RESPONDING TO GLOBAL CLIMATE CHANGE IN BRITISH COLUMBIA AND YUKON

Volume I of the Canada Country Study: Climate Impacts and Adaptation

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This is a component report of the Canada Country Study: Climate Impacts and Adaptation. In addition to a number of summary documents, the first phase of the Canada Country Study will produce six regional volumes, one volume comprising twelve national sectoral reports, and one volume comprising seven cross-cutting issues papers. This is Canada Country Study - Volume I: British Columbia and Yukon Regional Report.

For further information on the Canada Country Study (CCS), please contact the CCS national secretariat in Toronto, Ontario at 416-739-4389 (telephone), 416-739-4297 (fax), or ccs.cia@cciw.ca (e-mail).

Ce rapport est une partie composante de L'Étude pan-canadienne sur l'adaptation à la variabilité et au changement climatique. En plus de quelques documents sommaires, la première phase de L'Étude pan-canadienne produiront six tomes régionaux, un tome comprenant douze rapports nationaux au sujet des les secteurs sociaux et économiques, et un tome comprenant sept papiers concernant les questions polyvalentes. Ce rapport est L'Étude pan-canadienne - Tome 1: Rapport Regional pour la Columbie Britannique et Yukon.

Pour plusieurs renseignements concernant L'Étude pan-canadienne (ÉPC), contactez le secrétariat national de l'ÉPC à Toronto à 416-739-4389 (téléphone), 416-739-4297 (facs.), ou ccs.cia@cciw.ca (poste élect.).

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PREFACE

THE CANADA COUNTRY STUDY

Intent

The Canada Country Study (CCS): Climate Impacts and Adaptation is a national evaluation of the impacts of climate change and variability on Canada as a whole, including consideration of existing and potential adaptive responses. In presenting this national perspective, it draws upon studies of a number of regional, sectoral and cross-cutting issues, of which this volume is one.

The study was initiated by Environment Canada (EC) and is being lead by the Environmental Adaptation Research Group, a component of EC's Atmospheric Environment Service located in Downsview, Ontario. Among the participants are representatives of various levels of government, the university community, the private sector and non-governmental organizations.

In providing Canadians with a balanced, realistic picture of what climate change and variability means for Canada as a whole, the CCS effort builds upon a number of sectoral and regional impact studies that have been completed during the past decade.

The CCS will provide information to Canadian policy makers in the public and private sectors, socio-economic decision makers, the scientific community both domestically and internationally, non-governmental organizations, and the Canadian general public.

Structure

Work on the CCS is divided into two phases. Phase I began in the summer of 1996 and will conclude in the fall of 1997; it is focussed on an extensive review and assessment of all existing literature, the identification of knowledge gaps, and the development of recommendations for future research. The latter would be addressed in Phase II which is expected to begin in late 1997 and extend over approximately a five-year period.

In Phase I, a number of summary reports will be published - a national policy makers summary, a national plain language summary, and six regional plain language summaries. In addition, the basis of these summaries - 25 component studies and papers - are being published in 8 volumes as follows:

- Vol. I - British Columbia and Yukon
- Vol. II - Arctic
- Vol. III - Prairies
- Vol. IV - Ontario
- Vol. V - Québec
- Vol. VI - Atlantic
- Vol. VII - Sectoral (comprising 12 national papers on agriculture, built environment, energy, fisheries, forestry, human health, insurance, recreation and tourism, transportation, unmanaged ecosystems, water resources and wetlands)
- Vol. VIII - Cross-Cutting (comprising 7 national papers on changing landscapes, domestic trade and commerce, extra-territorial influences, extreme events, integrated air issues, sustainability, and the two economies).

THE CLIMATE BACKGROUND

Climate Change and Variability

Climate may be thought of as a description of the regularities and extremes in weather for a particular location. It is also, however, naturally variable; from our own experience, we know that one summer is often warmer than another, or one winter is colder or snowier than another. Such variability is a normal feature of a stable climate, and is related to changes in ocean currents or sea-surface temperatures, volcanic eruptions, alterations in the sun's output of energy, or other complex features of the climate system some of which are not yet fully understood.

Natural large-scale climate shifts (or climate changes, such as those that resulted in past ice ages or warm interglacial periods) are driven by long-term alterations in the position of the Earth with respect to the sun. Such alterations can be reflected in changes in the composition of the Earth's atmosphere, an important characteristic of which is the occurrence of certain greenhouse gases (such as carbon dioxide and methane). These gases keep the Earth's surface and atmosphere from cooling too rapidly and help to maintain surface temperatures within the range needed to support life.

Greenhouse gas concentrations have been observed to be lowest during periods of cold climate (ice ages) and highest during warm periods. This connection is of concern because human activities since the beginning of the industrial revolution over 200 years ago (mainly involving the burning of fossil fuels) have greatly increased the concentration of such gases in the atmosphere. Scientists expect to see a doubling of the atmospheric composition of carbon dioxide, for example, within the next century. The increase so far is already considered to have had a discernible effect on the Earth's climate, an effect which is expected to continue.

