity tends to vary widely. Communities prone to weather-related hazards, such as avalanches, floods, heat or cold waves, or storm surges, should generally be better prepared to cope with increased frequencies of such extreme events than communities that have rarely experienced them, although other factors are also important. This is exemplified by contrasting emergency response to the 1997 Red River flood in Manitoba, where disaster plans proved effective, with the 1998 ice storm in eastern Ontario and Quebec, where emergency power supplies, food distribution systems and emergency shelter provision were insufficient to deal with the crisis (Last and Chiotti, 2001). Measures have since been taken to strengthen emergency preparedness and response capacity in the region affected by the ice storm.

In addition to emergency management, another key component of responding to extreme climate events is the implementation of early warning systems (McMichael et al., 2001). Such a strategy has been successfully introduced in Toronto to help reduce the health impacts of extreme heat and cold. Other important adaptive measures to reduce the health risks of climate change include land use regulations, such as limiting floodplain development, and upgrading water and wastewater treatment facilities.

Several Canadian cities are promoting longer-term measures aimed at reducing the heat-island effect. Summer temperatures in urban areas tend to reach higher extremes than surrounding rural areas, in part due to the prevalence of infrastructure and surfaces, which act to absorb, rather than reflect, incoming solar radiation. In a Toronto-based study, researchers recommended promotion of cost effective measures, such as the large-scale use of light-coloured, reflective 'cool' surfaces for roofs and pavements, and the strategic placement of vegetation to provide shade (Basrur et al., 2001). These measures are being promoted as 'win-win' adaptation options, as they also serve to reduce energy usage.

Other researchers, however, note that adaptation measures may themselves entail some health and safety risks. For example, green spaces harbour animals, birds and biting insects or ticks, which may serve as reservoirs for infectious diseases such as Lyme disease (Daniels et al., 1997) and the West Nile virus. Therefore, careful planning and testing of proposed adaptation measures, as well as health surveillance after the introduction of adaptation measures, may be needed.

4.1 Facilitating Adaptation

A study of the health infrastructure in the Toronto-Niagara region revealed several barriers to effective adaptation to climate variability and change (Chiotti et al., 2002). These barriers stem from knowledge gaps, insufficient organization and coordination, and inadequate understanding and communication of climate change and health issues within the health community. If adaptation measures are to be successful, these barriers must be overcome.

Successful adaptation will also depend on Canadians becoming more aware of, and actively engaged in, preparing for the potential health impacts of climate change. Several nongovernmental organizations have begun to draw the attention of their members and the public to the causes and effects of climate change, and to the need for both mitigation and adaptation measures. Among these are the Canadian Public Health Association and the Canadian Institute of Child Health, which published its assessment of the implications of climate change for the health of Canadian children.

Some key recommendations stemming from these initiatives include:

- increasing the capacity of the health sector to manage the risk to human health and well-being from climate change, particularly for the most vulnerable population groups, including children, the elderly, and disabled persons; and
- managing population health risks in a systematic and comprehensive manner, so that climate change is integrated into existing frameworks, rather than being addressed as a separate issue.

5. Conclusion

Climate change has the potential to significantly affect human health and well-being in Canada. Some key concerns include an increase in illness and premature deaths from temperature stress, air pollution, and increases in the emergence and persistence of infectious diseases. The effects of climate-related natural hazards and extreme events on both physical safety and mental health are another concern. Communities in northern Canada will face additional issues resulting from the impacts of climate change on ecosystems. Although there will likely be some benefits, such as a decrease in cold-weather mortality, negative impacts are expected to prevail. The impacts will be greatest on the more vulnerable population groups, such as the elderly, children, the infirm and the poor.

Adaptation will be necessary to reduce health-related vulnerabilities to climate change. Some adaptation initiatives include the development of vaccines for emerging diseases, public education programs aimed at reducing disease exposure and transmission, and improved disaster management plans. The implementation of early warning systems for extreme heat is another effective adaptation strategy. Successful adaptation will require coordinated efforts among different groups and the consideration of climate change in health care decision making.

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23 paper

CLIMATE CHANGE AND COASTAL ZONE MANAGEMENT PROCESSES, THE GREAT LAKES, NORTH AMERICA

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ABSTRACT: The Great Lakes are the largest bodies of fresh water in the world. The majority of Canadians live within the Great Lakes drainage basins and many of our larger cities and industries are located along the shores of these lakes. The coastal zone is sensitive to climate change and all the global climate models indicate a lowering of lake levels, an increase in air and water temperatures, a change in the snow and rainfall and an increase in the severity and frequency of storm events. This will significantly affect coastal habitats and communities. Many stressors already exist on coastal ecosystems including changes in land use, pollution, the presence of non-native species such as carp (Cyprinus carpio), zebra mussels (Dressena polymorpha), mute swans (Cygnus olor) and purple loosestrife (Lythrum salicaria). Examples of recent efforts to restore degraded habitats are described in places such as Hamilton Harbour, the Toronto Waterfront and the Bay of Quinte. Major adaptation options to climate change including changes to fisheries, modification to marinas, harbours and canals, changes in power output in hydroelectric dams, changes in property boundaries and access to water are a stress on coastal wetlands that serve as habitat for a wide variety of fish and wildlife. Adaptation to a changing climate will affect the majority of Canadians. The involvement of local municipalities, conservation authorities, industry and farmers is essential in planning for a future sustainable environment in a changing environment.

Keywords: Great Lakes, climate change, coastal zone management, water

1. Introduction

The Great Lakes (Ontario, Erie, Huron, Michigan and Superior) cover an area of 244,160 square kilometres, have a total shoreline length of 17,000 kilometres and a volume of 22,684 cubic kilometres (see Figure 1) (Environment Canada, 1991). They are connected to the Atlantic Ocean by the St. Lawrence River. Dams control the water level on Lake Ontario at Cornwall on the St. Lawrence River and on Lake Superior at Sault Ste Marie. Hydroelectric power is generated at Niagara Falls and Cornwall for both Canada and the United States. The water levels on the lakes fluctuate by approximately 70 centimetres annually, though the difference between extreme high and extreme low water levels recorded during the past 150 years are as much as 200 centimetres. The majority of the Canadian population lives in the drainage basin of the Great Lakes with the majority clustered in several large and many small communities in the coastal areas. Major cities in Canada on the lakes include Toronto, Hamilton, Kingston, Windsor, Sarnia, Sault Ste Marie and Thunder Bay. The Great Lakes played a vital role in opening up the interior of North America to human settlement, industry and trade and they currently play a major role in the Canadian economy.

During the nineteenth and twentieth centuries, when the majority of industrialization and agricultural settlement occurred in the Great Lakes basin, land uses changed dramatically. The extensive forests around the southern lakes were cleared for farming; ports and harbours were established in many river mouths, and numerous wetlands along the shoreline were dyked and drained for farming. Dams were placed across most rivers to drive early saw and grist mills, for regulating water levels, and for providing hydro-electric power. Major commercial fisheries were developed on each of the lakes. During this period, many animals and plants were introduced into the Great Lakes ecosystems either on purpose or accidentally so that the ecosystems have changed radically since the first settlers appeared in the late eighteenth century.

FIGURE 1

Great Lakes Basin, North America

These communities, farms and industries have discharged many pollutants to the Great Lakes with the result that many natural biological communities have been severely degraded and altered. The International Joint Commission (IJC) of Canada and the United States has regulated water taking and water level regulation from the Great Lakes since 1909. In 1986, under the Great Lakes Water Quality Agreement, the IJC determined that 43 coastal sites were sufficiently polluted and degraded that they were designated as Areas of Concern (AoCs). Remedial Actions Plans (RAPs) were developed in each affected community and Technical and Public Advisory Committees identified the problems and developed ways in which the areas could be restored. This paper will deal with three Areas of Concern on Lake Ontario (Hamilton, Toronto and Bay of Quinte) to provide examples of management options that have been used in the past and may be used in adapting in the future.

2. The Present Great Lakes Environment

2.1 Climate

The present climate of the Great Lakes is characterized by frequent collisions of continental polar air masses with tropical air masses from the south (Allan et al., 1994). The Great Lakes themselves influence the otherwise continental climate in a variety of ways. Like most large bodies of water, the Great Lakes have a moderating effect on the climate of their surrounding areas, resulting in slightly cooler summers and warmer winters than adjacent inland areas. In addition to moderating temperature extremes, the lakes contribute to increased humidity and fog, increased severity of storms, increased cloud cover, and increased wind speeds (Smith and Lavender, 1998). The shape of the Great Lakes and prevailing winds also modify the distribution and amount of snowfall significantly. In the winter, moisture from the lakes is carried across the lakes by the relatively colder westerly and north-westerly winds and deposited downwind of the lakes as “lake effect snow”. The lee side of the Great Lakes therefore have areas referred to as “snowbelts” since they receive a large amount of snow each winter. Areas such as Trenton and Kingston at the easterly end of Lake Ontario receive more snow that Hamilton and Toronto at the westerly end.

2.1.1. Air Temperature

The climate of the southern Great Lakes is milder than the northern, and on Lake Ontario the western end is warmer than the eastern (see Table 1). This

Table 1 Temperature Differences on Lake Ontario (MSC Climate Normals 1971-2000)

LOCATION (CITY)	MEAN JANUARY TEMPERATURE (°C)	MEAN JULY TEMPERATURE (°C)	MEAN ANNUAL TEMPERATURE (°C)
Niagara-on-the-Lake	-4.2	22.2	9.0
Hamilton	-5.0	22.0	8.5
Toronto	-4.5	20.7	8.2
Trenton	-7.5	20.5	7.0
Kingston	-7.1	21.4	7.6

is reflected in the plant growing zones[1] which around Lake Ontario ranges from a Zone 7 in the western end around Niagara-on-the-Lake through Zone 6 around Toronto to Zone 5 in the Kingston area.

2.1.2 *Precipitation*

The precipitation in the Great Lakes basin ranges from about 550mm to 900 mm per year. Rainfall tends to be heavier at the eastern parts of the lakes (see Table 2). The high level for Niagara Falls is due to the effect of snowfall generated from Lake Erie to the west. There is considerable variability in the annual precipitation at any one location as well as considerable variation in precipitation around each of the Great Lakes.

Table 2 Precipitation at Five Sites on Lake Ontario (MSC Climate Normals 1971-2000)

LOCATION (CITY)	TOTAL RAIN (MM)	TOTAL SNOW (MM)	TOTAL PRECIPITATION (MM)
Niagara Falls	795	148	944
Hamilton	768	126	892
Toronto	705	112	813
Trenton	759	169	893
Kingston	780	179	960

2.1.3 *Water Levels*

Water levels in the Great Lakes fluctuate seasonally as well as annually. Because Lake Ontario has its lake levels regulated by control structures at Cornwall, the historical high and low levels have now been eliminated and this has major repercussions on the ecology of the coastal areas.

1 *Plant growing zones, also known as plant hardiness zones, advise on which plants will grow in what areas based on the region's temperatures.*

2.1.4 *Water Temperature*

The surface water temperature in Lake Ontario ranges from freezing to about 20°C in shallow areas. Increased air temperatures will influence the temperature of surface waters of the Great Lakes as well as the depth and gradient of the thermocline. This will affect the time of Spring and Fall overturns (mixing of lake waters) and therefore affect the oxygen concentration in waters of the hypolimnion. Oveall, this may have an effect on the distribution of fish, particularly the centrarchids that are likely to be able to increase their range northwards to the detriment of cold-water salmonids.

It is expected that the ice cover on the Great Lakes will slowly decrease with climate change. The amount and timing of freezing varies significantly, but it is expected that the southern Great Lakes, particularly Lake Erie will be most affected. However, many communities on Lake Huron, particularly those on the eastern and northern shoreline will be affected in that the certainty of a solid freeze-up will change and winter access over ice will become potentially hazardous.

2.2 Land Use

The land use of the majority of Lake Ontario's coast is primarily agricultural and urban. The western part of the basin with the warmer and longer growing season is used for fruit growing (grapes, apples, peaches, cherries) while the eastern end of the lake supports mixed agriculture with dairy, corn and other cereals. The Greater Toronto Area (GTA) is the largest population centre in Canada and is home to approximately 4.5 million people with another million or so living in the Golden Horseshoe which extends from Niagara Falls to Oshawa. Various major industries are clustered around the lake from the major heavy industry and steel making city of Hamilton, to the automobile manufacturing cities of St. Catherines, Oakville, Toronto and Oshawa. Major generating coal, gas and nuclear generating stations occur on the shores, and the port of Hamilton serves as an important gateway for a variety of goods.

The rapid expansion of urban and industrial areas during the past hundred years has had a profound effect on water quality and this is reflected in the uptake of contaminants in fish that are still monitored annually with advisories being placed as to safe limits for human consumption. Likewise, beach closures as a result of fecal coliform contamination still occur and major efforts have been made to improve water treatment in the urban areas. The majority of forests bordering Lake Ontario were cleared in the nineteenth century, but recent efforts by many conservation authorities to revegetate riparian buffers along rivers and streams have had a major improvement on reducing flood events and sediments discharged to the lake.

3. Future Climate and Land-use around Lake Ontario

3.1 Projected Climate

In the last twelve thousand years since the last glacial period, the climatic landscape in the southern parts of Ontario has changed dramatically with the glaciers receding and slow change from tundra plant communities, to boreal forests, to deciduous forests. However, during this period there were no constraints to the movements of animals and plants, and the changes in climate were relatively slow. Now, the climatic changes are relatively rapid and only fragments of natural ecosystems remain. In the coastal zone, the majority of wetlands have been drained and there are very few coastal forest patches left in the south. This means that for those organisms with poor dispersal powers, there is little chance that they will be able to move to new locations if they cannot adapt to the changing climate. It is probable that many species will adapt, particularly the generalists, but to protect biodiversity it is necessary to provide corridors for dispersal and ensure that there are enough natural habitats to allow dispersal between patches.

3.1.1 Global Climate Change Models

Numerous reports have identified some of the projected effects of climate change on the Great Lakes clearly (Argyilan and Forman, 2003; Kling et al., 2003; Mortsch et al., 2003; Nicholls, 1999). A variety of global climate models have been developed and while they have different projections depending on the input variables, they all tend to show similar trends. For example, it is projected that air and water temperatures (see Table 3) will increase, rainfall will increase and water levels will decrease.

Table 3 Projected Great Lakes Surface Water Temperatures (modified after Mortsch 1999)

LAKE	CHANGE IN MEAN ANNUAL SURFACE WATER TEMPERATURES (°C)			
	CCCMA-II	GFDL	GISS	CCCMA –CGCMI (2050)
Superior	+5.1	+7.4	+5.6	+2.9
Huron	+5.0	+6.0	+4.7	+2.6
Erie	+4.9	+5.0	+4.4	+2.2
Ontario	+5.4	+5.9	+4.9	+2.9

3.1.2 Increased Air Temperature

The primary climatic change is expected to be an increase in air temperature. This is projected to increase winter temperatures more than summer temperatures, and increase nighttime temperatures more than daytime temperatures. Because biological productivity is directly related to temperature, it is expected that productivity for terrestrial ecosystems will increase, providing that moisture levels are adequate,.

3.1.3 Increased Water Temperatures

Increased air temperatures will cause increased water temperatures (from approximately 2 to 6°C) which will have a number of impacts on aquatic ecosystems. It is expected that cold water fish will retreat to the northern lakes while there will be an increase in warm water species in the southern lakes. It is also expected that the warmer southern lakes will be susceptible to range expansions and colonization by non-native species. Shallow areas may be more susceptible to oxygen depletion and the formation of "dead zones", thereby decreasing productivity. It is also expected that blue-green algae will be more common and lead to water tainting problems. There are not many management options available to limit the impacts of increased water temperatures on aquatic ecosystems. However, the options for purifying water are available and will add to infrastructure costs in the coastal zone.

The increase in winter temperatures will lead to a decrease in ice cover. This combined with an increase in the expected frequency and severity of storms will leave coastal areas more vulnerable to the effects of erosion and flooding. Management options exist that can reduce the vulnerability of some coastal areas to storms. Another impact of increased winter storms is that the near shore areas may have deeper and more frequent disturbances, which could re-suspend toxins buried in surface sediments.

3.1.4 Increased Precipitation

Most of the climate models forecast an increase in precipitation. More of this will fall as rain rather than as snow. There may well be an increase in the number of ice storms in parts of the Great Lakes. It is expected that precipitation will be greater in the fall and winter months and generally less in the summer, leading to an increased frequency of drought conditions during the late summer months. This may well impact wetlands and other natural habitats as well as farming activities.

3.1.5 Lower Water Levels

While precipitation is expected to increase, the combined increase in evaporation and evapotranspiration caused by higher temperatures is expected to lead to an overall reduction in Great Lakes water levels. Water management structures have been built to deal with the variability of water levels in the present climate, though whether they are sufficient to deal adequately with future climates is not known. Levees have been built to withstand flood events and dams and reservoirs have also been built to manage water flow in streams and rivers (Deloe and Kreutzwiser, 2000). One adaptive response that has been proposed to deal with projected lower lake levels is to regulate water levels with further control structures and diversions.

Changing water levels are expected to be one of the most significant impacts on the coastal environment. Mean annual water levels are expected to decline to below historic levels because of increased evaporation and evapotranspiration in the region. Based on the results of the Canadian Global Climate Model CGCMI 2050 scenario, the mean Great Lakes water levels are expected to drop from 0.3 to 1.0 metre (Mortsch, 1999).

4. Examples of Management Options in the Great Lakes Coastal Zone

Some methods of management on Lake Ontario may also be used in managing the impacts of climate change. Several authors (Mortsch and Mills, 1996; DeLoe and Kreutzwiser, 2000) agree that various factors should be considered when considering possible climate change management options. They are:

- **Economic feasibility and efficiency**: Is this option affordable? Who will pay? Who will benefit? Will there be an economic risk? Will resources be allocated and used efficiently?
- **Technical feasibility:** Is the technology available or can it be developed? How much time will it take to develop and or implement it?
- **Social acceptability:** Does society want it? Who will benefit from it? Who will be affected? Does it reflect society's needs, values and goals?
- **Legal acceptability:** Are there any laws, regulations or policies that would prevent implementation?
- **Political realism and acceptability:** Do the politicians and the electorate support the measure? Can existing institutions implement it?

- **Environmental sustainability:** Will the environment be impaired to the detriment of future generations? Will the complexity and resilience of ecosystems be maintained?
- **Flexibility:** Does this option allow for future corrective actions? Does a wide range of alternative actions remain available?

It is important to note that many constraints exist to the implementation and use of successful management options. If an option is economically and technically feasible, it may still be constrained by perception or attitudes. It is also important to note that the issue of scale is relevant to adoption of management options.

4.1 Fisheries & Adaptation

The fish community of Lake Ontario has changed dramatically since European settlement of the area in the late 16th Century. Early settlers exploited large populations of sturgeon, salmon, lake trout and herring. The commercial fisheries rapidly expanded to utilize this seemingly limitless resource. But decade-by-decade, the fish community and many species that were once so prolific such as Lake Trout, Herring and Whitefish became rare (Regier et al., 1988). Together with the loss of the larger predatory fish came introductions of other fish. Pacific Salmon (Coho and Chinook) were introduced, alewives came in with the construction of navigation channels. Wetlands were drained and dyked reducing the available nursery habitats. Pollution had major impacts on algal growth and oxygen levels particularly in the shallow protected areas such as the Bay of Quinte. It is expected that cold water species will become restricted to the Upper Great Lakes and centrarchids will displace salmonids in Lake Ontario. However, fisherman will adapt to the available fish populations with adjustments in nets and equipment, timing of fishing seasons, and species caught. There has been a major increase in the recreational fishery on Lake Ontario which was worth at least $200 million in 1989 and is increasing annually.

Climate change is likely to exacerbate the already growing problem of invasive species in the Great Lakes region. Warmer water temperatures will likely allow the expansion of warm water species to the north. Invasive species which are often brought into the Great Lakes from the Ponto Caspian region in ship's ballast water, will find it easier to establish themselves in a warming climate. The recent expansion of the Round Goby in Ontario with its relationship to type e botulism and the death of many waterbirds has been reported in recent years.

Carp were introduced in the nineteenth century into millponds in Ontario and for many decades they were only a minor component of the southern Great Lakes fish community (Scott and Crossman 1973). In the past century they have multiplied extensively, particularly in the southern Great Lakes and have become a particular problem, reducing biodiversity and destroying many sensitive wetland areas. As part of the Hamilton Harbour Remedial Action Plan, and in an effort to restore the once prolific and diverse wetland area called Cootes Paradise, a fishway was constructed in the Desjardines Canal between Cootes Paradise and Hamilton Harbour in the spring of 1995. The fishway prevents carp from entering the marsh while providing both upstream and downstream access for other species of fish such as pike, walleye and bass. All large fish are caught in a series of traps that are lifted twice daily during the spring and fall migration movements and carp are returned to the harbour while the other species are allowed to move into the wetland and into the spawning streams. The carp control has been very successful with reduced numbers in the wetland and there has been a major improvement of biodiversity in this large wetland. The water level of Lake Superior is controlled at Sault Ste Marie primarily for navigation purposes.

4.2 Water Quality Improvement

Numerous pollutants have entered the Great Lakes during the past two hundred years. Some of these are relatively short-lived within the ecosystem and others are long lived. During the mid-1960s, major fish kills occurred in Lake Erie and it was found that the lake was dying due to eutrophication caused by algal growth growing on an abundance of nutrients, particularly phosphorus. In 1972, Canada and the United States signed the Great Lakes Water Quality Agreement to begin a binational Great Lakes cleanup that emphasized the reduction of phosphorus entering the lakes.

The high levels of phosphates in the lakes were the result of phosphates in washing detergents and from agricultural fertilizers. Water treatment plants now remove phosphates from urban wastewater and there have been substantial improvements to water quality. However, further reductions are necessary from non-point sources such as the agricultural use of fertilizers, particularly in southern Ontario. Major advances have been made in many watersheds and the enclosed Bay of Quinte has seen substantial improvements in water quality from improvements to agricultural practices and the protection of water sources.

However, further north in the Georgian Bay area of Lake Huron, there are an increasing number of cottagers living along the shores of the many islands and channels. Because of inadequate sewage treatment, the nature of the coastal region, low water levels and warmer summers, there are now major impacts to the costal zone. Major blue-green algal blooms have occurred in recent years, and the once pristine coastal inlets are polluted. While there may be solutions to improving the technology of wastewater treatment, low water levels have meant water access to many houses is now difficult for some summer months and solutions are being sought. These various issues must be addressed now, as with the projected changes in the coastal zone due to climate change, land use should be changed to sustainable levels. The tax base of some municipalities is declining as property values decrease and the options for adaptation are limited. The tasks are enormous and so extensive in some areas that governments cannot reasonably undertake them. Therefore there is a desperate need for public communication and a restriction on the numbers of people living in the coastal zone.

4.3 Wetlands and Water Quality Improvement

Natural wetlands perform many functions. Besides providing habitat for a great many species, they also provide valuable water cleansing functions as well as helping provide a steady base flow to many streams and rivers (Hammer and Bastian 1989). The loss of wetlands has reduced the capability of watersheds to perform many ecosystem functions that are critical to the larger lake ecosystem. In some cases it is still possible to protect watersheds and wetlands and ensure that watercourses are clean by providing adequate riparian buffers, and if they are degraded, revegetating them. In many urbanised areas, this is no longer possible and end of pipe solutions must be used. In the Toronto Area of Concern, an end of pipe system developed by Karl Dunkers was built to improve water quality. It consists of a series of cells in which water from the combined water discharge flows is recycled, allowing contaminants and sediments to settle out before water is discharged to Lake Ontario.

Many stakeholder groups have spent considerable hours and efforts in reclaiming abandoned sites and improving habitats around the Great Lakes. There have been major efforts to restore habitats for fish, amphibians, reptiles, birds and mammals. Pollution reduction and habitat creation and protection have meant that a number of species such as Otters and Bald Eagles are returning to Lake Ontario. In Hamilton Harbour, for example, the shoreline has been recreated to provide islands for nesting colonial waterbirds such as Caspian and Common Terns; beaches, pools and wetlands created for amphibians and turtles to breed; and off shore reefs constructed for fish nursery habitat. The projects were undertaken in a series of stages with input from many stakeholder groups and government agencies. Final plans were completed and construction undertaken in the mid 1990s. The colonial waterbirds, for example, have largely moved from the heavily contaminated areas of the harbour to new island habitats.

5. Policy and Public Involvement in a Changing Environment

The public is generally very aware of the environment and some 85 percent of Canadians participate regularly in nature-related activities such as hiking, bird-watching and fishing. The majority of Canadians are concerned about the environment and 98 percent view nature in all its variety as being essential to human survival (Boyd 2003). Many volunteer groups have become involved in restoring shoreline habitats around the Great Lakes. This can take many forms of activity. Cleaning up garbage from natural areas is an activity that is done on a regular basis by many groups while restoring habitats through planting trees, shrubs and wild flowers is another. Some groups are involved in stream restoration, stabilizing banks with shrubs and root balls while others are involved in removing non-native vegetation such as Purple Loosestrife or Garlic Mustard. Many local newsletters and guided walks serve to transmit information from knowledgeable people to those interested, and help bring about a more informed public.

However, many environmental issues are relatively low on the government's agenda. The laws protecting the environment and the coastal zone were introduced many years ago, long before climate change became an issue. There are many factors that assume the environment is relatively static, that shorelines are not moving and that the climate we know today is the one that will occur in the future. However, many factors such as changing shorelines, or changing the frequency of major rainfall events, are likely to have impacts on properties, on infrastructure and on ecosystems around the Great Lakes.

It will be necessary to harmonize the many laws and regulations to ensure that truly sustainable environments are protected for the long term. This should be measured in hundreds of years rather than the four or five years that most elected governments are in office.

The laws and regulations in Canada are divided between several layers of government; the federal, provincial, regional and municipal levels and many responsibilities overlap. The federal government has provided funding for many restoration efforts in Areas of Concern, and in some cases, the provincial government has been involved as a partner. The Conservation Authorities have played a relatively active role in undertaking restoration initiatives at the local level and provide the expertise not available to many municipalities. However, funding at the local level is very limited because of their revenue source that is primarily dependant on property taxes. A major problem with the current situation is that the federal and provincial governments develop large scale plans regarding the protection of the natural environment but in most cases do not provide funding for the area municipalities and Conservation Authorities that are likely to undertake the work. This is a major disconnect and requires to be remedied before comprehensive coastal protection and restoration can be undertaken. Changes in municipal Official Plans and the responsibilities of Conservation Authorities and Regional Governments to manage the coastal resources in a sustainable manner are currently lacking.

6. Conclusions

Climate change is already affecting the coastal zone of the Great Lakes. Lower water levels, increasing water temperature, changes in the ice cover regime, changes in the frequency and intensity of rain events will all impact coastal processes. The key to dealing with climate change in the coastal zone will be to balance the competing demands of biological systems and society's needs to ensure sustainability of all species and ecosystems. Many of these features are interconnected and while some of these projected changes can be adapted to, others cannot. It is essential to recognize the importance of natural ecosystems and the values they provide which may not be fully costed in terms of the benefits they provide. To protect coastal ecosystems in the long-term requires that an ecosystem approach be undertaken to coastal and landuse management. While it may be possible to adapt to some changes in the coastal zone, many of these adaptations are costly and are not proven to be sustainable in the long term.

Therefore it is imperative that reasonable long-term land use plans be developed in which all components of the environment are addressed. This requires that policies and laws be developed for all levels of government that are rational and harmonized. One reason for involving local stakeholders is that adaptation options should be developed by the people who are most familiar with the problems, as solutions will generally be implemented at the community level, tailored to specific regions and sectors and actively involve those who live and work there (Smith et al., 2001). In areas where there are a number of competing interests, it is especially important to involve local stakeholders from a number of sectors, so that a range of interests are represented. The people of Canada and the United States must realize that natural resources are limited and that over-exploitation in the short-term may lead to the extinction of species and the loss of valuable resources for future generations.

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STUDIES ON CLIMATE AND THE GLACIAL SYSTEM, MT. YULONG, CHINA

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ABSTRACT: Investigations of the glacial system in Mt. Yulong, Lijiang, China, where is controlled by the south-western monsoon climate, have been carried out since 1999, with the following achievements. (1) The climatic records in a 10.10 meter long firn core indicate that the amplitude of isotopic variations in the profile decreased with increasing depth, and isotopic homogenization occurred below 7.8 meters as a result of meltwater percolation. Variations of $\delta^{18}O$ above 7.8 meters showed an approximate correlation with the winter climatic trend at Lijiang station, 25 kilometers away. Concentrations of Ca^{2+} and Mg^{2+} were much higher than those of Na^+ and K^+, indicating that the air masses for precipitation were mainly from a continental source, and that the core material accumulated during the winter period; (2) Investigations of the spatial variations of oxygen isotopes in the atmosphere-glacier-river system confirm that there is an apparent inverse relation between the oxygen isotopic composition of precipitation and air temperature/precipitation amount in this region, with lower $\delta^{18}O$ values when the amount of precipitation and air temperature in summer is higher, due to the influence of intense summer monsoons in the study area. There are marked differences of the $\delta^{18}O$ values of winter-accumulated snow, glacial meltwater, summer precipitation and the glacier-fed river water. Spatial and temporal variations of isotopic composition are controlled by varied weather conditions at different altitudes; (3) Glaciers have greatly retreated after the Little Ice Age because of climate warming. The recent 50-year climate data at Lijiang, the closest meteorological station to Mt.Yulong, indicate that there are 2 to 3 year periodic changes for the local temperature and apparent 11 to 12 year periodic cycles for precipitation, showing a corresponding pattern with that in the northeastern part of India. During the most recent half-century, glaciers in Mt. Yulong have alternately retreated and advanced, with smaller amplitudes. Those glaciers on Mt. Yulong with the lowest latitude and smallest area have reduced in size by 60 percent from the Little Ice Age to the present (He et al, 2003a). It is evident that there is a close relation between the atmospheric temperature and glacier retreat at Mt. Yulong. Therefore we conclude that global warming is the major and most important reason for glacier retreat in the Lijiang-Mt. Yulong region.

Keywords: climate change, glaciers, China

1. Introduction

Mt. Yulong, located in the Hengduan Mountain Range (southeastern edge of the Tibetan Plateau), north of Lijiang, Yunnan Province, China (27°10'-27°40'N; 100°07'E-100°10'E), is the southernmost glacierized area in Eurasia (see Figure 1). The climate of the high altitude area (above 4100 meters) on Mt. Yulong, which is controlled by the South-Asia/Indian monsoon, has provided the cold, moist conditions necessary for glacier development. The 19 glaciers on Mt. Yulong cover 11.61 square kilometers. Their high accumulation and ablation, high temperatures, basal sliding and rapid movement are typical of sub-tropical temperate- glaciers (Li and Su, 1996). The largest glacier, Baishui No.1, has an area of 1.52 square kilometers and is 2.7 kilometers long (see Figure 1). Its broad, flat accumulation area covers about 1.0 square kilometers between 4800 and 5000 meters. The glacier terminates at about 4150 meters. Its tongue is heavily crevassed, reflecting very active motion. Glacial meltwater flows to the Baishui River, within the upper Yangtse River basin.

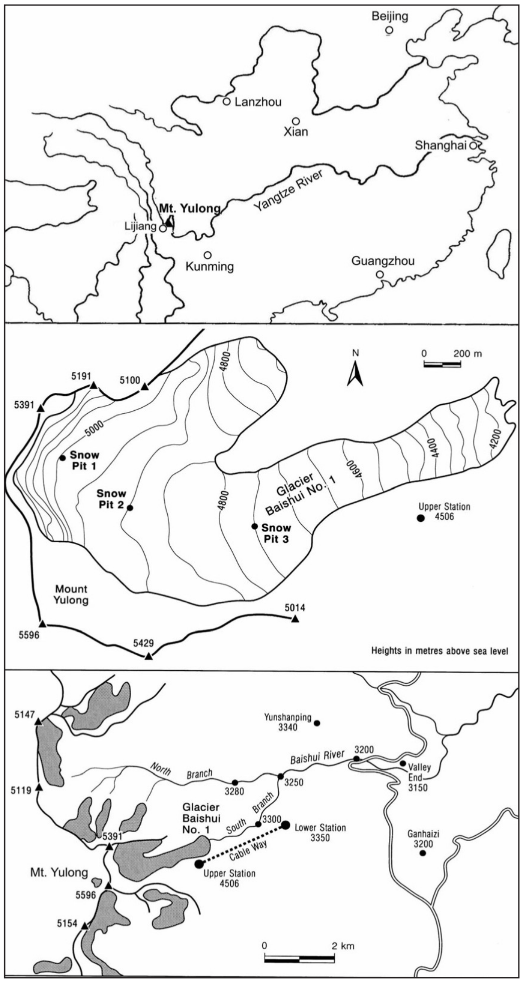

FIGURE 1

Location of Baishui Glacier
The sketch map indicating the location of Mt.Yulong in southeastern Asia (top), the glacier Baishui No. 1, with the of locations of snow pits used in 2000 (middle), and the area around Mt. Yulong, with precipitation and river water sampling sites (bottom).