Models and Scenarios

In order to understand how the world's climate may respond, elaborate supercomputer models of the climate system are used. Known as general circulation models or GCMs, these models are used to simulate the type of climate that might exist if global concentrations of carbon dioxide were twice their pre-industrial levels. Although the models disagree about many of the details of a doubled carbon-dioxide climate, the results of the simulations all agree that the Earth would be warmer, on average (with more warming occurring towards the poles), and would experience overall increases in both evaporation and precipitation. These simulations of climate are referred to as "GCM-driven scenarios" - distinct from actual forecasts for the future - since they depict a possible future based on certain assumptions about atmospheric composition. The most recent report of the Inter-governmental Panel on Climate Change (IPCC - *qui vive*), issued in 1995, projects an increase in global surface temperature of 1 to 3.5°C over the next 100 years. This may be compared with the observed increase of 0.3 to 0.6°C over the past 100 years.

For its first Phase, the CCS does not follow a single climate scenario. It reflects the range of scenarios that have been used as a basis for the various papers and reports appearing in the scientific literature. In general, the main model scenarios used come from one of five GCMs which have been developed in Canada, the United States, or the United Kingdom.[1]

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[1]

- CCC92 - Canadian Centre for Climate Modelling and Analysis 2nd Generation model
- GFDL91 - Geophysical Fluid Dynamics Laboratory model (US)
- GISS85 - Goddard Institute for Space Studies model (US)
- NCAR93 - National Center for Atmospheric Research model (US)
- UKMO95 - UK Meteorological Office model

While there is an increasing level of comfort with the validity of GCM results at the global scale, such comfort decreases when we look at the regional scale. For Canada there are broad areas of agreement in model results including warming over much of the western and northern areas, but there is also some disagreement between models as to the location and magnitude of areas of surface temperature or precipitation change, particularly in eastern Canada. This disagreement is reflected in the words of uncertainty that appear at times in this volume of the Canada Country Study.

THE INTERNATIONAL CONTEXT

International concern about the future of our climate has been building steadily over the past 20 years. One of the first important international conferences to look at the issue was held in Canada in 1988 - The Changing Atmosphere: Implications for Global Security. Also that year, the IPCC was established by the World Meteorological Organization and the United Nations Environment Programme with a mandate to assess the science of climate change, its environmental and socio-economic impacts, and possible response strategies. The IPCC subsequently published formal assessments in 1990 and 1995, with a third to follow in 2000 or 2001.

In 1992, the United Nations Conference on Environment and Development was held in Rio de Janeiro and resulted in consensus on a Framework Convention on Climate Change (FCCC). This Convention's objective is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". It has now come into force and involves commitments to actions including emissions reductions, assistance to developing nations, reporting on emissions inventories, scientific and socio-economic research to reduce uncertainties, as well as education and training. Canada's domestic response to the FCCC has been its National Action Plan on Climate Change.

To date, as the objective of the FCCC would suggest, much of the international emphasis on response strategies for dealing with the impacts of climate change has focussed on reducing emissions of greenhouse gases. Respecting that climate change will be with us for a long time, a very important complement to such reductions is the need to understand the impacts of and to adapt to changing climate. The Canada Country Study is one of Canada's responses to recognizing the importance of impacts and adaptation.

CLIMATE IMPACTS AND ADAPTATION

The major concern arising from the climate change issue is the impact it may have on our environment, our economy, and therefore, on the way we live both now and in the future.

In Canada, we are accustomed to dealing with variations in climate both geographically and seasonally across the country. These variations have many impacts that can reverberate through natural and man-made systems, including water resources, vegetation and wildlife, agricultural practice, forestry and fisheries, energy supply and demand, buildings and roads, recreation and tourism, the insurance industry, and human health.

At present, there are many good examples of our ability to adapt to the range of climate conditions which we both collectively in our economy and as individuals in our everyday life are used to facing. If we depend upon wildlife species for sustenance, we follow them when migratory routes change; we plant different types of crops in different locations at different times of the year; we construct roads and buildings using designs that are compatible with ground that may or may not be characterized by permafrost or with differing snow and wind loads; we build ships and other marine platforms capable of withstanding expected wave heights and sea-ice conditions; we locate recreational facilities and events where they can benefit from appropriate climate conditions, such as sufficient snow for skiing or enough wind for sailing.

When thinking about adaptation as a way to respond to current climate and we then consider an on-going climate change and its impacts, we look for answers to the following questions so that our future planning can be done most effectively:

- What are the impacts of a changing climate and how will they affect me and my family through our lives?
- Are decisions being made today which will increase our vulnerability in the future because they are not taking such impacts into account?
- Will the approaches we use to adapt to the current climate still be workable in the future, or will new approaches be necessary to adapt to changes beyond our historical experience?
- Will the rate of changing climate allow enough time to adapt?
- Should society become more adaptable or flexible to changes in climate than it is now, and if so, how?

The Canada Country Study is aimed at helping to answer some of these questions.

INTRODUCTION

Evidence is mounting that we are in a period of climate change brought about by increasing atmospheric concentrations of greenhouse gases. Global mean temperatures have risen 0.3 to 0.6 degrees Celsius since the late 19th century and global sea levels have risen between 10 and 25 centimetres. Changes in the intensity and patterns of precipitation may also be linked to rising greenhouse gas concentrations. The Intergovernmental Panel on Climate Change has determined that the expected global rise in temperature over the next century would probably be greater than any seen in the last 10,000 years. Warmer temperatures will lead to a more vigorous hydrological cycle including an increase in both evaporation and precipitation. Scientists suggest that these changes would increase the likelihood of more floods as well as more droughts. Such climatic changes may bring about significant natural, social and economic consequences to British Columbia and Yukon.