Mt. Yulong, with a highest peak, Satseto, of 5596 meters, is in the subtropical zone. 70 percent of the region's precipitation falls between June and September from the warm, moisture-rich air masses of the prevailing southwestern summer monsoon from the Indian Ocean. In the winter, the climate is relatively dry, controlled by the winter monsoon of closer continental origin. The multi-year mean annual precipitation at Lijiang meteorological station (2393 meters) is 772 millimeters, and the four-year average at the mountain foot (3240 meters) is 1646 millimeters (Su and Pu, 1996). An ice core acquired in 1999 at around 4950 meters indicated a four-year mean annual net accumulation of 900 millimeters water equivalent (He et al., 2001). Because the measured net accumulation is the only data obtained in relation to the atmospheric precipitation above 4800 meters in Mt. Yulong, it is assumed to represent an "average" rate in the glacier's accumulation area although it might be different in other sites. Using the mean net accumulation rate recovered in the core, together with the ablation rates measured by Su and Wang (1996), the mean annual precipitation amount in the accumulation area (above 4800 meters) of the glacier is roughly estimated in a range of 2400-3100 millimeters (He et al., 2001). However, the precipitation in the glacier's ablation area between 4150 and 4800 meters is still unknown.

The mean annual temperature at Lijiang is 12.6 degrees Celsius, with a positive mean temperature in every month. At 5400 meters, the mean annual temperature is about -7.5 degrees Celsius, and all monthly mean temperatures are below 0 degrees Celsius. The mean annual temperature above the equilibrium line (4800-5000 meters) is -3.3 to 4.7 degrees Celsius (Wang, 1996). This suggests an adiabatic lapse rate of about 0.7 degrees Celsius/100 meters, which is higher than that for a pure maritime area because Mt.Yulong is distant from India Ocean, under the monsoon climate of wetter summer but drier winter. Since 1999, studies in relation to the climatic records in a shallow ice core, environmental signals in the atmosphere-glacier-river system, and glacial variations in the 20th century have been conducted (He et al, 2000abc, 2001, 2002ab, 2003ab). The results of these scientific investigations are reviewed and summarized in this paper.

2. Climatic Records in a Shallow Ice Core

In July of 1999, a 10.10 meter long core was drilled at 4950 meters in the accumulation area of the glacier Baishui No. 1, using a US-made PICO corer. 101 samples, each 0.1 meters long, were collected for isotopic and ionic analysis. Five net accumulation layers could be identified from the periodic variations of the $\delta^{18}O$ values in the core, with their abrupt changes between higher and lower values. These were at depths of 0-2.0 meters, 2.0-3.2 meters, 3.2-5.0 meters, 5.0-6.5 meters and 6.5-7.8 meters, corresponding to the balance years 1998/99, 1997/98, 1996/97, 1995/96 and 1994/95, respectively. The variations of $\delta^{18}O$ values within an annual layer represent air temperature trends during precipitation events. The decreasing amplitude between the surface and 7.8 meters, and smoothed values below 7.8 meters, reflect a gradual homogenization process caused by meltwater percolation. $\delta^{18}O$ values between the surface and 7.8 meters are roughly correlated with the variations of temperature and precipitation at Lijiang station during the winter months between the balance years of 1998/99 and 1994/95 (see Figure 2). Below 7.8 meters, however, the climatic signals are smoothed as a result of a slowly occurring homogenization process because the glacier at Mt. Yulong is a high-melting temperate glacier. The correspondence between cationic

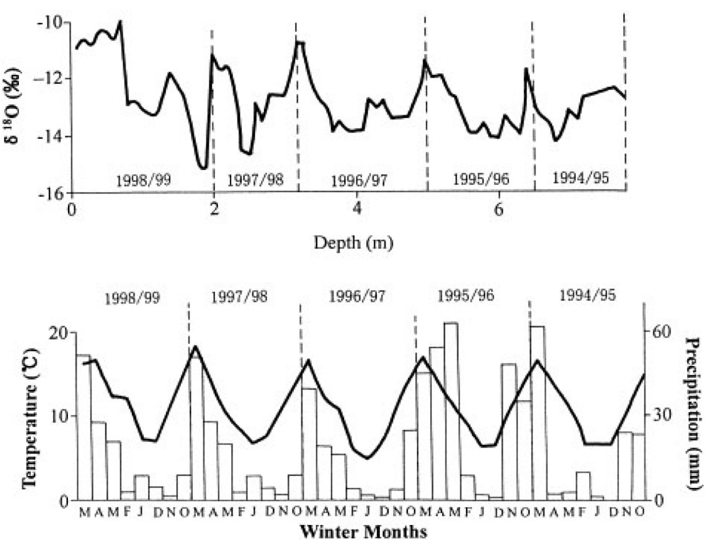

FIGURE 2

Isotopic variations above the depth of 7.8 meters in the core collected in 1999 (top) and the mean temperature and total precipitation at Lijiang meteorological station during the winter months of the balance years 1994/95 to 1998/99 (bottom).

concentrations and the isotopic profile is pronounced. Peak values of cationic content appear at the depths of identified summer surfaces and the positions of thick dirty ice layers.

There is a significant relationship between Cl^- and Na^+ and the correlation coefficient between the two ions for 101 samples is 0.53 (see Figure 3), indicating their common source. The ratios of Na^+/Cl^- are also calculated and plotted. Gradually reduced variation amplitude of the ratios, corresponding to those of $\delta^{18}O$ and other ions, further indicates a progressive effect of meltwater percolation and the homogenization process in the core. Concentrations of Ca^{2+} and Mg^{2+} are much higher than that of Na^+. This reflects the fact that more of the impurities in the core came from a continental source rather than from a marine one. Most materials in the core are believed to be deposited during the winter season, between October and May. Winter air masses, forced

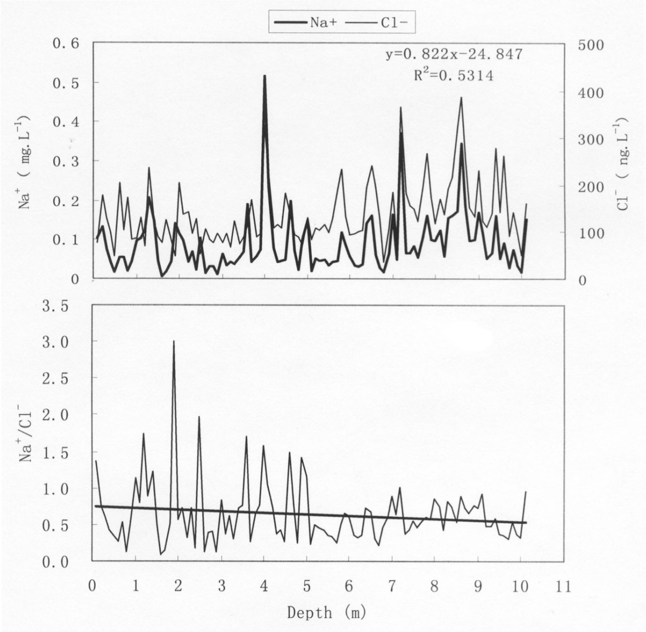

FIGURE 3

The relationship between Cl^- and Na^+ and variation of Na^+/Cl^- ratios in the core from the glacier Baishui No.1 indicates their common source.

upwards by the blocking mountain, carry more land-surface impurities, resulting in the higher concentrations of Ca^{2+} and Mg^{2+} because of the positive mean air temperature in the study area between July and September.

3. Environmental Signals in the Atmosphere-Glacier-River System

Stable isotopes and ions are useful tracers in glaciological and hydrological research (Dansgaard, 1964; Moser and Stichler, 1980). In July 1999, samples of recently deposited snow, summer rain, supraglacial and subglacial meltwater were collected from the glacier Baishui No.1, and river water samples were collected from the glacier-fed Baishui River. The samples were collected at the field sampling sites (see Figure 1). The analyzed results are shown in Figures 4 and 5.

The high-altitude winter deposited snow samples were more enriched in the heavy isotope than any other samples, such as recently deposited (one month) snow and summer rain obtained during the 1999 study. The general increase of $\delta^{18}O$ values with altitude (see Figure 4) indicates an irregular and varied spatial pattern, in contrast with the situation in the northern part of the Tibetan plateau (Yao et al., 1991), in this monsoon-dominated region.

Four samples of summer rainfall were collected at the Baishui No. 1 glacier during a single precipitation event in July 1999. There was a trend of increasing $\delta^{18}O$ values with decreasing elevation (see Figure 4), but the range was low (1.23‰). $\delta^{18}O$ values of precipitation samples collected during a single event may differ, and their average value, which depends strongly on the meteorological situation at different altitudes of the air in which it is produced and through which it falls (Rozanski et al., 1993). Accordingly, the slight differences of $\delta^{18}O$ values in this single summer rain event are caused by the different climatic conditions at varied elevations. Decreasing $\delta^{18}O$ values with altitude rising corresponds to increasing of precipitation amount and decreasing of temperature with increasing altitude, indicating a complicated isotopic variation during the course of the single precipitation.

Eight meltwater samples were collected in the glacier's ablation area. Their $\delta^{18}O$ values tended to increase with decreasing altitude , but the range was small (0.80‰). In general, the samples were less depleted of ^{18}O than were the rainfall samples (see Figure 4). The $\delta^{18}O$ values of the samples from the Baishui

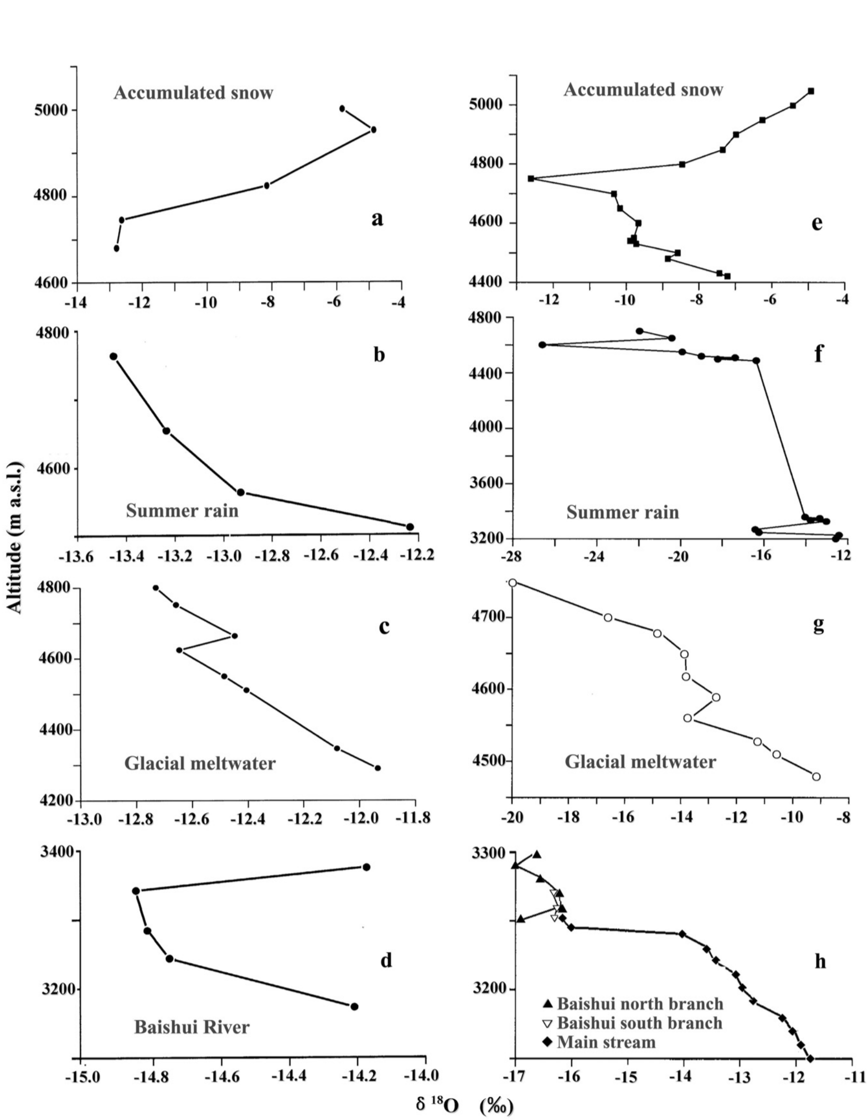

FIGURE 4

Altitudinal variations of δ18O values in accumulated snow, summer rainfall and glacial meltwater at the glacier Baishui No.1, and in glacier-fed river water, July 1999 and July 2000.

River varied only slightly from a mean of 14.56‰, suggesting that glacial meltwater was mixed with water that was more depleted of the heavy isotope.

Variations of dissolved ions in the different sources of supply to, and output from, a glacio-hydrological system reflects their different origins. Most of the ions in the accumulation area of the Baishui No. 1 glacier probably came from nearby sources: wind-blown crustal materials from the mountain slopes; impurities carried by moist air moving up the slopes; avalanches from the valley walls; and contact with the glacier bed by flowing ice and meltwater. Ionic concentrations in rainwater were low, particularly at high altitude (see Figure 5), and it is apparent that the impurity content of the precipitation falling on the Baishui No. 1 glacier was small. Solutes are acquired by meltwater and glacier river water as a result of contact with other sources. The increasing contact area between meltwater and the glacier bed with decreasing altitude led to higher ionic concentrations in the meltwater and the Baishui River (see Figure 5). The increase of Cl^- indicates gradual absorption of dissolved chloride from bedrock and till.