The need to better understand and document regional climate change detection and impacts is the motivation behind the creation of the British Columbia and Yukon Climate Change Program. Formed in 1996, this program brings together a number of professionals from such diverse backgrounds as agriculture, biology, climatology, engineering, fisheries, forestry, and hydrology to examine the issue from each of their unique perspectives.

One of the first undertakings of the British Columbia and Yukon program was to organize a workshop to encourage public discussion about the potential regional impacts of climate change. This workshop was held on February 27-28, 1997, at Simon Fraser University downtown campus at Harbour Centre. The objectives of the workshop were as follows:

- to summarize what is known about the expected impacts of future climate change on British Columbia and Yukon.
- to identify what steps need to be taken to improve our projections of the impacts of climate change.
- to identify what needs to be done to get the public, industry, agencies and governments to consider climate change in their decision making activities.

This report documents much of what is presently known about the impacts of climate change on a number of sectors within British Columbia and Yukon. It also summarizes the outcomes of the February workshop, and constitutes the British Columbia and Yukon Climate Change Program's contribution to *The Canada Country Study: Climate Impacts and Adaptation*. In addition, it contributes to the goals of the 1995 British Columbia Greenhouse Gas Action Plan.

Support for the workshop and report was provided by the following organizations: Environment Canada; British Columbia Ministry of Environment, Lands and Parks; Canadian Institute for Climate Studies; Natural Resources Canada; Agriculture and Agri-Food Canada; Department of Fisheries and Oceans; British Columbia Ministry of Forests; Maria Wellisch Associates; Lynn Ross Energy Consulting; BC Hydro; and Royal BC Museum.

This report represents the efforts of many people who have given generously of their time, knowledge and resources so that we may better understand the impacts of climate change in British Columbia and Yukon, and the national and regional greenhouse gas emission reduction strategies. In particular, we thank the many authors who contributed to this report: Leslie Beckmann, Klaas Broersma, Rob Butler, Joe Caprio, Stewart Cohen, Mauro Coligado, Hal Coulson, Colin Clark, Bill Crawford, Pat Duffy, Mike Dunn, Joan Eamer, Henry Hengeveld, Lee Harding, Richard Hebda, Basil Hii, Stephan Kesting, Gary Kofinas, Pam Krannitz, Stan Liu, Emily McCullum, Peter Mills, Kathleen Moore, Hugh Morris, Gerry Neilsen, Alain Pietroniro, Paul Raistrick, Lynn Ross, Don Russell, Scott Smith, Dave Spittlehouse, Bill Taylor, Bruce Thomson, Rick Thomson, Maria Wellisch, and Bernie Zebarth.

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EXECUTIVE SUMMARY

Global climate is changing. Since the beginning of the century, temperatures have risen around the world by about a half a degree, while British Columbia has warmed by up to one degree in some areas. Meanwhile, precipitation on the west coast of British Columbia has increased by about 20%. Large changes have also been recorded in the Fraser River, with decadal river flows falling to low levels in the 1940s, rising about 30% by the late 1960s and falling again through to the present day.

Further and more rapid climate change - sometimes called "global warming" - will likely occur during the next few generations if atmospheric greenhouse gas concentrations continue their relentless climb. This increase in greenhouse gas concentrations, caused by a growing world population using large amounts of energy and changing natural carbon balances, warms the globe by trapping heat in the atmosphere. British Columbia and Yukon will not escape any global climate changes, which are expected to involve a warming rate greater than any seen in the last 10,000 years. More than subtle alterations in temperature and precipitation, climate change could result in an increased frequency of dangerous flooding in some areas, injurious droughts in others, and widespread disruptions to forests, fisheries, wildlife and other natural systems. In short, climate change will have some significant impacts in British Columbia and Yukon.

Below are synopses of the many potential impacts of climate change on physical environments, natural ecosystems and economic sectors that are described in this report. Also listed are actions that governments and citizens in British Columbia and Yukon can take to respond to these changes.

POTENTIAL IMPACTS OF CLIMATE CHANGE ON THE PHYSICAL ENVIRONMENT

- **Rising Sea Levels** - By 2050 sea level will have risen up to 30 centimetres on the north coast of British Columbia and up to 50 centimetres on the north Yukon coast. Sea level rise will also occur on the south coast of British Columbia but will be less dramatic. Warmer ocean waters resulting from climate change will be the main cause of this sea level rise. Tectonic uplift and the continuing crustal rebound from the weight of massive ice sheets that covered the British Columbia coast 12,000 years ago will generally act to restrict the rising seas.

- **Spring Flooding** - Existing flood protection works may no longer be adequate and spring flood damage could be more severe and frequent along rivers and streams of the coast and throughout the interior of British Columbia and Yukon.

- **Summer drought** - Conversely, stream flow in late summer and fall will likely decrease along the south coast and the southern interior, while stream temperatures will rise. This will reduce fish survivability. Soil moisture will also diminish in southern British Columbia. Without access to more reservoir capacity, water supply will be reduced in the dry summer season when irrigation and domestic water use is greatest.

- **More landslides -** Landslides and debris torrents in unstable mountainous areas of British Columbia and Yukon will become more common as winter precipitation rises, permafrost degrades, and glaciers retreat. Water quality, fish and wildlife habitat, as well as roads and other man-made structures will be at increased risk.

- **Glacier reduction and disappearance** - Many glaciers in southeastern British Columbia and the southern Rocky Mountains could substantially melt or disappear completely. The flow of rivers and streams that depend on glacier water in the late summer and fall will then diminish. This could negatively impact tourism, hydroelectric generation, fish habitat, and lifestyles in southeastern British Columbia.

- **Coastal risks** - Increased sedimentation, coastal flooding and permanent inundation of natural ecosystems will occur in low gradient, intertidal areas. These areas may not be able to migrate inland due to the presence of man-made dykes, particularly in the Squamish, Nanaimo and Fraser River estuaries. Sea level rise will also cause salt water to penetrate further inland in the Fraser River and other estuaries, resulting in changes in natural estuarine communities.

POTENTIAL IMPACTS OF CLIMATE CHANGE ON NATURAL ECOSYSTEMS

- **Marine life and wildlife threats** - Increased precipitation inland, particularly on the south coast in winter, will wash increased amounts of organic material into estuarine areas, resulting in increased fish die back due to oxygen depletion. Waterfowl that reproduce in areas along the British Columbia and Yukon coast may experience die back due to a combination of sea level rise and an increase in extreme storm events and storm surges.

- **Forest transformation** - The many widely diverse biogeoclimatic zones of British Columbia, varying from the frigid alpine tundra zone to the dry bunchgrass zone to the wet coastal western hemlock zone may undergo profound changes. Some forested ecosystems in already warm and dry areas may disappear completely. Interior steppe and pine savanna vegetation may expand upslope and northward, displacing valuable douglas fir ecosystems. Increased fire, pests, and disease may be the agent of forest changes.

- **Extinction of rare species** - Many species of plants and animals that are at their southern geographical limit in British Columbia may disappear. For example, most kelp along the British Columbia coast will be adversely affected by warming water and may be eliminated. Forests will invade sensitive alpine, arctic tundra and shrub tundra communities as treelines move upwards hundreds of metres. Undesirable plant and animal species may invade from the south.

- **Migratory bird impacts** - Changes in high level winds may hinder the reproductive capacities of migratory birds.

POTENTIAL IMPACTS OF CLIMATE CHANGE ON ECONOMIC SECTORS, MANAGED ECOSYSTEMS AND LIFESTYLES

- **Coastal infrastructure threats** - Low-lying homes, docks and port facilities may be frequently flooded along the southern British Columbia coast during severe storms if a sea level rise of only a few tens of centimetres occurs. Upgrading existing dykes protecting the city of Richmond, which will not be possible in some areas, may cost hundreds of millions of dollars. Sea level rise will raise groundwater levels in low-lying areas of the Fraser Valley, forcing additional expenditures on water pumping. Recreation beaches will be more costly to maintain as a result of rising seas. Salt water intrusion will affect some wells. Increased winter precipitation will put greater stress on water and sewage systems, and increase the danger to environmental and human health.

- **Fisheries declines** - Many important salmon stocks from the Fraser and other southern rivers may decline. Pacific cod abundance likely will be reduced. Exotic species will doubtless be introduced into warmer rivers and streams where they will displace resident species. Cold water fish such as trout, char, whitefish, and grayling may suffer as water temperatures rise and predators invade from the south. Milder temperatures in northern British Columbia and Yukon may lead to some increased salmon productivity.

- **Air Quality Degradation -** In conjunction with the rapid urbanization, air quality may become seriously degraded in the Lower Fraser Valley and the Okanagan Valley.

- **Energy disruptions** - Drier summers and falls may reduce hydroelectric generation in southeast British Columbia.

- **Agriculture Improvement -** Where irrigation is not necessary, agriculture could expand and new, higher value crops could be introduced.

- **Aboriginal Impact -** Changes in the distribution and abundance of key fish and wildlife resources will negatively impact aboriginal lifestyles.

- **Human Health Risks -** Some parasites, such as those that cause Montezuma's revenge and beaver fever, will thrive in a warmer climate. Fleas and mites that are now killed off completely each winter in the lower Fraser Valley will flourish in a warmer climate.

HUMAN RESPONSE TO CLIMATE CHANGE

- **National Actions -** The Framework Convention on Climate Change (FCCC) is the United Nations-directed plan that aims to achieve stabilization of greenhouse gas concentrations in the atmosphere. Canada is a party to the FCCC and continues to reaffirm its commitment to the process of greenhouse gas emission reduction.

- **Provincial Actions** - British Columbia, Yukon and Canada are unlikely to stabilize emissions of greenhouse gas at 1990 levels by the year 2000 as earlier expected. Greenhouse gas emissions in British Columbia in 1995 were 15% higher than 1990 levels. Much of this increase is caused by the rapid rate of population and economic growth in the province. The British Columbia government is continuing its program to limit these greenhouse gas emissions through energy efficiency and encouragement of low emission transportation alternatives.

- **Local Actions** - Climate change is everybody's business. We all need to take responsibility for contributing to the problem and make an effort to both reduce greenhouse gas emissions as well as adapt to inevitable changes.

- **Improving communication** - Scientists must make an increased effort to communicate clear information on climate change to policymakers and the wider community.

RÉSUMÉ

Le climat de la planète est en train de changer. Depuis le début du siècle, les températures ont monté dans le monde entier d'environ un demi-degré; en certains endroits de Colombie-Britannique, le réchauffement a atteint un degré. Dans le même temps, les précipitations sur la côte de cette province ont augmenté d'environ 20 %. On a aussi noté d'importants changements dans le fleuve Fraser, dont les écoulements décennaux ont marqué un minimum dans les années 40, monté d'environ 30 % à la fin des années 60 et baissé de nouveau jusqu'à aujourd'hui.