In most of the samples collected in 1999, Ca^{2+} and Mg^{2+} concentrations were much higher than those of Na^+ and K^+ (see Figure 5). Ca^{2+} inputs to the Baishui No. 1 glacier catchment probably are from local (continental) sources primarily. K^+ may originate from continental dust sources. Mg^{2+} has marine as well as continental sources. The data suggests that the impurities deposited in the glacier's system were mainly of a continental origin. Concentrations of Mg^{2+}, Ca^{2+} and K^+ were higher in snow at high altitude than in that closer to the equilibrium line, but N^{a+} and Cl^- concentrations were lower at higher altitude. In general, the elution of Ca^{2+} and Mg^{2+} from a snowpack is more rapid than is that of Na^+ and K^+ (Davies et al., 1987). Thus, the decrease of ionic concentrations with decreasing altitude in the surface snow at the Baishui No. 1 glacier might be the result of a longer period of melting at lower elevations. However, this cannot account for the pattern of Na^+ and Cl^- concentrations. SO_4^{2-} was detected in surface snow only at the highest site (5000 meters). Most SO_4^{2-} in snow is removed relatively rapidly in the early part of the melt season, and concentrations decrease particularly quickly at lower altitudes, where melting starts earlier (Raben and Theakstone, 1994). Early-season ionic elution of snow results in meltwater with a high ionic content. This has readily observed effects on river water (Tranter et al, 1987). The supraglacial meltwater formed from the leached snow is depleted of SO_4^{2-}. SO_4^{2-} was detected in meltwater at the glacier Baishui No.1 only at

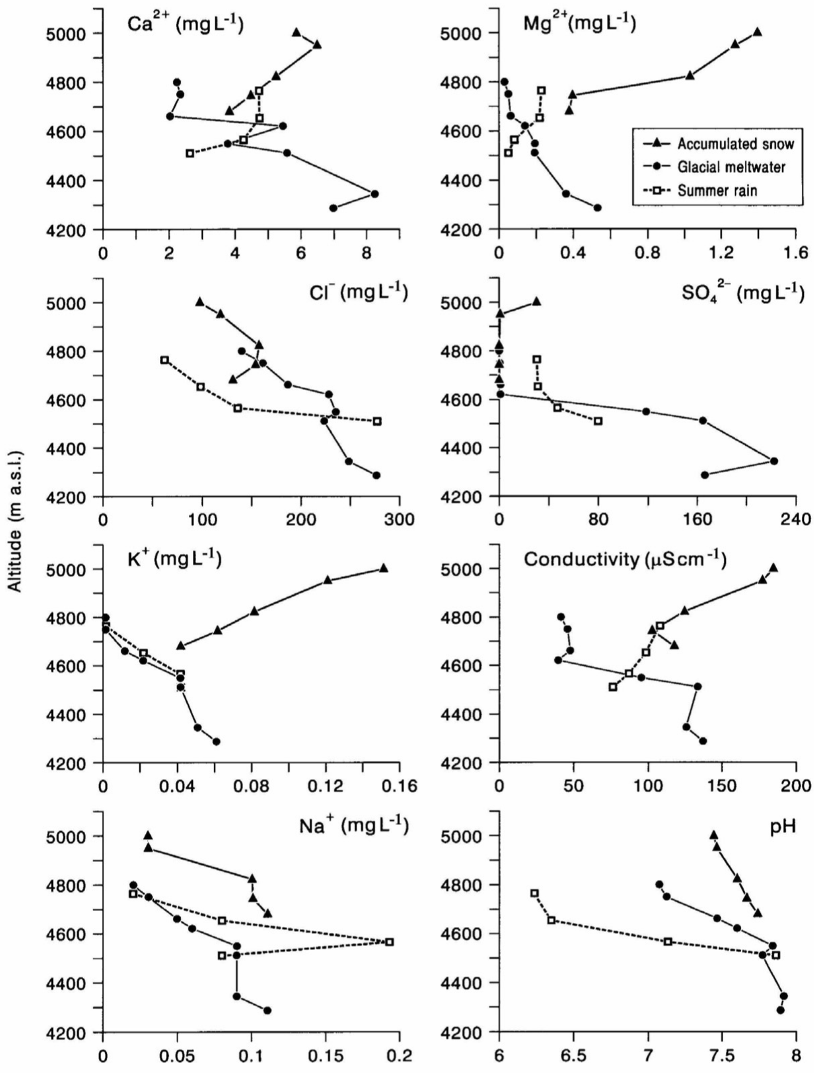

FIGURE 5

Altitudinal variations of Ca^{2+}, Cl^{-}, K^{+}, Na^{+}, Mg^{2+}, SO_4^{2-}, conductivity and pH values in accumulated snow, summer rainfall and glacial meltwater at the glacier Baishui No.1, Mt. Yulong, July 1999.

lower altitudes; the concentrations were higher than in the one sample of summer rain in which SO_4^{2-} was found (see Figure 5).

Differences of conductivity of the samples of surface snow, rainfall, and meltwater reflected the general trends apparent in the concentrations of individual ions (see Figure 5).

Sampling in the Mt. Yulong area in 2000 was more detailed than those carried out in 1999. $\delta^{18}O$ of all samples were analyzed with a new Delta Plus mass spectrometer in the Laboratory of Ice Core and Cold Environment, Chinese Academy of Sciences.

The $\delta^{18}O$ values of winter accumulated snow, collected at the surface above the elevation of 4800 meters on 5 July, decreased with decreasing altitude (see Figure 4). However, the $\delta^{18}O$ values of a set of samples from about 30 millimeters of newly precipitated snow, which were collected on 10 July between 4400 and 4750 meters when the temperature was lower (about -5 to 0 degrees Celsius), decreased with increasing altitude. The samples of surface snow from above 4800 meters represent a winter precipitation event, but those from new accumulated snow below 4800 meters represent a summer precipitation event. The $\delta^{18}O$ values indicate that the patterns of variation of winter and summer snowfalls differ.

Samples of summer rain were collected during a single precipitation event with a higher amount of precipitation (50 millimeters on average). Air temperature during sampling between 4700 and 3200 meters ranged from 10to 20 degrees Celsius. Summer rain was much more depleted of ^{18}O than the winter and summer snow covers were (see Figure 4). Four rainfall samples were collected at each of four locations (see Figure 4) - Ganhaizi (3200-3270 meters), the Lower Cableway Station (3330-3360 meters), the Upper Cableway Station (4490-4520 meters), and the glacier (4550-4700 meters). The $\delta^{18}O$ values were highest at Ganhaizi where precipitation amount was lowest. The lowest values were for the samples collected between 4600 and 4700 meters, where precipitation amount was highest.

It is apparent that, below 4800 meters, the higher $\delta^{18}O$ values of summer snow correspond to a lower-temperature environment and the lower values of summer rain is associated with a higher-temperature condition. The lowest values of summer deposited snow between 4650 and 4750 meters and of summer rain between 4600 and 4700 meters (see Figure 4) suggest that there probably is a highest precipitation-amount zone between 4600 and 4750 meters in the glacier area. This irregular and varied pattern is characterized by an obvious reverse relation between $\delta^{18}O$ values and temperature/precipitation amount in the prevailing summer monsoon period when samples were collected.

Ten samples of glacial meltwater were collected between 4530 and 4750 meters. $\delta^{18}O$ values displayed a general increase with decreasing elevation (see Figure 4). The mean value (13.94‰) was much lower than the means of winter deposited snow (9.46‰) and accumulated snow at the pit sites (6.70‰), indicating that alternative isotopic depletion and fractionation occurred during the processes of snow-ice transformation, ablation, evaporation, and supraglacial meltwater flow.

Water samples were collected from various sections of the glacier-fed Baishui River at altitudes between 3300 and 3150 meters. The mean of the five $\delta^{18}O$ values of samples from the river's southern branch was 16.59‰ and that of the three from the northern branch was -16.28‰ (see Figure 4). Below the junction at 3250 meters (16.09‰), values increased, suggesting that re-fractionation occurred during water flow, percolation, evaporation and contact with the river bed and groundwater. The highest $\delta^{18}O$ value (11.75‰) was at the valley's end (see Figure 1). The mean value of the twenty Baishui River samples (-15.44‰) was between those of glacial meltwater (13.94‰) and summer rain (16.98‰), demonstrating that the river water was a mixture of glacial meltwater and sources more depleted of ^{18}O, including summer precipitation. Ground water may enter the river, and further sampling and analysis is needed to calculate the relative contributions of meltwater, groundwater and precipitation to river discharge. The spatial and temporal variations of stable isotopes in the river may be used to identify the different sources of supply.

4. Glacier Variations since the Little Ice Age

Glaciers have greatly retreated after the Little Ice Age because of warming of the climate. The recent 50-year climatic data at Lijiang, the closest meteorological station to Mt.Yulong, indicates that there are 2 to 3 year periodic changes for the local temperature and apparent 11 to 12 year periodic cycles for precipitation, showing a corresponding pattern with that in northeastern part of India (see Figure 6). During the most recent half-century, glaciers in Mt. Yulong have alternately retreated and advanced, with smaller amplitudes (see Table 1). Since the 1950's, global climatic change has had a significant response in China's monsoonal temperate-glacier region. Observed data indicate that, in the Lijiang–Mt. Yulong region, the average annual temperature between 1982 and 2001 was 0.2 degrees Celsius higher than that of 1962-1981 and, in particular, the average annual temperature between 1998 and 2001 was 0.6 degrees Celsius higher than that of 1982-1997. In Zhongdian, close to Lijiang, the average annual temperature during the 20 years 1982-2001 increased by 0.7 degrees Celsius in comparison with that of the previous 20 years, 1962-1981. The average annual temperature during the most recent 4 years (1998- 2001) was 0.8 degrees Celsius higher than that between 1982 and 1997, demonstrating a rapid warming trend in the area (He et al, 2000a, 2003ab, Jones et al, 1999). Against this climatic background, a more rapid speed of glacial changes has occurred on Mt. Yulong (see Table 1), indicated by increased ablation of the glaciers, retreat of the glacier margins, reduction of the glaciers' areas and a rise of the snow line.

The Baishui glacier No.1 on Mount Yulong (see Figure 1), the southernmost glacier of Eurasia, with a small area, is most sensitive to climate, and its area has decreased by 60 percent from the Little Ice Age to the present. The data

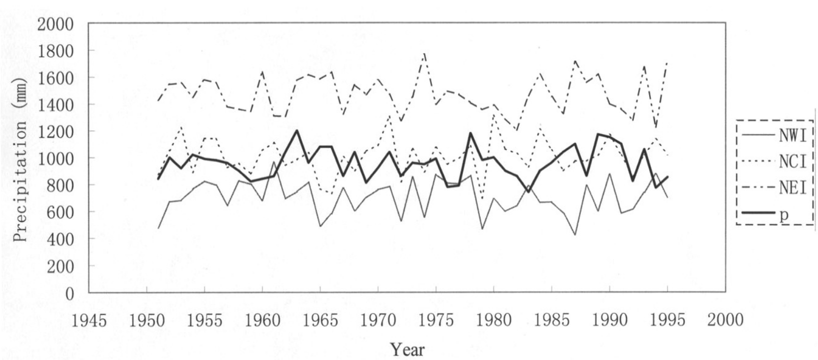

FIGURE 6

Variations of mean annual precipitation at Lijiang station (P), northwestern India(NWI), north central India (NCI) and northeastern India (NEI) from 1950 to 1996, indicating 11-12 year periodic cycles and 2-3 year sub-periodic cycles for southwestern monsoon.

Table 1 Variation of Baishui No. 1, Mt Yulong since the Little Ice Age

Biashui Number 1 Glacier, Mt. Yulong
(Area, 1.7 square kilometers; Length, 2.5 kilometers)

TIME PERIOD	ALTITUDE OF GLACIER END IN METERS (M)	ADVANCE (+) AND RETREAT (–), IN METERS (M)
Little Ice Age (17-19 centruries)	3800	+
19th century to 1957	4353 (1957)	–1250
1957 – 1982	4100 (1982)	+800
1982 – 1997	4200 (1997)	–150
1998 – 2002	4250 (2002)	–100

listed in Table 1 was from local historic records and geomorphic evidences of newer moraine and snow line variations, indicating that the glacier retreated about 1250 meters between the Little Ice Age and the middle of the 20th century, and it has retreated again since the 1980s (see Table 1). As a distinct indicator of climate change, the end of glacier Baishui No.1, the largest glacier on Mt. Yulong, has retreated by 100 meters during the most recent 4 years, from 1998 to 2002, and the glacier's size and thickness have been reduced at the same time (He et al, 2000a, 2003ab).

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25 paper

TOURISM, RECREATION AND CLIMATE CHANGE:

THE ROLE OF PROTECTED AREAS AND BIOSPHERE RESERVES

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ABSTRACT: Tourism, in its many forms, has been stated by the United Nations to be the world's largest industry. It is a world-wide activity, important in both developing and industrialized countries. It provides a significant part of the economy of many countries and is an important educational, physical and psychological element in the life of millions of people. A large portion of tourist activities is oriented toward experiencing nature, and the phenomena that are attractive to tourists are commonly sensitive to climate change. Many popular outdoor recreation activities depend upon environmental conditions remaining within a fairly narrow range of those prevalent at present. Any significant change of climate could have serious consequences for tourism and outdoor recreation. The large investments in facilities to support tourism or outdoor recreation may be at serious risk from small climate changes likely in store. Similarly, the values which justify protected natural areas in the long-term public interest and are attractive to tourists may be particularly sensitive to changes in climate, and raise difficult long-term policy questions. Adaptation of the tourist and recreation industry to climate change will require increased knowledge of climatic, hydrological, and ecosystem dynamics at appropriate scales to identify and appraise the sensitivity of tourist destinations and outdoor recreation sites. Ecotourism, and the programmes of Biosphere Reserves, will benefit and increase their usefulness, if they deliberately include climate change as a factor in their activities. Protected areas should include climatic information at appropriate scales in their data-gathering activities, should expand programmes of research on the sensitivities and responses of ecosystems, and should include the likelihood of changed conditions due to climate change in their forward planning.

Keywords: biosphere reserves, climate change, ecotourism, protected areas

1. Introduction

One aspect of the increasing prosperity of citizens in many countries, both those industrially developed and those undergoing development, is an increasing amount of free time and some disposable wealth which individuals can use for their personal satisfaction. This development has led to an enormous increase in tourist travel. Tourism is no longer the activity of relatively few well-to-do eccentrics or adventurers, but today involves persons from all walks of life and from many cultures. Similarly, there has been a growth and broad social acceptance of individual active "outdoor" recreation.

Tourism and outdoor recreation, and the investments in facilities and the provision of services that make these activities possible, have become important factors in the economies of many countries. They have provided some important psychological, educational, and spiritual factors that affect the sense of country, of belonging, and the values of citizens and societies.

A large proportion of tourist activities, both international and domestic, is directly or indirectly oriented toward "Nature" or natural phenomena. The desire to observe or visit natural features, to be where wild creatures are, to escape temporarily from modern stresses imposed by technology, commerce, and human conflicts into a setting not exclusively dominated by human actions is a strong instinct in many people. It is also a major incentive for at least half of the tourist activities in the last few decades.

These aspects of "Nature" that underlie much of modern tourism are the product of natural physiographic processes and biological/ecological evolution under the recent and current climate. Any important change in climate will have an effect on these natural features and thus on tourism. In a similar way, a great deal of the popular outdoor recreational activities – visits to beaches, sailing, canoeing and kayaking, wilderness hiking, mountain-climbing, skiing, recreational fishing and hunting, bird-watching – are dependent on climate-sensitive environmental conditions. Even small changes in regional or local climates can have profound effects on such activities.

This paper will review some aspects of tourism and outdoor recreation as they might be affected by climate changes that are likely to occur in the near future and the role played by proteced areas and biosphere reserves. An awareness of the possible effects of climate change may help reduce some of the disadvantages and point ways for tourism and outdoor activities to benefit from changes to come.

These comments will touch briefly on:

- Some characteristics of protected natural areas and their relation to climate;
- Some of the different kinds of tourism and outdoor recreation and how they may be sensitive to changes in climate;

- Some effects that climate change may have on tourism, outdoor recreation, and protected areas;
- Biosphere reserves and the contribution they can make; and
- Conclude with some issues and needs for the adaptation of tourism to changes in climate.

2. Protected Natural Areas

About one hundred and thirty years ago, some influential citizens realized that the natural resources and indeed the natural landscapes which produced products used by humans had values in themselves quite aside from their immediate products, and that these values were being progressively and irrevocably destroyed by human exploitation. They persuaded their governments to "set aside" tracts of land that had particular scenic or natural aesthetic or cultural value. They protected these lands by law, from private ownership or exploitation. A strong element in this development was the expectation that non-exploitive tourism on these public lands would preserve and enhance their value to the nation. Such increased value, in perpetuity, would more than offset the loss to the economy from the withdrawal of these lands and their products from private commerce. This was the beginning of "national parks".

From its origins in North America, the concept of natural parks and protected areas has spread throughout the world. There is now a vast array of protected areas - national, sub-national and local parks, conservation areas, nature reserves of one kind or another - in more than 140 countries. Tourism is an important or dominant activity in most although a few are strictly wilderness areas where humans are excluded except through special permit. In almost all of the protected natural areas throughout the world, however, the central purpose is an appreciation of the value of natural features and natural processes, and recognition of the benefit to society of maintaining that value for the future. The natural World Heritage Sites recognized by UNESCO are demonstrations of the international importance of these intrinsic values.

The natural characteristics that have led to the selection of particular places as "protected areas" are of course characteristics that developed under the recent and present climate regime. A change in the climate regime will in some way affect the natural characteristics of the selected area and quite possibly change the values for which the area was protected. As tourism plays a large part in the operation and valuation of many protected areas, it is of interest to consider some of the issues of tourism, protected areas, and climate change together.

3. Modern Tourism

In the last two decades, tourism has grown to such an extent that in the year 2000 it was stated by the United Nations to be the world's largest industry in terms of worldwide export earnings (WTO, 2000; di Castri and Balaji, 2002, p. 16; UNESCO, 2002, p. 67). It is also the industry most widespread throughout the world, from least-developed to highly industrialized countries, from small rural enterprises to activities of large multi-national tourist organizations. Tourism accounts for more than 50 per cent of the capital flow from industrialized to developing countries (WTO, 2000). The World Tourism Organization (WTO) reports that the number of Persons listed as "arrivals" at WTO member facilities has grown from 25 million in 1950 to 700 million in the year 2000. Expenditures by "international" tourists in the year 2000 is estimated at USD455 billion. It has been speculated that un-organized, unreported domestic or non-national tourism is, in aggregate, just as extensive as that reported by the WTO.