D'autres changements plus rapides parfois désignés sous le vocable de “réchauffement planétaire” se produiront probablement au cours des prochaines générations si les concentrations atmosphériques de gaz à effet de serre continuent de monter comme elles le font. Cette hausse des concentrations de gaz à effet de serre est due au fait que la population mondiale augmente et utilise beaucoup d'énergie, ce qui modifie l'équilibre naturel du carbone; elle piège la chaleur dans l'atmosphère, ce qui réchauffe la planète. La Colombie-Britannique et le Yukon ne pourront pas échapper aux changements climatiques planétaires, qui devraient y induire un réchauffement plus rapide que tout ce qui a pu survenir dans les 10 000 dernières années. Plus que par de subtiles modifications des températures et des précipitations, le changement climatique pourrait se traduire par une fréquence accrue des inondations dangereuses dans certaines régions, des graves sécheresses dans d'autres et des perturbations généralisées des forêts, des pêches, des espèces sauvages et de divers systèmes naturels. Bref, le changement climatique aura des incidences significatives sur la Colombie-Britannique et le Yukon.

On trouvera ci-dessous des résumés des nombreux impacts que pourrait avoir le changement climatique sur les environnements physiques, sur les écosystèmes naturels et sur les secteurs économiques décrits dans le rapport. On trouvera aussi des listes des actions que les gouvernements et les populations de Colombie-Britannique et du Yukon pourraient entreprendre pour y faire face.

IMPACTS POSSIBLES DU CHANGEMENT CLIMATIQUE SUR L'ENVIRONNEMENT PHYSIQUE

- **Élévation du niveau des mers** - D'ici 2050, l'élévation du niveau de la mer pourra atteindre 30 centimètres sur le nord de la côte de Colombie-Britannique, et 50 cm sur le nord de la côte du Yukon. La hausse du niveau marin touchera aussi le sud de la côte de Colombie-Britannique, mais y sera moins marquée. C'est le réchauffement des eaux océaniques dû au changement planétaire qui sera la principale cause du phénomène. Le soulèvement tectonique et la poursuite du relèvement isostatique consécutif à la disparition des lourds glaciers qui couvraient la côte de Colombie-Britannique il y a 12 000 ans contribueront cependant en général à atténuer l'élévation du niveau de la mer.

- **Inondations printanières** - Les actuels ouvrages de protection contre les crues ne seront peut-être plus suffisants et les inondations printanières pourraient être plus graves et plus fréquentes le long des cours d'eau de la côte et dans tout l'intérieur de la Colombie-Britannique et du Yukon.

- **Sécheresses estivales** - À l'inverse, le débit des cours d'eau à la fin de l'été et en automne baissera probablement sur le sud de la côte et dans le sud de l'intérieur, et les températures de l'eau monteront. Il s'ensuivra une réduction des chances de survie des poissons. En outre, l'humidité du sol diminuera dans le sud de la Colombie-Britannique. Sans accès à une plus grande capacité de réserve, l'approvisionnement en eau sera réduit pendant la saison sèche de l'été, période de très grande utilisation d'eau pour l'irrigation et à des fins domestiques.

- **Augmentation du nombre de glissements de terrain** - Les glissements de terrains et les coulées de débris dans les régions montagneuses instables de la Colombie-Britannique et du Yukon seront plus fréquents avec l'augmentation des précipitations hivernales, la dégradation du pergélisol et le recul des glaciers. La qualité de l'eau, les habitats des poissons et des espèces sauvages, de même que les routes et autres structures érigées par l'homme, s'en trouveront mis en péril.

- **Diminution et disparition des glaciers** - Nombre des glaciers du sud-est de la Colombie-Britannique et du sud des Rocheuses pourraient subir une fonte substantielle, voire disparaître complètement. Le débit des cours d'eau alimentés par l'eau de fonte des glaciers à la fin de l'été et en automne s'en trouvera réduit, ce qui pourrait avoir des impacts négatifs sur le tourisme, la production d'hydroélectricité, les habitats des poissons et les modes de vie en général dans le sud-est de la Colombie-Britannique.

- **Risques pour les régions côtières** - Les zones intertidales à faible gradient pourraient connaître une augmentation de la sédimentation, des inondations sur les côtes, voire l'ennoyage d'écosystèmes naturels. Ces régions risquent de ne pas pouvoir se décaler vers l'intérieur, en raison de l'existence de digues érigées par l'homme, surtout dans les estuaires de la Squamish, de la Nanaimo et du Fraser. L'élévation du niveau marin fera aussi pénétrer l'eau salée plus loin dans les terres, dans les estuaires du Fraser et d'autres cours d'eau, ce qui entraînera des changements dans les communautés estuariennes naturelles.

IMPACTS POSSIBLES DU CHANGEMENT CLIMATIQUE SUR LES ÉCOSYSTÈMES NATURELS

- **Menaces pour les espèces marines et sauvages** - Du fait de l'augmentation des précipitations sur les terres, surtout sur le sud de la côte en hiver, des quantités accrues de matière organique seront entraînées dans les zones estuariennes, ce qui causera une hausse de la mortalité des poissons par appauvrissement de l'oxygène. Les oiseaux aquatiques qui se reproduisent le long des côtes de la Colombie-Britannique et du Yukon pourront aussi être affectés par la combinaison de l'élévation du niveau marin et de l'augmentation des épisodes de tempête extrêmes et des ondes de tempête qu'ils soulèvent.