Clearly, tourism in the early 21st century is big business. As di Castri and Balaji (2002) point out, the natural and cultural environment is the main resource for tourism, everywhere in the world. And a large portion of that resource is very climate-sensitive.

Tourism related to nature takes many forms including organized mass tourism, adventure tourism, ecotourism and outdoor recreation.

Organized mass tourism, exemplified by sophisticated large tourist ship cruises or organized bus tours, takes large numbers of people on scheduled itineraries, advertised in advance and with facilities arranged beforehand, to pre-selected sites that are well known as "tourist" destinations. The most popular destinations are places of spectacular scenery, outstanding wild animal habitat, or places where the scenery and environment are distinctly different from the home environment of most of the tourists. The tourists themselves are for the most part passive observers, recipients of information. They are often enriched and educated by what they have observed, but remain detached from it.

Adventure tourism, in its purest form, involves the tourist directly into the characteristics and variations of the environment, including the climate, which may be seen as challenges and part of the attraction to the tourist. In such activities, as for example in advanced mountaineering or small boat transit of the Northwest Passage, the experience of being in competition with natural forces is an important goal in itself, as important as the attainment of any physical destination or quarry. There are many milder forms of adventure tourism, where knowledgeable people, preferably in small groups, deliberately seek out particular habitats or natural features, such as those who specialize in alpine flowers, scuba dive on coral reefs, or take part in extended hiking or trail riding holidays.

With increasing awareness in many societies of the need for conscious attention to the relationships of humans to the natural world, there has arisen in the last few years a new kind of tourism - *ecotourism.* Ecotourism seeks to use travel to selected places as a means of learning about nature and ecology, and to develop understandings that can change societal awareness and behaviour in ways that lessen the disruptive impact of human activities in natural systems. There is no single satisfactory definition of ecotourism, but it involves all tourism in which the main motivation of the individual tourists is conscious observation and appreciation of nature and its workings. In ecotourism, education and learning is an essential part of the experience. Ecotourism avoids negative impacts on the natural and socio-cultural environment, and thus fosters increasing understanding of the necessity for protecting and conserving natural values.

Recognising the importance of this development of a kind of tourism that has an orientation toward understanding and protecting the environment, the United Nations General Assembly proclaimed the year 2002 as the *International Year of Ecotourism* (UNGA/A/RES/53/200). Principal events to mark the year were the World Ecotourism Summit organized by World Tourism Organization and the United Nations Environment Programme, held in Quebec City, Canada, attended by more than 1200 participants from 130 countries; and an international workshop on Ecotourism and Sustainable Development in Biosphere Reserves, also held in Quebec City, organized by the UNESCO Man and the Biosphere Programme (MAB). These activities produced declarations and recommendations (UNESCO/MAB, 2002) that are intended to encourage tourism to learn from nature, and to facilitate the growth of responsibility to live in harmony with it. But they failed to recognize the need for tourism to adapt to natural changes caused by changes in the climate or other environmental factors.

A very important but somewhat different kind of human activities, which are related to and often include tourism, can loosely be called *outdoor recreation.* In these activities, "Nature" is not the object of the travel or visitation, but natural conditions provide the setting or medium through which the participant achieves satisfaction through exercise, challenge, relaxation, or social enjoyment. Such activities have been characteristic of all civilizations throughout history. They range from simple family picnics in the woods to mass holidays at the beach; from week-end fly-fishing to round-the-world sailing races. The facilities and investments connected with them range from multi-million-dollar ski resorts and beach developments to exclusive spas at hot springs and to manufacturers of high-tech mountain bicycles, yachts, and kayaks. In all of these activities, the direct contact between humans and the natural environment is an essential part of the experience. Changes in climate, affecting natural environmental conditions, will have subtle or profound effects on outdoor recreation.

4. Response of Natural Systems to Climate Change

The effects on landscapes and natural systems due to changes in climate are common knowledge in a general way and for the most part well studied. The atmospheric drivers of these changes include:

- changes in mean temperatures and extreme temperatures, and in particular changes in the timing, throughout the year, and in the intensity of seasonal changes of temperature;
- changes in precipitation, in the variability and intensity of precipitation events and their timing throughout the year; and
- changes in the geographical patterns of temperature and precipitation regimes and in the stability or variability of such patterns on a range of space scales.

These basic changes in the dynamics of the atmospheric environment on local or regional scales lead to the familiar environmental changes that people associate with climate change such as changes in winds, storm patterns, in the duration, timing, and intensity of wet and dry periods; and changes in hydrology, run-off and soil moisture; floods, droughts; duration, extent and thickness of snow cover; freeze-up and break-up of rivers and lakes, growth and decay of glaciers, and sea ice.

Such changes in the physical environment in turn lead to changes and adaptations in the natural biological world. The response of natural systems to climate change is rarely the result of a single environmental stress because of the complexity of biological systems and the inter-connectedness of ecological relationships. In most cases, the response reflects the influence of a combination of different but related changes. The adaptation responses of different components of an ecosystem typically differ widely in timing and scope. Small changes in climate may have considerable ecological consequences because the different components are interdependent, even though they respond differently to imposed stress.

There is reason for concern that climate changes in the near future, which individually may not be great in themselves, may lead to considerable disruption of ecosystems in many parts of the world. The changes will be manifest not only in changes in abundance of characteristic plants or animals but more profoundly and subtly in changes in the period or timing of recurring natural events – the phenology – like the flowering of plants, the appearance of insects, or the migration of birds. The changes will be seen ultimately in the species composition of plant and animal communities in the area. Such changes in environmental conditions and ecosystems could have profound effects on tourism, outdoor recreation, and the characteristics and value of protected areas.

5. Examples of the Effects of Climate Change on Tourism Values, Recreational Activities, and Protected Areas

The variety of nature-sensitive tourist activities is so great that an attempt to group those features that are likely to be particularly affected by rapid change of climate would be cumbersome and have little meaning. Some examples may serve to show the need to give thought to climate-sensitive factors important to tourism.

In general, nature-seeking tourists tend to go to places that are unusual, which are outstanding examples of "Nature" at its most dramatic, or pleasing to modern conventions of beauty or spiritual satisfaction. On a world basis, the most popular tourist destinations are in mountains, on seacoasts or small islands. These are also areas where the physiography and the biological systems are particularly sensitive to climate change. Mountain scenery with glaciers or snow and lakes, waterfalls, remnants of once-mighty forests, sand beaches not conspicuously altered by humans, coral atolls are among the world's most sought-after tourist destinations. All of these owe their attractiveness to a dynamic balance between physical and chemical processes each of which is sensitive to changes in climate.

Organized mass tourism must develop destinations where large numbers of people can observe and enjoy nature, and in a passive way briefly experience it as a whole before moving on to the next destination, without impairing its value for the next group of tourists. To provide satisfaction to each individual within large numbers of tourists in a dependable manner, the locations chosen and the activities conducted there must be such that the experience is positive regardless of the normal variations in weather, water levels, or biological activity. Small changes in climate may influence the delicate environmental/ecological balances that provide tourist satisfaction and support the tourism enterprises. The changes in natural conditions as a result of changes in climate will have an effect on the length of the "tourist season" which is important to tour operators, and be a factor in the relative attractiveness of one tourist destination compared to another in a different region. For example, Canada has an international tourist trade deficit that was estimated to be $2.1 billion in the year 2000 (Canadian Tourism Commission, 2001), due largely to Canadian tourists going to warmer lower latitudes during the winter; Scott and McBoyle (2001) concluded that this deficit could diminish considerably under conditions of climate change to warmer Canadian winters.

Adventure tourism, which involves smaller numbers of people but is an activity where the participants directly experience the natural world, is often climate-sensitive in a different way. The effect of climate change may be positive or negative. In its more strenuous forms, such as advanced mountaineering or long-distance sea-kayaking, the different physical conditions resulting from climate changes may add to the challenges and, ultimately, to the satisfaction to the tourist. The increasingly broken state of alpine glaciers due to recent climatic warming, or the increasing incidence of violent storms in waters tempting to amateur rough-weather sailors are examples. In the milder and more popular forms of adventure tourism, such as canoeing, hiking, ski touring or wilderness camping, the changes in climate that seem plausible in the near future may have an important influence through changes in water levels in streams and lakes, changes in the timing and severity of summer or winter seasonal conditions, in snowfall or the proportion of clear and stormy days. An important aspect may be changes in the richness of the wilderness experience because natural habitats and wildlife are stressed or impoverished by changes in forage richness, in insect infestations, etc. Such changes may persuade the tourist to simply not come, or to go elsewhere (Lise and Tol, 2002).

Some forms of popular outdoor recreation are likely to be significantly affected by climate change in the near future. Perhaps the most dramatic example is that of ski resorts. Recreational skiing, centred mainly in sophisticated modern resorts, has grown in the last forty years to a multi-billion-dollar business in Europe, North America, Japan, Australia, and New Zealand. Switzerland alone has 230 fully developed ski resorts, and Japan has 61. Many of these resorts are a principal source of income for the mountain communities in which they are located. A recent study (UNEP, 2003) concluded that more than half the established ski resorts throughout the world are in a seriously vulnerable position for survival in face of likely weather and climate trends (Toepfer, 2003; Radford and Wilson, 2003). These conclusions have been supported by studies or estimates of skiing areas in many parts of the world, which show contraction or elimination of recreational skiing as a consequence of projected climate change (e.g. Lamothe and Periard, 1988). Clearly, if there is not enough snow and it does not stay long enough during the winter sport season, skiing as a popular activity in areas where it is presently practiced will decline or disappear. Clearly, other popular outdoor activities that depend on cold winter conditions, such as ice-fishing and motorized snowmobiling, which have hundreds of thousands of devotees and are major factors in the economy of same areas, will be impacted severely by even minor changes in winter climate (Scott et al., 2002).

Ecotourism, by its nature, should be able to observe the environmental and ecological effects of changes in climate and be enriched by them. The changes and their consequences should serve as examples or models through which the ecotourist can learn, an to increase understanding of the dynamic aspects of the natural world in which we live. This kind of tourism, to be successful, requires a good degree of knowledge about environmental characteristics and processes, and adequate advance preparation by both tour leaders and tourists. It should be undertaken by small groups, with time for adequate detailed observation or study by each participant (UNESCO/MAB, 2002). Ideally, the information from each ecotourism event should be placed into the context of wider environmental and ecological information and changes. In this way, ecotourism itself can broaden understanding of the importance and consequences of climate change in the area visited. This is a more difficult, but more rewarding, form of tourism.

6. Biosphere Reserves

An international mechanism that could be useful for obtaining and sharing information on climate change and its effects on tourism is the World Network of Biospheres of the Man and the Biosphere Programme (MAB) of the United Nations Educational, Scientific, and Cultural Organization UNESCO.

UNESCO/MAB Biosphere Reserves are selected areas of terrestrial and coastal landscapes and ecosystems that are recognized by UNESCO as places where the relationship of the natural biosphere to on-going human activities can be particularly well studied, where there is good scientific information and continuing research, where there is a strong incentive or determination by the local citizens to maintain natural values, and cooperation or support from businesses and all levels of government.. Biosphere Reserves should not only be justified in themselves, but can be models or demonstrations of how progress toward sustainable life styles and use of natural resources can be achieved without diminishing environmental quality or productivity (UNESCO, 2002).

At the beginning of 2004, there were 425 UNESCO Biosphere Reserves, in 95 countries, constituting a World Network that includes examples of all major terrestrial and coastal ecosystems except those of Antarctica. China has 23 Biosphere Reserves; Canada has 12. An important feature of the World Network system is the opportunity for direct cooperation and sharing of information or research programmes between Biosphere Reserves in different countries but who have similar issues. There is good opportunity for such sharing and cooperation between Chinese and Canadian Biosphere Reserves. In 1996 a delegation of representatives from Biosphere Reserves and the MAB programme in China visited three Biosphere Reserves in Canada and other protected areas, and much useful information was exchanged (Birtch, 1997). This has been followed by visits of Canadian

National Parks officers to Yunnan, China (Welch, 2004). An important area for future cooperation and sharing of information could be the issues related to climate change, as manifested in different Biosphere Reserves in the two countries.

An introductory research study to assemble data and evidence of climate changes in each of Canada's Biosphere Reserves was undertaken by the Canadian Biosphere Reserves Association, supported by Environment Canada, in 1998-99 (Hamilton et al, 2001). This project, which was aimed at providing information and incentives from Biosphere Reserves to help communities in the area understand and deal with the implications of climate change, could be a start for international cooperative activity in this subject. Tourism is an important activity in many Biosphere Reserves (UNESCO/MAB, 2002; Di Castri and Balaji, 2002), and in some areas is a major contributor to the regional economy. In the Juizhaigou Biosphere Reserve in Sichuan province, China, for example, where the number of tourists increased from 181,000 in 1997 to 580,000 in 2000, the revenue from tourism has increased the per capita income for the whole province five-fold from that in 1995 to "six times the average income of farmers in Sichuan province" (Han, 2001). The taxes from the Biosphere Reserve constituted 80 percent of the taxes collected by the county government (UNESCO, 2002). In its contribution to the United Nations World Summit on Sustainable Development in Johannesburg in 2002, Canadian Biosphere Reserves developed a series of "cooperation plans" describing the multi-faceted contribution of each Biosphere Reserve to sustainable development, and in each example noted tourism and the investment in recreational facilities as an important factor in both the economy and the environment (CBRA, 2002).

7. Conclusions

Adaptation of tourism to the changed conditions as a result of climate change will raise many problems. Some of the responses will be automatic and inevitable - tourists just won't go any more to places that don't satisfy them. The results for the tourist industry could be devastating in some instances, and result in "overloading" with decline in tourist appeal in others. Very careful consideration must be given by the industry to planning, investment, and allowance for variations because the changes in environmental conditions are outside the immediate control of the tourist business.

The most important first need is more thorough and focussed information on environmental, hydrological, and climate information at the sub-regional or local level in areas important to the tourist industry. This is needed together with information about how the ecosystems are sensitive to climate and hydrology, particularly those vegetative ecosystems and the fauna that together form the basis of much of the "Nature" appeal to tourists. This will require specific data-gathering and in some cases dedicated research, in different areas important to tourism (Scott, 2003). The task is enormous, but without this information, attempts to adapt to the changes likely in store will be largely speculative. Techniques such as the "tourism climate index" as developed by Scott, McBoyle and others (Scott and McBoyle 2001) can be very pertinent. There is no recent or historical precedent or experience for the environmental changes that may happen in the near future, nor for the way those changes could affect the discretionary spending of the people who today are tourists.

A second important need is to increase the awareness and knowledge of climate change and its consequences as it relates to tourism and outdoor recreation. Businesses related to tourism must factor climate change into planning and investment, not as an "unknown" or 'contingency", but as an integral element based on continually improving knowledge. This awareness and knowledge also includes an opportunity to identify areas and situations that could become more attractive tourist or recreational destinations with changes in climate potentially, such as higher-altitude ski areas or new routes for recreational boating. And those sectors of the public who are interested in nature and tourism, those who are the potential tourists and customers, or who invest in private recreational cottages, need to receive more balanced information about climate changes and the implications of such changes on the environment and thus on the landscape and the vegetation, the animals, birds and insects, and other things.

Climate change and its consequences are subjects that easily become over-dramatized in popular literature, leading to exaggerated predictions, usually dire, of the future effects; and this tendency inevitably leads to loss of credibility or trivializing of the subject. Partial or incorrect information harms tourism and distorts public understanding of a very important topic. It is a responsibility of the tourism industry and all connected with it to become well-informed about issues of climate change and to help the public cultivate a balanced perspective about it.

Protected areas, themselves needing to cope with many issues posed by changes in climate with regard to the ecosystems and natural features can play a very significant role in helping tourism adapt to climate change. The long-term responsibilities of national parks and other protected areas to assess natural values and monitor changes in them, to disseminate information to the public about the importance of the role of Nature and natural process to the life of every citizen and to the health and well-being of the nation, as well as the fact that tourism itself is an important activity in nearly all of them, make these places key players in the sensible adaptation of tourism to changed conditions brought about by climate change.

The National Parks Service in Canada is developing an integrated source of climatic and environmental data, some of which goes back one hundred years. Biological inventories, while still incomplete, are being compiled and organized; and research is underway to identify and fill gaps in knowledge about the sensitivities of species and ecosystems to environmental disturbance (Welch, 2004). Many other protected areas in Canada are taking steps toward the same objectives.

Information is being exchanged with other protected areas around the world, and international bodies, such as the International Federation of Parks and Protected Areas (IFPPA) and the World Conservation Union (IUCN), and the Conferences of Parties (COP) of the United Nations Convention on Biological Diversity are also beginning to focus on issues related to climate change. These developments will help provide the scientific and communication basis essential if tourism policies, investments, and the general public awareness is to adjust successfully to new conditions caused by changes in climate.

Biosphere Reserves can play a key role. All Biosphere Reserves have protected lands – parks or their equivalent – as core areas, and in most, tourism is an important activity. Biosphere Reserves are in an unique position to study and monitor the effects of climate change on human activities as well as on natural systems, and to translate the environmental and ecological information from changes in the core protected areas to the wider world of ordinary human affairs. Not least of these opportunities is that provided by tourism, and especially ecotourism. A very large proportion of the tourists in protected areas has a “base” in, or is serviced by, activities and investments in the outer zones of Biosphere Reserves. Thus, information and understandings from the Biosphere Reserves as a whole can be important, and indeed lead the way, to successful adaptation of tourist activities and outdoor recreation to forthcoming changes in climate.

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26 paper

DISTRIBUTION OF PLANT SPECIES RICHNESS ALONG ELEVATION GRADIENT IN HUBEI PROVINCE, CHINA

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ABSTRACT: Plant species richness (spermatophyte) patterns along an elevation gradient in Hubei province of China were studied using published elevation range data. The result showed a hump-shaped distribution, with high species richness in the middle elevation range from 800 to 1400 meters. The maximum value of species richness was observed at 1000 meters, and this is accounted for about 52 percent of the total number found in Hubei province. The observed pattern in the Hubei province is compared with reports from other regions, and is related to hypotheses published in the literature. Possible factors, such as resource availability, overlap of habitats, the total land area at each elevation band, hard boundary, and human activities, may underlie the patterns. Greater efforts in conserving biodiversity in the high species richness areas of Hubei province should be made.

Keywords: biodiversity, conservation, elevation gradient, Hubei province, species richness

1. Introduction

A fundamental characteristic of mountain ecosystems is the drastic change in vegetation as well as in climate from the base to the summit of the mountains. Elevation gradients create varied climates, and a soil differentiation that may promote the diversification of plant species (Brown, 2001; Lomolino, 2001). Many studies have investigated species richness along elevation gradient across habits and taxa (Rahbek, 1995, 1997; Austrheim, 2002; Vetaas and Gerytnes, 2002; Sanders et al., 2003), as part of efforts to understand ecosystem effects on biodiversity and conservation of biodiversity (Tilman and Downing, 1994; Vetaas and Gerytnes, 2002). Furthermore, the observable associations between species distribution and elevation bands may help to understand the possible effects of climate change, e.g., by providing baseline information from which to measure or gauge the effect of climate change and anthropogenic changes on vegetation.

The regional patterns of species richness are a consequence of many interacting factors, such as plant productivity, competition, geographical area, historical or evolutional development, regional species dynamics, regional species pool, environmental variables, and human activity (Woodward, 1988; Palmer, 1991; Eriksson, 1996; Zobel, 1997; Criddle et al., 2003). In general, as identified by Rahbek (1995, 1997), there are three main patterns: a decline in species richness from low to high elevation, a hump-shaped pattern with a maximum at mid-elevations, or essentially a constant from the lowlands to mid-elevations followed by a strong decline further up.

This study is conducted with the aim to investigate the main patterns of spermatophyte richness along elevation gradient in Hubei province. Published data on distributions and elevation ranges of each plant species in Hubei province were used. The results are in turn compared with the reports from other regions. Finally, what factors may underlie the patterns is discussed.

2. Materials and Methods:

Study region

The Hubei Province is chosen as the study region because of its rich mountain habitats and high plant species diversity. It is located in the center of China (29° 05′ ~ 33° 20′ N; 108° 21′~116° 07′ E). Of its total land area of 185,900 sq km, 55.5 percent is mountains, 24.5 percent hills and 20 percent plains. It has eight major mountain ranges: Shennong Jia (peak height: 3105 meters), Julong (1852 meters), Dabie (1729 meters), Wudang (1612 meters), Jiugong (1543 meters), Tongbo (1140 meters), Dahong (1055 meters), and Jigong (744 meters) (Atlas of China, 2000). The predominant geological compositions are of granite, schistose and sedimentary rocks. The climate is continental, subtropical and seasonal, with an annual precipitation of 800-1600 mm. The province, claiming a total of 5650 spermatophyte species, is considered as one of the most important centers of biodiversity in China (Zheng, 1993). It is the native home to such important relic species as *Metasequoia glyptostrobodies* Hu et Cheng, *Ginkgo Biloba* L, and *Davidia involucrata* Bail.

3. Data source and Data analysis

Data on elevation ranges in the *Contemporary flora of spermatophyte plant species* in Hubei province (Zheng, 1993) was used in this study. The elevation gradient was divided into 15 200 meter intervals between 400 and 3105 meters above sea level, with the starting interval at 0 – 400 meters and the final one at 3000 – 3105 meters. This was due to fact that the lowland forest was transformed to agricultural land and according to the terrain of Hubei province.
Based on the information on the geographic range of each plant species in

Hubei province that was described in Zhang's book, the presence of each species in every 200 meter interval was recorded. Species richness here is defined as the total number of species present. Hence, the species richness for each of the elevation zones is the total number of species recorded as present within that band (i.e., gamma diversity, following Whittaker, 1972; Shimada and Wilson, 1985).

The patterns of species richness were showed in scatter plots, where horizontal axes are defined as elevation and the vertical axes as species richness.

4. Results and discussion

The patterns of plant species richness (spermatophyte) in Hubei province along an elevation gradient is shown in Figure 1. There is a significant increasing trend in total species richness from 400 meters to 1000 meters. From 1000 meters to 3105 meters, there is a clear decrease, except for a plateau between 1200 and 1600 meters. Thus, the high plant species richness in Hubei province is peaked at middle elevation range from 800 to 1400 meters, with the maximum value observed at 1000 meters. This value accounts for about 52 percent of the total number of spermatophyte found in Hubei province.

This falls within the general pattern of an initial increase in species richness with elevation, followed by a peak and then a decline with further increased elevation. It is similar to those found of forest tree species in the Qilian mountain

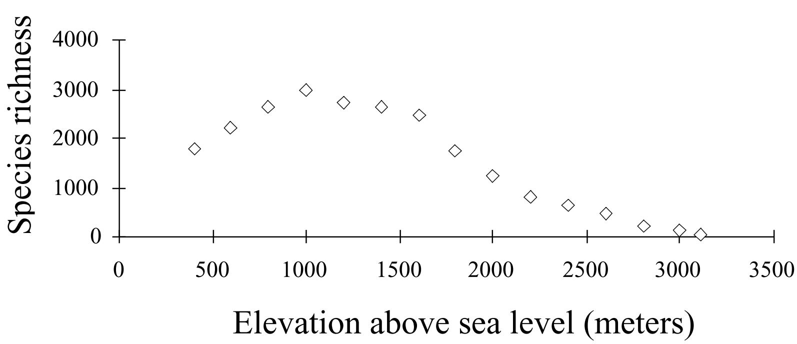

FIGURE 1

Plant species richness along elevation gradient of Hubei Province, China which peaked at 2400-2800 meters (Wang et al., 2003), of pteridophytes in Panama with maximum at 500-1500 meters (Lellinger, 1985), of vascular plant species of semi-natural subalpine grasslands in Vang, Southern Norway (Austrheim, 2002), and of tropical rain forests species (Lieberman et al. 1996; Vazquez Garcia and Givnish, 1998). Further examples of species richness peaking at intermediate elevations were reported by Edwards and Armbruster (1989) along a steppe tundra gradient in Alaska, and by Shmida and Wilson (1985) along an elevational gradient in Israel. According to Vetaas and Gerytnes (2002), about half of the published studied showed a mid-elevation peak in plant species richness.

Vegetation interacts with topography and soils, modifying microsites and creating ecological niches for various plants and animals. As a result, animal or insect species richness often mirrors plant species richness along elevation gradients. For example, the ant species richness peaked at mid-elevation range as showed by a study on the patterns of ant species richness along elevational gradients in an arid ecosystem in Spring Mountains, Nevada, U. S.A (Sanders et al., 2003). Similar patterns were also reported in insects (McCoy, 1990) and in small mammals (Heaney 2001; Richart, 2001).

The distribution of species richness along elevation gradients is governed by a series of interacting biological, climatic and historical factors (Colwell and Lees, 2000). Further, elevation represents a complex gradient along which many environmental variables change simultaneously (Austin et al., 1996). Thus, the effect of each variable could be difficult to separate and these interacting factors would be difficult to disentangle. While the present study did not include a specific test on the mechanisms that resulted in the patterns of species richness in this study, the concordance of proposed hypotheses in the literature with this observed actual pattern was evaluated. Factors that might affect this pattern were also discussed.

Several hypotheses have been put forward to explain elevation patterns of species richness. For example, optimum humidity conditions at mid-elevations (Rahbek, 1995, 1997) and the high productivity in the mid-elevation region which resulted by optimal combination resource availability (Rosenzweig, 1995). This observed hump-shaped species richness patterns of spermatophyte in Hubei province is in accordance with the hypothesis of productivity and optimum resource combination in the intermediate portion of the elevation gradient. The mid-elevation ranges with an optimal combination of environmental resource were more preferable for many species to coexist (Lomolino 2001; Brown, 2001), therefore, more species of spermatophyte was found in this elevation band in Hubei Province.

Few species are able to tolerate the entire spectrum of environment and range throughout the gradient (Pauses and Austin, 2001; Brown, 2001). Hence, species with elevational limited range always replace each other with some overlap along mountainside (Brown, 2001). A study of tree species distribution on Mt Emei in China, displayed a trend in which there is a unique set of temperature regimes that allow species usually associated with warmer temperatures to co-exist with species adapted to colder temperatures at higher elevations (Tang et al., 1997). This mixed community of low elevation and high elevation species has greater species richness than communities at lower or higher elevations. Such a tendency of overlapping habitats and resources in mid-elevation areas could be partially responsible for the high species richness of spermatophyte at mid-elevations in Hubei province.

The major decline in species richness above 1600 meters found in Hubei could be due in part to ecophysiological constrains, such a reduced growing season, low temperature and low ecosystem productivity in high elevation (Körner, 1998). In addition, the boundary effect could also influence the species richness at high elevation (Colwell and Lees, 2000; Gerytnes and Vetaas, 2002). Boundary effect is defined in relation to the degree of species resistance to dispersals and survival (Colwell and Lees, 2000). Mountains can be represented as islands through their reduced connectivity to means of colonization by plants and animals. As elevation increases, the isolation of slopes from pathways of migration increases linearly. With a reduction in the channels available for immigration, there is a reduction in the number of species that occupy high elevation sites. Moreover, a limited species pool of spermatophyte will also affect the species richness in high elevation, as environmental constraints are expected to exclude species from high elevation habitats (Körner, 1995).

Mountains generally have a conical shape and as the elevation increases, the area of the elevation band with certain set of environmental and climatic conditions decrease with increasing elevation. With a reduced area, there are fewer microsites for plants to occupy through the development of specific adaptive traits. The 200 meter interval used in this analyses do not represent equal area because of the topography of Hubei province. Therefore, the area effect could also account for the decline of species richness of spermatophyte in Hubei province in high elevation ranges (Rosenzweig, 1995; Zobel, 1997; Körner, 2000).

Other factors, such as soil fertility, topography may also affect the patterns of species richness along an elevation gradient. In mountain regions, the pattern of different forest types and other communities often corresponds to elevation and topography. Variation in microclimate with topography and elevation is a major factor of species distribution within a forest landscape. Mark et al (2000) found topographic features (elevation, exposure and slope) to be responsible for the macroscale patterns of alpine vegetation distribution on Mount Armstrong in New Zealand.

Human activities, such as changes in land-use, have a long lasting and direct impact on species richness in mountain environments. A study conducted by Curtin (1995) in southwest Colorado demonstrated that species diversity in the subalpine at elevations between 3000-3200 meters could be affected by human land use up to 110 years after the departure of the inhabitants. This study also showed that plant communities in high elevations are very sensitive to human disturbance.

In summary, the species richness of spermatophyte along elevation gradient in Hubei province is a hump-shaped distribution, with a high species richness in the middle elevation range from 800 to 1400 meters. These possible factors that might affect this pattern were resource availability, overlap of habitats, land area, and human activities. The high species richness in the elevational range of 800 -1400 meters means greater effort should be made focused on conservation on biodiversity of this area. Furthermore, our study could serve as baseline information to measure the effect of climate change. Further study on the factors that influences the species richness in Hubei province and the possible effects of climate change on the species richness patterns are needed.

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27 paper

PLANT PHENOLOGY IN CANADA and CHINA: BIOMONITOR FOR CLIMATE CHANGE

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ABSTRACT: The timing of spring plant development can be considered to be the most sensitive and easily-observed indicator of the biotic response to climate change. Spring bloom and leafing dates for perennial plants are largely controlled by heat accumulation, and trends in these dates can help reveal the rate of climate warming. These phenology data have been recorded in Canada for over a century, while the record in China goes back 3000 years. Analyses of phenology data show trends to an earlier onset of spring development in many temperate areas of the world, particularly over the last three decades. This trend has been detected also by remote sensing. Impacted sectors of society and the environment could include agriculture, forestry (including carbon sequestration), human health (for example, allergy seasonality), and biodiversity. Ecological implications include impacts at the level of species, populations, communities and ecosystems. Canada's Plantwatch program (www.plantwatch.ca) is coordinated by the Canadian government, educational institutions and non-profit organizations, and targets the public to report phenology for selected indicator plants. The Chinese Meteorological Agency currently has 400 stations tracking phenology. Future cooperation to establish observation of key indicator plant species on a wide geographic basis could greatly enhance our understanding of the effects of climate change.

Keywords: Agriculture, Bloom timing, Canada, China, Climate change, Forestry, Health, Phenology, Plantwatch, Remote sensing

1. Introduction

Plant phenology provides a useful tool to measure the effects of climate change. The rate of species development in spring is largely influenced by temperature, and trends to earlier development are being seen across much of our globe's temperate zone (Peñuelas and Filella 2001). Phenological data gathered by networks date back a century in Canada, and the current Plantwatch program has the potential to engage many Canadians in tracking the "green wave of spring" (Schwartz and Beaubien, 2003). In China the phenological record goes back 3000 years. It has been used to create calendars to guide farmers, and more recently to reveal historic climate change. Plant phenology and remotely sensed NDVI (normalized differential vegetation index) data for northern China have been linked to predict the effects of increased temperatures on the lengthening of the growing season.

Observed shifts in phenology have potential impacts on the economy through effects on sectors as diverse as agriculture, forestry, and human health. If this cost-effective method of tracking environmental change can be enhanced with cooperation between Canada and China, it will greatly increase our ability to track biotic change in space and time.

2. Plant Phenology

Phenology, the study of the seasonal timing of life cycle events, provides data useful in a variety of applications. The timing of spring plant development is considered to be the simplest, most sensitive and easily-observed biotic response to climate change. These data can also assist in decision-making and adaptation to change for agriculture, forestry, human health and tourism, and as validation for remote sensing imagery.

The variables tracked by phenology studies include stages of plant development such as timing of bud break, leafing, first bloom, full bloom and leaf colouring. In the zoological realm, examples of events recorded include timing of bird arrival, nesting and fledging, as well as insect development stages and mammal migration, reproduction and hibernation.

The timing of spring development of perennial plants in temperate zones of the earth is largely driven by accumulated temperature above a threshold value (Rathcke and Lacey, 1985). Photoperiod plays a greater role in the timing of late summer stages such as fruiting and leaf colouring. Moisture seems to have little effect on phenology in temperate zones (Menzel, 2003b). Because other organisms such as insects also develop in spring in response to temperature, the sequence of species development across trophic levels is largely consistent and predictable (Lieth, 1974).