- **Transformation des forêts** - Les nombreuses et diverses zones biogéoclimatiques de la Colombie-Britannique, que ce soit la toundra alpine au climat glacial, les prairies sèches ou les forêts humides de pruches de l'ouest de la côte, pourront subir de profonds changements. Certains écosystèmes forestiers de régions déjà chaudes et sèches peuvent même disparaître complètement. La végétation de steppe et de savane de pins de l'intérieur pourra migrer en altitude et vers le nord, déplaçant les précieux écosystèmes de douglas verts. D'autres changements subis par les forêts pourront aussi être imputables à l'accroissement du nombre des incendies, des ravageurs et des maladies.

- **Extinction d'espèces rares** - Nombre d'espèces animales et végétales dont l'extrême limite méridionale se situe en Colombie-Britannique pourront disparaître. Par exemple, la plupart des laminariales de la côte de Colombie-Britannique seront touchées à des degrés divers par le réchauffement de l'eau et risquent l'élimination. Les forêts envahiront des communautés fragiles d'espèces alpines, de la toundra arctique et de la toundra arbustive, à mesure que les limites forestières se décaleront de plusieurs centaines de mètres en altitude. Des espèces animales et végétales indésirables peuvent gagner la région par le sud.

- **Impacts sur les oiseaux migrateurs** - Des changements des vents en altitude peuvent nuire aux capacités de reproduction des oiseaux migrateurs.

IMPACTS POSSIBLES DU CHANGEMENT CLIMATIQUE SUR LES SECTEURS ÉCONOMIQUES, LES ÉCOSYSTÈMES AMÉNAGÉS ET LES MODES DE VIE

- **Menaces pour les infrastructures côtières** - Les habitations situées à bas niveau, les quais et les installations portuaires du sud de la côte de Colombie-Britannique risquent d'être souvent inondés pendant les violentes tempêtes, advenant un rehaussement du niveau marin de seulement quelques dizaines de centimètres. La mise à niveau des digues qui protègent actuellement la ville de Richmond pourrait coûter des centaines de millions de dollars, et ce genre de travaux ne sera pas faisable partout. L'élévation du niveau de la mer fera monter les niveaux des nappes phréatiques dans les terres basses de la vallée du Fraser, ce qui imposera des dépenses supplémentaires pour le pompage de l'eau. Les plages seront plus coûteuses à maintenir en état du fait de cette hausse du niveau marin. Certains puits seront affectés par les intrusions d'eau salée. Les précipitations hivernales étant plus abondantes, les systèmes d'adduction d'eau et d'égout seront davantage sollicités, et le danger pour la santé de l'homme et de l'environnement sera accru.

- **Déclin des pêches** - Nombre des grands stocks de saumon du Fraser et des autres cours d'eau du sud pourront connaître une baisse. L'abondance de la morue du Pacifique sera aussi probablement réduite. Des espèces exotiques vont sans aucun doute être introduites dans les cours d'eau plus chauds, où elles prendront la place des espèces résidentes. Les poissons d'eau froide, comme les truites, les ombles, les corégones et l'ombre, pourront être affectés par la hausse des températures et l'invasion de prédateurs venus du sud. Le temps plus doux dans le nord de la Colombie-Britannique et au Yukon pourrait cependant entraîner une hausse de la productivité du saumon.

- **Dégradation de la qualité de l'air** - Avec l'urbanisation rapide, la qualité de l'air pourrait sérieusement se détériorer dans les vallées du bas Fraser et de l'Okanagan.

- **Perturbations de l'alimentation en énergie** - Des étés et des automnes plus secs pourraient réduire la production d'hydroélectricité dans le sud-est de la Colombie-Britannique.

- **Amélioration de l'agriculture** - Dans les endroits où il n'est pas nécessaire d'irriguer, l'agriculture pourrait connaître une expansion et on pourrait introduire de nouvelles cultures de plus grande valeur commerciale.

- **Impacts sur les Autochtones** - Des modifications dans la distribution et l'abondance des ressources halieutiques et fauniques essentielles auront un impact négatif sur les modes de vie des populations autochtones.

- **Risques pour la santé humaine** - Certains parasites, comme ceux qui causent la diarrhée et la giardiase, vont proliférer dans un climat plus chaud. Les puces et acariens qui sont maintenant totalement détruits chaque hiver dans la vallée du bas Fraser pourront alors survivre.

RÉPONSE HUMAINE AU CHANGEMENT CLIMATIQUE

- **Actions nationales** - La Convention-cadre sur les changements climatiques (CCCC) est un plan, sous l'égide des Nations Unies, qui vise la stabilisation des concentrations de gaz à effet de serre dans l'atmosphère. Le Canada est partie à la CCCC et réitère son engagement au processus de réduction des émissions de gaz à effet de serre.

- **Actions provinciales** - La Colombie-Britannique, le Yukon et le Canada n'arriveront probablement pas à stabiliser leurs émissions de gaz à effet de serre aux niveaux de 1990 d'ici l'an 2000 comme on le prévoyait auparavant. En 1995, les émissions de gaz à effet de serre de la Colombie-Britannique étaient supérieures de 15 % aux niveaux de 1990. Une grande partie de cette hausse est causée par l'augmentation rapide de la population et la croissance économique de la province. Le gouvernement de Colombie-Britannique poursuit son programme de limitation des émissions de gaz à effet de serre via l'efficacité énergétique et la promotion des modes de transport à faible émission.