3. Phenology in Canada

3.1 History in Canada

After deglaciation approximately 10,000 years ago, Canada was occupied by aboriginal peoples who depended on hunting, fishing, and collection of berries, roots and other plant products. Knowledge of the best timing for these activities enhanced these First Nations' chances of survival. Traditional knowledge of phenological calendars, or the timing and sequence of natural events, was passed down orally to successive generations. In British Columbia, ethnobotanic research has found over 140 phenological indicators among more than 20 First Nation linguistic groups, where a growth stage of one organism was used to predict a phase of another organism that was an important resource. Examples included prediction of the spawning time of salmonid fish, readiness for harvesting (in terms of adequate fat content) of certain animals, and availability of clams, berries or seaweed (Lantz and Turner, 2003).

In 1891, the Royal Society of Canada launched the first extensive survey of phenology in Canada (where extensive is defined as a survey involving many observers, for many years, and over a wide geographic area). Events tracked by volunteers included the timing of plant blooms, bird arrivals, freeze and thaw of lakes and rivers, and thunderstorms. The Botanical Club of Canada coordinated the survey until 1910, followed by the Canadian Meteorological Survey until 1922. Results were published annually in the Proceedings and Transactions of the Royal Society of Canada.

The next large survey was Canadian involvement in the United States' Regional Agricultural Experiment Station Regional projects. The projects began in the USA in the 1950's. In 1970, stations in several eastern Canadian provinces were added and continued at some stations through 1986. Phenological observations of lilac and honeysuckle continued until 1977. At that time, the Canadian province of Quebec had the largest participation of any state or province with 300 locations, of which about 50 were located at meteorological stations. This data was used by Dr. P. A. Dubé of Laval University to define bioclimatic and agricultural taxation zones in Quebec (Schwartz and Beaubien, 2003).

3.2 Plantwatch

Plantwatch in Canada began at the University of Alberta in 1995, a natural addition to the Alberta Wildflower Survey initiated by Beaubien in 1987. Plantwatch engaged Canadians in tracking bloom times of eight key species and reporting via the Internet, at www.devonian.ualberta.ca/pwatch (Beaubien and Freeland, 2000). One of the species, the common purple lilac (Syringa vulgaris), was tracked internationally. A teacher's guide was posted on this website in 2001, providing curriculum adaptations in science, mathematics, and social studies.

Beginning in 2000, PlantWatch expanded with assistance from Environment Canada's Ecological Monitoring and Assessment Network Coordinating Office and the Canadian Nature Federation. There are now coordinators who work on a volunteer basis in each of Canada's 13 provinces and territories. Promotional materials have been produced including a booklet "Plantwatch: Canada in Bloom" and a website is maintained where data is reported and the results can be viewed immediately on a map (www.plantwatch.ca). Canadians can choose to observe up to 15 widespread indicator plant species and many other regional species as well.

Global circulation modeling predicts that global warming will show the largest and fastest increases in northern ecosystems (Maxwell, 1992). To boost observation of the plant response, the northern Plantwatch coordinators have successfully combined forces and secured funding from Environment Canada's Northern Ecosystem Initiative program. Plantwatch North posters and booklets (Morin et al., 2003) have been produced in the English, French and Inuktitut languages. However, the progress of Plantwatch on the national scale is currently hindered by a lack of funding. There is no funding for coordinators to do the annual tasks of promotion and fundraising, as well as volunteer and data management, and progress is therefore intermittent.

3.3 Trends in phenology

Trends to an earlier spring have been noted in western Canada. An index of spring flowering was calculated as an annual mean of first bloom dates for three woody species, *Populus tremuloides* (aspen poplar), *Amelanchier alnifolia* (saskatoon or service berry) and *Prunus virginiana* (chokecherry). Data for the period 1936-1996 for Edmonton, Alberta revealed that bloom time has become earlier by eight days, while the tree species that blooms at the very start of spring, *P. tremuloides,* is blooming earlier by almost a month over the last century. Alberta's prevailing winds come from the west from the Pacific Ocean, and El Niño climatic events have an influence on the phenological response. Years of medium or strong El Niño events are also years of early bloom in Alberta (Beaubien and Freeland, 2000). Bloom time of Macintosh apples in Summerland, British Columbia shows a five day trend to earliness over the years 1936 to 2000 (Beaubien and Hall-Beyer, 2003).

In eastern Canada shifts to earlier bloom have as yet not been reported in keeping with temperature and other climate variables. In Nova Scotia

Plantwatch data for 1996-1998 were compared with historic data from the early 1900's, and significant differences in bloom time were not found for most plant species (Vasseur et al., 2001). Schwartz and Reiter (2000) show results for trends in eastern Canada over the 1959-1993 period.

These trends are not limited to plants. The timing of egg-laying in tree swallows *(Tachycineta bicolour)* across North America showed an advance in dates of up to nine days (1959-1991), which is attributed to increased temperatures during that period (Dunn and Winkler, 1999). Data from southern Ontario suggests that climate warming of 5 degrees Celsius in May could result in tree swallows laying eggs about one week earlier (Hussell, 2003).

4. Phenology in China

4.1 Observation networks

Modern phenological observation and research in China started in the 1920s with Dr. Kezhen Zhu (1890-1974). Beginning in 1921, Zhu observed spring phenophases of several trees and birds in Nanjing, China. (A phenophase is an easily observed growth stage). In 1931, Zhu summarized phenological knowledge from the last 3000 years in China. He also introduced phenological principles developed in Europe and the United States from the mid eighteenth to the early twentieth century (Zhu, 1931).

In 1934, Zhu organized and established the first phenological network in China. Observations of some 21 species of wild plants, nine species of fauna, some crops, and several hydro-meteorological events continued until 1937 when they ceased at the start of the War of Resistance against Japan (1937-1945). Twenty-five years later, in 1963, the Chinese Academy of Sciences (CAS) established a countrywide phenological network which continued until 1996. In 2003, phenological observations resumed again with a reduced number of stations. This observation program included a total of 173 observed species. Of these, 127 species of woody and herbaceous plants had a localized distribution. There were 33 species of woody plants, two species of herbaceous plants, and 11 species of fauna observed widely across the network (Institute of Geography, Chinese Academy of Sciences, 1965).

The Chinese Meteorological Administration (CMA) established another countrywide phenological network in the 1980s. This network is affiliated with the national-level agrometeorological monitoring network. The phenological observation criteria for woody and herbaceous plants and fauna were adopted from the Chinese Academy of Sciences network. In addition to phenological observations of native plant species, the network also carries out phenological observation of crops (National Meteorological Administration, 1993). There were 587 agrometeorological measurement stations in 1990. As the phenological and meteorological observations are parallel in this network, the data are especially valuable for understanding phenology-climate relationships. These data can also be used to provide agrometeorological services with predictions on crop yield, soil moisture and irrigation amounts, plant diseases and insect pests as well as forest fire danger (Cheng et al., 1993).

4.2 Traditional research

Traditional phenology research in China focuses mainly on compiling phenological calendars, defining phenological seasons, phenological mapping, detecting historical climate using phenological data, as well as phenological modeling and prediction.

Zhu and Wan (1973) compiled a phenological calendar based on observational data from 1950 to 1972 in Beijing, China consisting of the average, earliest, and latest dates of 129 phenological events. In the 1980s, the Institute of Geography at the Chinese Academy of Sciences devised uniform criteria to compile phenological calendars at stations of the Chinese Academy of Sciences network. Altogether 45 phenological calendars in China were published (Wan, 1986; 1987). In each calendar, the main phenological events of plants and fauna, together with hydro-climatic events, were chosen to represent an ordinal succession of phenophases in the annual cycle at each station.

In order to detect the spatial difference of phenological occurrence dates in a relatively small area, a specific observation network of ~17,000 km^2 was established in the Beijing area. Based on the observed data for 1979-1987 of this network, 16 phenological calendars were published (Yang and Chen, 1995). In order to represent the most detailed and continuous succession of phenophases, each phenological calendar in this area included almost all observed phenological occurrence dates. The results showed that the spatial difference of the average occurrence dates of a spring phenophase was three to seven days between urban and rural areas on the plain, but increased to ten days to one month between plain and mountain areas. Generally speaking, phenophases during spring and summer appeared first in the urban area and then in rural and mountainous areas. In contrast, phenophases during autumn and early winter appeared first in mountainous and rural areas and then in the urban area.

An earlier method for determining phenological seasons was developed by Wan (1986). In order to be able to compare phenological seasons among different stations, both temperature and phenology indicators were used. Daily mean temperatures of 3 degrees Celsius and 19 degrees Celsius were thresholds indicating the beginning dates of spring and summer, whereas 19 degrees Celsius and 10 degrees Celsius were thresholds indicating the beginning dates of autumn and winter. Beginning dates of sub-seasons were also defined using other specific temperature thresholds. Phenological indicators for the beginning dates of the temperature seasons were determined by reference to the local phenological calendar. However, the same plant phenophase occurred under different air temperatures in different areas (Japanese Agrometeorological Society, 1963; Reader et al., 1974).

In order to determine phenological seasons accurately, a new procedure called "phenological frequency distribution pattern" was developed at Beijing, China (Chen and Cao, 1999). The mixed data set was composed of phenological

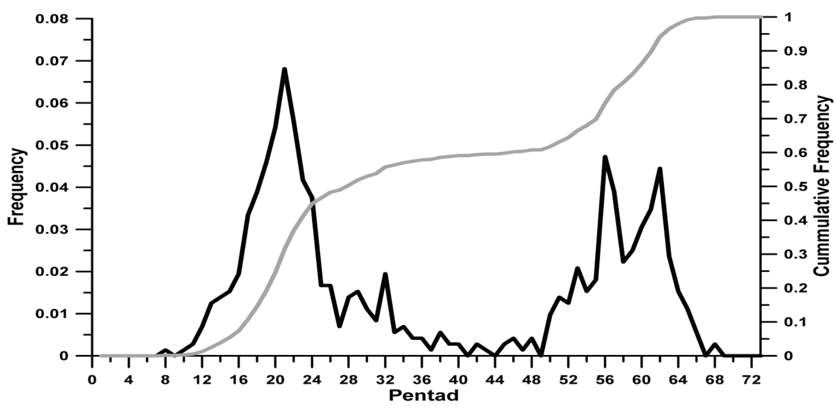

FIGURE 1

Frequency (black, left scale) and cumulative frequency curve (gray, right scale) of phenophases in Beijing (1979-1987).

occurrence dates of all observed deciduous trees and shrubs, including bud-burst, first leaf unfolding, 50 percent leaf unfolding, first bloom, 50 percent bloom, the end of blooming, fruit or seed maturing, fruit or seed shedding, first leaf coloration, full leaf coloration, first defoliation and the end of defoliation. Sequential and overlapping occurrences of phenophases represent seasonal succession of the local plant community. From these data, the frequency and cumulative frequency of phenophases in every five-day period, or pentad, throughout the year are calculated. Phenological seasons could be identified according to the turning point of the empirical cumulative frequency curve, the changing rates of phenological cumulative frequency, and fluctuation patterns of phenological frequency (see Figure 1).

Zhu (1973) pioneered revealing historical climate change using phenological evidence in China. Using ancient phenological data and other data, he reconstructed a temperature series of the past 5000 years in China. Three main results were shown. Firstly, during the initial 2000 years, the annual mean temperature in most eras may have been 2 degrees Celsius higher than the present with the winter temperature being 3-5 degrees Celsius higher. Secondly, there were several fluctuations towards lower temperatures in 1000 B.C., 400 A.D., 1200 A.D. and 1700 A.D. with an amplitude of 1-2 degrees Celsius. Thirdly, in each period of 400-800 years, several smaller cycles of 50-100 years with an amplitude of 0.5-1 degrees Celsius could be identified. A strong agreement was found between Zhu's temperature series and the temperature series obtained by variations of the isotope O^{18} content of the Greenland ice sheet during the last 1700 years (Zhu, 1973).

Approximately 200 kinds of archaic personal diaries remain in the Chinese literature, and 10-20 percent of them contain phenological data. Using the historical phenological data and other evidence, as well as the modern phenological data since 1950, Gong et al. (1984) reconstructed the spring phenological series from 1849 to 1981 in Beijing, China. The statistical analyses indicated that there were 7.4-year, 4-year, and 2-year cycles in the time series.
Statistical models can simulate temporal and spatial phenological performance. In order to predict flowering dates, linear regression equations were established between flowering dates of different trees in Beijing (Yang and Chen, 1985) and in North China (Chen and Yang 1988; Chen 1990). Another kind of statistical model was constructed between the average occurrence date of a phenophase and geographical coordinates at different stations.

Based on a linear regression equation established between average occurrence date of a phenophase and annual mean temperature at all stations, the possible effects of a temperature rise of 0.5 degrees Celsius, 1.0 degrees Celsius, 1.5 degrees Celsius, 2.0 degrees Celsius, and the doubling of the atmospheric carbon dioxide concentration scenario on plant phenology were extrapolated. Results showed that the corresponding phenophases may advance 4-6 days in spring and summer, and delay 4-6 days in autumn under the scenario of doubled carbon dioxide concentration in the atmosphere (Zhang, 1995).

4.3 Growing season and climate change

The climate of the earth has warmed by about 0.6 degrees Celsius over the last century. The period of warming from 1976 onwards shows the fastest rate of increase of any warming period over the last 1000 years (IPCC, 2001). A temperature-related shift in response was detected in a survey of 143 studies of plants and animals, and over 80 percent of these species showed changes or shifts in the expected direction (Root et al., 2003).

In recent years, determining the growing season of land vegetation at a large scale has become an important scientific question for global climate change research. Several studies have shown a lengthening of the growing season in the Northern Hemisphere (Keeling et al., 1996; Myneni et al., 1997; Zhou et al., 2001). These results are also supported by surface phenological observation of individual plant species in Europe (Menzel and Fabian, 1999; Peñuelas et al., 2002) and North America (Schwartz and Reiter, 2000). However, before a detailed integrative comparison between surface vegetation dynamics and remote sensing reflectance values (such as the normalized difference vegetation index or NDVI) can be carried out, a relationship between these measurements must be established at the regional scale. Therefore there is merit in first determining the temporal relationship of surface green wave phenology with NDVI phenology (Schwartz, 1994). Because current understanding of how well satellite sensor-derived greenness actually represents ground phenology is relatively poor (Markon et al., 1995), Chen et al. (2000, 2001) proposed a new statistical procedure to determine the growing season based on plant phenological and NDVI data at three sample sites, and assessed its feasibility in extrapolating the growing season from the sample sites to other sites in northern China (see Figure 2).

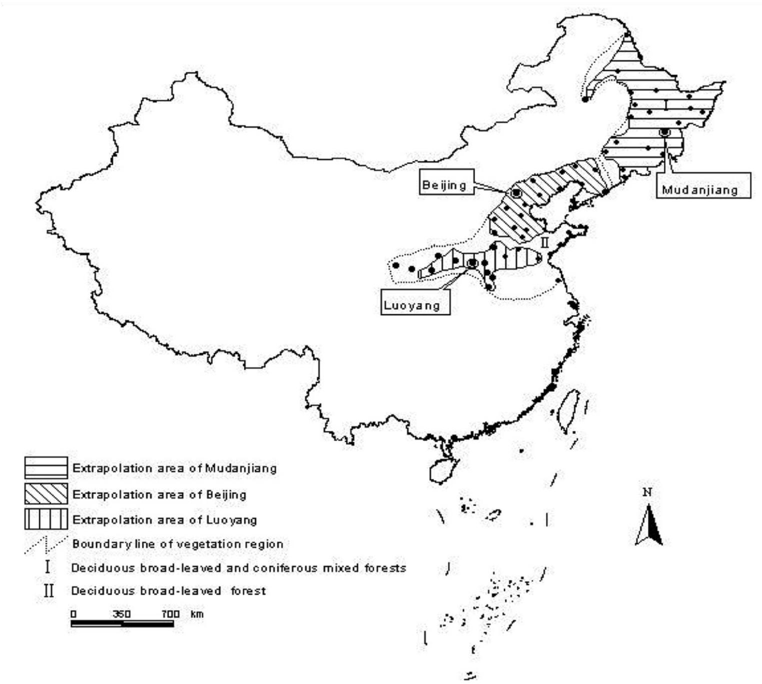

FIGURE 2

Sample sites and spatial extrapolation areas of the growing season in northern China (1983)

In order to explore phenology-climate relationships at the plant community level, a correlation analysis was undertaken to compare the beginning of the growing season, the end of the growing season, the length of the growing season, and seasonal climate variables (Chen and Pan, 2002). The beginning of the growing season is influenced mainly by mean air temperature and growing degree days above 5°Celsius from January to March at Beijing and Luoyang, China and from February to April at Mudanjiang, China. The overall negative correlation indicates that higher mean temperatures and growing degree day totals in late winter and spring may induce an earlier onset of the phenological growing seasons of local plant communities. However there is no significant correlation between the beginning of the growing season and seasonal precipitation.