- **Actions locales -** Le changement climatique est l'affaire de tous. Nous devons tous accepter notre part de responsabilité dans ce problème et tout faire pour à la fois réduire les émissions de gaz à effet de serre et nous adapter aux changements qui surviendront inévitablement.

- **Amélioration des communications -** Les scientifiques doivent faire un plus grand effort pour communiquer aux décideurs et au grand public des informations claires sur le changement climatique.

Part 1

CLIMATE CHANGE WORKSHOP

Chapter 1

CLIMATE CHANGE WORKSHOP: RESULTS AND RECOMMENDATIONS

Patrick Duffy

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OVERVIEW

On February 27 and 28, 1997, a successful workshop entitled "Responding to Global Climate Change in British Columbia and Yukon" was held at the downtown campus of Simon Fraser University in Vancouver, B.C. The workshop consisted of plenary sessions as well as breakout groups who were responsible for identifying knowledge gaps surrounding the impacts of climate change in British Columbia and Yukon. Workshop participants were also charged with determining climate change messages and communication strategies with respect to climate change impacts in specific geographic regions of British Columbia and Yukon. In addition, each breakout group prepared a set of overall workshop recommendations. This section of the report presents the results of the breakout groups and the workshop recommendations.

INTRODUCTION

A successful workshop on "Responding to Global Climate Change in British Columbia and Yukon" was held on February 27 - 28, 1997 at Simon Fraser University, Harbour Centre, in Vancouver, B.C., Canada. The workshop objectives were to:

- Identify and prioritize science and other knowledge gaps surrounding climate change impacts in British Columbia and Yukon.

- Identify what needs to be done to get the public, policymakers and other stakeholders to include climate change (impacts, adaptation options, and mitigation) in their decision making activities.

There were 110 participants representing levels of government (from federal, through provincial to regional districts, and municipal), universities, industry, consultants, and non-government organizations. Breakout groups were attended by 10 - 20 persons each. The workshop was sponsored by Environment Canada, British Columbia Ministry of Environment, Lands and Parks, and the Canadian Institute for Climate Studies.

Day One

The agenda on the first day morning featured descriptions of climate change at the global level, including estimates of costs from the economic and social science perspectives. Then sectoral presentations focussed on climate change impacts on hydrology in B.C., on Yukon River resources, on fish and aquatic systems, and on forest and terrestrial ecosystems.

These presentations were followed in the afternoon by six breakout groups which concentrated on the question, "What are the important science and other knowledge gaps in our understanding of potential impacts of climate change in British Columbia and Yukon?" The breakout group titles were:

- Forestry and Agriculture
- Energy
- Fish
- Water resources - Direct physical impacts
- Water resources - Impacts on managed and unmanaged ecosystems
- Ecosystems, biodiversity, and wildlife

Each group worked to produce a prioritized set of knowledge gaps that need to be filled, and suggestions on what should be done to obtain this knowledge. This information was subsequently presented to a plenary session.

Day Two

On the second day, the workshop was addressed by the Honourable Sergio Marchi, Federal Minister of Environment. He outlined the government's program to provide support and leadership to both the national and global programs on greenhouse gas emission reduction. He made suggestions on how to communicate the subject of climate change implications to stakeholders, recognising the broad interests and responsibilities the subject demands across government and society.

Presentations were then made to illustrate the broad latent interest in climate change because of self interest, security and survival. Thus the list of stakeholders is both very long and very diverse. This presents a challenge to communicate the subject effectively, given that at present the informed parties are mostly in the technical and scientific sector.

Breakout groups then met to focus on geographic regions of B.C. and Yukon and to draft plain language messages pertaining to climate change specific to the geographic area and which should be conveyed to policy makers and public and other stakeholders. There were six breakout groups, each dealing with a different area and group of subjects:

- South Coast of British Columbia: Natural ecosystem impacts
- South Coast of British Columbia: Human and infrastructure impacts
- Northern British Columbia - Coast and Interior
- Southwest Interior, including the Okanagan Valley
- Southeast Interior, including the Columbia Valley
- Yukon

Each group endeavoured to produce, as a deliverable to a plenary session, a list of plain language climate change messages and a list of activities that could be undertaken to communicate these and other climate change messages to the public, industry, and other stakeholders.

Following the reports of the breakout groups, the workshop turned to the drafting, discussion, and finalization of overall workshop recommendations, with advice on which offices and agencies should receive them. When this task was completed the workshop was concluded.

What follows is an abbreviated report on the proceedings of the workshop, shortened because of space limitations. The complete output from the workshop is retained by the organizing committee for subsequent use in follow up communications.

WORKSHOP REPORTS - DAY 1

Introduction

Each group sought to identify up to 6 climate-sensitive issues and the associated knowledge gaps which inhibit effective action to deal with the issues. The following information was requested for each issue:

- The climate sensitive issue
- The geographic location
- The primary impacts of climate change on the issue
- The secondary impacts of climate change on the issue
- The knowledge gaps that need to be filled to improve estimates of these impacts, and what should be done to obtain this knowledge.

Forestry

Forestry Issue 1: *Climate change will likely increase the frequency, intensity, and duration of extreme climate events that influence B.C.*

Location: All of B.C. and Yukon.

Primary impacts: Increase in frequency in summer drought, convective and winter storms, and extreme temperatures and precipitation events.