On average, if annual mean temperature and mean temperature during late winter and spring increase by 1 degree Celsius, the growing seasons would lengthen 6.7-7.2 days and 10.4-11.5 days, respectively, while if annual total growing degree days increases 100 degree days, the growing seasons would lengthen 4-5 days. Since the growing season length models were based on the spatial-temporal series of all three sample sites, they should not only be useful to estimate the response of the growing season to climate change at the sample sites but also at other adjacent sites with similar vegetation dynamics and climate conditions.

5. Trends in phenology from other parts of the world

Schwartz and Reiter (2000) used modeled and actual lilac data for 1959-1993 and found an average 5 to 6 day advance in onset of spring in North America. The greatest trend noted was in the northeast and northwest. In the western USA, increases in temperature of 1 to 3 degrees Celsius began in the 1970's, coincident with earlier streamflow pulse dates, and with earlier bloom of lilac and honeysuckle of 0.15 to 0.35 days per year (Cayan et al., 2001). Bradley et al. (1999) found an average of 0.12 days per year advance in phenological data for plants and birds in southern Wisconsin from 1936 to 1998. These data included a 30 year gap.

Over the last decades a lengthening of the growing season is evident in the phenological record, and also in remote sensing data, temperature data, and atmospheric carbon dioxide concentration records (Menzel, 2003b). In the mid 1970's there is a flex point in both temperature and phenological data, where temperatures started an upward swing and phenological events shifted to earlier onset (Peñuelas and Filella, 2001). A study of precise phenological data obtained from International Phenological Gardens from Scandinavia to Greece (1959-1993) showed an 11 day trend to a longer growing season. An earlier arrival of spring by six days was also seen (Menzel and Fabian, 1999). In northern and central Europe the timing of some spring events such as growing season start can be correlated with values of the NAO (North Atlantic Oscillation) index related to winter climatic conditions (Menzel, 2003a).

Phenological responses to temperature are similar in plants and birds, as shown by data on spring arrival of birds, hatching of flycatchers, and leaf unfolding in birch and horse chestnut trees in Germany (Walther et al., 2002). Regional climate trends can also be different even within a small area (Schwartz, 1999).

While for most of Europe Spring is arriving earlier, certain areas such as southeastern Europe are showing a delayed spring response (Menzel and Fabijan, 1999).

Europe has much long-term data in phenology as shown in the review by Menzel (Menzel, 2003a). In the last decade, two vigorous new observation networks, both called "Nature's Calendar" and involving thousands of observers, have been created in the United Kingdom (www.phenology.org.uk) and the Netherlands (www.natuurkalender.nl).

6. Implications of shifts in phenology

Environmental change is one major possible result of shifts in phenology. Using observed and predicted shifts in climate and in phenology, Lechowicz (2001) notes that species could respond in three possible ways. Firstly, they could migrate to climatic areas that suit their suite of phenological responses. Movement of plant species is limited by many factors including reproductive strategies and suitability of the substrate in the new region. In temperate and Arctic zones there could be a shift of vegetation communities upwards in altitude, and towards the Poles. These shifts have occurred across a wide range of taxonomic groups including high latitude plants, many species of butterflies, and red and arctic foxes. As well the position of treeline has moved (Walther et al., 2002).

Secondly, plant species can stay where they are and exploit what genetic variability they have to adapt to the changing conditions. Thirdly, if species are unsuccessful in adapting to new conditions of climate and habitat, they will lose their dominance position in the plant community, or disappear. Changes at the species level will impact communities and ecosystems in unknown ways. The synergism of temperature increases, habitat destruction, and other possible stresses such as pollution and invasive species will result in differential species responses and lead to many extirpations and possibly extinctions (Root et al., 2003).

Species respond to abiotic factors in different ways. Changes in ecological partnerships such as decoupling of species interactions, including pollination, predator-prey relations, etc., can be expected. For many birds, photoperiod, which is unaffected by climate change, triggers the start of migration. If their food supply is available earlier over time as a result of climate warming, nestling survival could be jeopardized.

There are a number of other implications of shifts in phenology. Climate change, including warming, results in changes in carbon uptake and sequestration and has impacts on the global carbon cycle. In the area of human health, changes in the timing of pollen seasons and potential lengthening of the growing season could extend the allergy season in temperate climates. In agriculture, changes in climate and the phenological response affect the incidence of new pests and diseases, timing of fertilization and irrigation, suitability of new crops, timing of crop protection, and quality of produce. In forestry, changes in phenology will impact fire incidence and fuel availability. Phenology data is essential for modeling of mixed forest growth (Rötzer et al., 2004) and for modeling the future distribution of tree species (Chuine and Beaubien, 2001).

7. Benefits of future cooperation between Canada and China and with other countries

The tracking plant phenology provides a cost-effective way to track ecological changes resulting from climate change. Other changes such as shifts in species distributions, populations or communities will be more difficult and costly to detect (Menzel, 2003b).

Phenological research is essential to understand the dynamics of climate change. To track biotic response change over a wide geographic area, networks of public observers combined with more technical observers should be sought. These skilled observers could be found at research stations for meteorology, agriculture, or forestry, at university biological stations and at national parks and botanic gardens.

Phenological data are useful to monitor ecosystems and understand the dynamics of plant communities and thus animal communities. These data can be used to plan landscape design, prevent garden and crop pests and diseases, optimize the timing of farm activities, provide ground validation for remote sensing images, and even assist in planning for tourism. China has experience in the application of phenological calendars and data modeling that may help agriculture become more sustainable.

What is needed is a global observation system of common plants, including both native plants and cloned cultivars, integrated into the meteorological services around the world (Schwartz, 2003). This program would likely be most useful in the temperate zone where phenology is largely driven by temperature.

A Global Phenological Monitoring (GPM) program was started in 1998 using cloned plant cultivars and 15 gardens now exist for this purpose in Asia, Europe, and the United States (Bruns et al., 2003).

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appendix

CONFERENCE PROGRAM

气候变化
CLIMATE CHANGE:

适应能力建设
Building the Adaptive Capacity

An international conference on adaptation science, management and policy options

May 17-19, 2004
Lijiang, Yunnan, China
Lijiang Jade Dragon Garden Hotel

CONFERENCE OBJECTIVES

- showcasing the most recent science, management and policy options available in the community of climate change adaptation.
- strengthening the capacity of key Chinese institutions, and sectors such as agriculture, to identify and assess the sensitivities and vulnerabilities associated with climate change.
- promoting the integration of adaptation strategies into Chinese government development and planning initiatives.
- enhancing the adaptive capacity of Chinese institutions, sectors, agencies and people.

Monday, **May 17**

0900 to 1000 OPENING STATEMENTS

Co-Chairs: Lin Erda, AgroMeteorological Institute,
Chinese Academy of Agricultural Sciences
Don MacIver, Meteorological Service of Canada

Gao Guangsheng, Director-General, Office of the National Coordination Committee for Climate Change (ONCCCC), National Development and Reform Commission,China (NDRC)

Gao Feng, Acting Director-Genera, Dept. of Treaty and Law, Ministry of Foreign Affairs

Leigh Sarty, Counsellor, Political, Canadian Embassy to China

Wu Fan, Deputy Director-General of Yunnan Development and Reform Commission, China

Chao Qingchen, Deputy Director-Genera, Dept. of S&T, China Meteorological Administration

1000 to 1200 KEYNOTE ADDRESSES

Co-Chairs: Lin Erda, AgroMeteorological Institute,
Chinese Academy of Agricultural Sciences
Don MacIver, Meteorological Service of Canada

Climate Change: Building the Adaptive Capacity
Ian Noble, Advisor (Adaptation), World Bank Group

U.S. Climate Change Science Program: Adaptation
Richard Moss, U.S. Climate Change Science Program Office

1200 to 1400 LUNCH

1400 to 1530 ADAPTATION SCIENCE (THEORY)

Chair: Adam Fenech, Meteorological Service of Canada

Climate Change Impacts and Adaptation Strategies
Ian Burton, President, International Society of Biometeorology

Climate Change Vulnerabilty and Adaptation
Lin Erda, AgroMeteorological Institute, Chinese Academy of Agricultural Sciences

1530 to 1600 Break

1600 to 1730 **ADAPTATION SCIENCE, IMPACTS AND POLICY**

Chair: Yongyuan Yin, Meteorological Service of Canada

The UK Experience with Adaptation
David Warrilow, UK Department for Environment, Food and Rural Affairs (invited)

Adaptive Strategies – Investing in Disaster Resilient Housing
Paul Kovacs, Institute for Catastrophic Loss Reduction, Canada

An Adaptation Protocol under the FCCC
Lv Xuedu, Division of Resources and Environment,
Ministry of Sciences and Technology, PR China and
Li Yu'e, AgroMeteorological Institute, Chinese Academy of Agricultural Sciences

1730 to 1830 **POSTER SESSION**

Tuesday, May 18

0900 to 1030 ***Concurrent Session 1***

Chair: Xiu Yang, Chinese Academy of Agricultural Sciences

CLIMATE CHANGE ADAPTATION – WATER AND SNOW

The Interaction of human activity, Climate, Hydrology and Ocean and the Impact Adaptation in the costal zone of China
Liu Chunzhen Cheng Weijun, Information Center, Ministry of Water Resources

Impact and Adaptation in China - Coastal Zone
Yang Shouye, Li Congxian, Tongji University

Climate Change and Coastal Zone Management Processes
Mark Taylor, Amec Earth and Environmental, Canada
Changing Features of the Climate and Glaciers in China's Monsoonal Temperate-Glacier Region

Yuanqin He CAREERI, CAS

0900 to 1030 ***Concurrent Session 2***

Chair: Ian Burton, President, International Society of Biometeorology

CLIMATE CHANGE ADAPTATION – REGIONAL ASSESSMENTS, AND HUMAN HEALTH

Regional Assessments of Climate Change Adaptation in Canada: Okanagan Case Study
Stewart Cohen, Meteorological Service of Canada

The United Kingdom's Climate Impacts Programme
Gerry Metcalf, United Kingdom Climate Impacts Programme

Adapting to Climate Change Impacts on Human Health
Dieter Riedel, Health Canada

Integrated Assessment Modelling for Regional Municipalities in Mitigating and Adapting to Climate Change
Adam Fenech, Meteorological Service of Canada

1030 to 1100 **BREAK**

1100 to 1230 ***Concurrent Session 3***

Chair: Jiaguo Qi, Michigan State University, USA

CLIMATE CHANGE ADAPTATION – ECOTOURISM AND BIODIVERSITY

Ecosystem vulnerability assessment
Dr. Yu, Yua ESSI, Nanjing University

Plant Phenology: Biomonitor for Climate Change
Elisabeth Beaubien, University of Alberta, Canada
Tourism and Recreation, Protected Areas, and Climate Change
Fred Roots, UNESCO MAB Program

Biodiversity and Climate Change
Don MacIver, Meteorological Service of Canada

1100 to 1230 ***Concurrent Session 4***
Chair: Ian Burton, President, International Society of Biometeorology

CLIMATE CHANGE ADAPTATION – SOCIO-ECONOMICS, ENERGY AND INFRASTRUCTURE

Socio-ecological adaptive choices of climate change in ancient China
Dr. David Zhang, Hong Kong University

Changing Weather Hazards and the Vulnerability of our Infrastructure
Heather Auld, Science Assessment and Integration Branch, Meteorological Service of Canada

Climate Change and Extreme Weather Events: Vulnerability and Adaptation of the Canadian Energy Sector
Monirul Mirza, Burtoni Fellow

Energy Efficiency and Energy from Renewables: Bringing Mitigation and Adaptation Together
Quentin Chiotti, Pollution Probe, Canada

1230 to 1400 LUNCH

1400 to 1530 OPEN PLENARY SESSION FOR C5 AND AS25 PROJECTS

Chair: Dr. Wang Bangzhong, China Meteorological Administration
Prof. Lin Erda, Chinese Academy of Agricultural Sciences

Don MacIver, Adaptation and Impacts Research Group, Meteorological Service of Canada

Madame Sun Cuihua, State Development and Reform Committee, Peoples Republic of China

Dr. Si Zhizhong, C5 Local Project Manager, Environment Canada

Communication under the C5 Project
Mary Murphy, Climate Change Bureau, Environment Canada

The AIACC Project: Assessments of Impacts and Adaptations to Climate Change
Ian Burton, President, International Society of Biometeorology

1530 to 1600 BREAK

1600 to 1730 ***Concurrent Session 5***

CANADA - CHINA COOPERATION IN CLIMATE CHANGE (C5) PROJECT: ADAPTIVE CAPACITY TRAINING (WBS 3333) WORKSHOP

Chair: Prof. Lin Erda, Chinese Academy of Agricultural Sciences
Rapporteurs: Dr. Ma Shiming and Robin Bing Rong

Assessing PRECIS RCM Simulations of Climate over China
Xu Yinlong, AgroMeteorological Institute, Chinese Academy of Agricultural Sciences

Development of socio-economic scenario for China
Yao Yufang, Jiang Jinhe, Chinese Academy of Social Sciences

Agricultural Adaptation to Climate Change in China: Management and Options
Ma Shiming, Ju Hui, AgroMeteorological Institute, Chinese Academy of Agricultural Sciences

1600 to 1730 *Concurrent Session 6*

INTEGRATED ASSESSMENTS OF VULNERABILITIES AND ADAPTATION TO CLIMATE VARIABILITY AND CHANGE IN THE WESTERN REGION OF CHINA - AIACC AS25 PROJECT WORKSHOP

Chair: Dr. Wang Bangzhong (DG, China Meteorological Administration)
Rapporteurs: Dr. Xu Yin (China Meteorological Administration)

Overview of the AS25 project progress
Prof. Peng Gong (Director, ESSI/Nanjing University and University of California at Berkeley)

Methodologies, work plans, and research activities
Dr. Yongyuan Yin, Co-Principal Investigator of AS25, Meteorological Service of Canada

Climate and land interaction processes in arid and semi-arid ecosystems
Dr. Jiaguo Qi, Michigan State University, USA

Climate change scenarios
Dr. Xu Yin, Chinese Meteorological Administration

1730 to 1900 **DINNER**

1900 to 2030 *Concurrent Session 7*

Chair: Prof. Lin Erda, Chinese Academy of Agricultural Sciences
Rapporteurs: Dr. Ma Shiming and Robin Bing Rong

CANADA - CHINA COOPERATION IN CLIMATE CHANGE (C5) PROJECT: ADAPTIVE CAPACITY TRAINING (WBS 3333) WORKSHOP - CONTINUED

Climate Change Adaptation and Sustainable Development
CHEN Ying, Chinese Academy of Social Sciences

Sensitivity and Vulnerability mapping
Dr. Yang Xiu, Chinese Academy of Agricultural Sciences

Adaptive Capacity - Social and Economic Coping Capacity and its Indicators in Northeast China
Bing Rong and Dr. Ma Shi Ming

Latest Impacts and Adaptation Assessment for Agriculture
Professor Lin Erda

1900 to 2030 *Concurrent Session 8*

Chair: Dr. Wang Bangzhong (DG, China Meteorological Administration)
Rapporteurs: Dr. Xu Yin (China Meteorological Administration)

INTEGRATED ASSESSMENTS OF VULNERABILITIES AND ADAPTATION TO CLIMATE VARIABILITY AND CHANGE IN THE WESTERN REGION OF CHINA - AIACC AS25 PROJECT WORKSHOP – CONTINUED

CAREERI vulnerability and adaptation research in Heihe Region
Long, Aihua CAREERI, CAS

GIS Applications in AS25 and Website Design
Nicholas Clinton, ESSI, Nanjing University

Assessment of water system vulnerabilities to Climate Change
Dr. Zhang, Jishi CAREERI, CAS

2030 to 2100 **OPEN PLENARY – CONFERENCE CLOSING**

Wednesday, May 19

An optional one-day Study Tour around the city of Lijiang including: Jade Dragon Snow Mountain (Yulong Mountain); Spruce Plateau (Yunshan Plateau); Baisha Mural and Naxi Ancient Music; Dry Sea (Ganhai); White Water River and the Lijiang Old Town.

Canada