Secondary impacts:

- Summer drought will lead to water deficits which will limit tree growth and increase fire frequency.
- Convective storms will cause higher frequency of lightning strikes and fires. Extreme winds will result in increased windthrow.
- Winter storms will increase snow loading and forest damage and will increase wind throw.
- Extreme precipitation events will lead to more soil erosion and mass wasting.
- Extremes of high temperature will increase tree mortality. In the case of high temperatures, higher frequency of extreme fire hazard conditions can be expected.

Knowledge gaps:

- How will climate change influence the frequency, distribution, and intensity of the extreme events noted above?
- What is the natural historical variability and frequency of these extreme events? Baseline "normal" data for extreme events is needed.
- What salvage opportunities exist for the recovery of damaged forests after extreme events?

Candidate agencies:

- Universities (tree ring analysis, paleobotany).
- Ministry of Forests, Forest Renewal B.C.
- Environment Canada and Natural Resources Canada.
- Council of Forest Industries
- Environmental groups.

Forestry Issue 2: *Forest disturbances by pests, fire, and wind will likely occur as a result of climate change.*

Location: Interior of B.C. for fire. Other disturbances will affect all of B.C. and Yukon.

Primary impacts: Increase in drought intensity and duration would lead to an increase in frequency of fires and hectares burned. Increase in damage due to insect pests and due to windthrow.

Secondary impacts:

- Communities on the urban/forest interface may be threatened with an increase in fire damage.
- Fire management strategies will need to be reviewed and may be altered (e.g. whether or not to burn) and the current policy of attacking fires within 24 hours may need to modified.
- There will be an increase in carbon dioxide emissions from forest fires.
- There may be an increase in biodiversity as more edge is created by disturbance in the forest.

Knowledge gaps:

- What conditions lead to disturbances? For instance, how do antecedent conditions influence the damage from extreme events?
- How does heavy rain and soil saturation influence windthrow damage?
- What is the ecosystem response to forest disturbance and how is succession modified in different geographic areas?
- What are the baseline conditions for forest disturbance?
- How can changes in disturbance be detected and followed if monitoring systems are reduced or eliminated? Example: Forest Insect and Disease Survey of Natural Resources Canada.
- What new forest pests will be causing problems in different areas of B.C. and Yukon?
- How will the amount of old growth and non-old growth or climax vegetation change with more disturbance?

Fish

Fish Issue 1*. Ocean productivity and current changes*

Location: Georgia Strait and Johnston Strait. South Coast outside of Vancouver Island and to the Columbia River outlet, North Coast and Queen Charlotte Sound.

Primary Impacts: Wind changes and ocean upwelling and temperature changes. Intensification of the Aleutian Low. Increased temperatures both geographically and bathymetrically. Fresh water discharges will alter marine conditions as well.

Secondary impacts:

- Northern oceanic productivity will increase.
- Fish migratory patterns will change and predator/prey distributions will be altered.

Knowledge gaps:

- How can we produce a useful list of multi-disciplinary indicators which scientists could use to show that climate change is happening or is about to happen?
- How can we collaborate and create an integrative research approach to develop system component knowledge?
- What will it take to obtain an improved understanding of regional impacts created by changes in ocean productivity and climate change, e.g. more observations of wind parameters on a local scale? This will require more sophisticated and enhanced modelling. The information and data need to be collected over time and space to be useful.

Fish Issue 2*. How will the reproductive success of freshwater species be affected?*

Location: Freshwater lakes and rivers.

Primary impacts: Include physical impacts such as increased ultraviolet radiation exposure throughout the life cycle, changes in water availability due to precipitation changes and water temperature changes. Also important are changes due to water quality and chemistry from sedimentation and pH. Flow regimes will change as well, including the timing of high and low flows which on some water bodies will affect timing of freeze-up and breakup.

Secondary impacts: Biological effects such as changed competition, spawning and migration disruptions, predator shifts, egg sensitivity.

Knowledge gaps:

- How can we focus research into the effects of climate change induced temperature shifts on top of natural variation in temperature which would occur without climate change effects ?
- What will it take to plan and stimulate more research into the effects of extreme temperature changes on aquatic ecosystems?
- How can better forecasting competence (based on specific species-based information on such items as biotic and abiotic factors which affect species) be worked into system models for forecasting?

Energy

This working group approached the subject differently from the others. It decided that the impacts of climate change on the energy sector were negligible compared to the impacts of new policies and regulations aimed at moving industry to alternative energy sources, greater energy conservation, and more energy efficiency.

Energy Issue. *Transition to lower carbon energy sources; alternative energy.*

Location: B.C. and Yukon

Discussion:

- Shifts in primary energy resourcing will require careful consideration of present conditions of wind, precipitation, run-off, solar radiation and cloud cover, as well as the frequency of severe weather (storm) events.
- Although alternative energy sourcing, energy conservation and energy efficiency are widely understood, they are used in this region only sparingly. If the energy industry is to beneficially restructure, there will be a requirement for a policy review, research into opportunities in the unique B.C. and Yukon energy mix, legislation development, and new regulations and economic instruments.
- One of the outcomes of restructuring could be increased competition for some primary natural resources such as water and land, particularly if hydroelectric alternatives are favoured.
- An important element in the mounting of these initiatives will be the need to increase public awareness of the potential applications, incentives, and disincentives.

Knowledge gap: How are the alternative energy technologies matched with conditions here in B.C. and Yukon and what would the cost implications be in switching to other sources of energy?

Water Resources - Direct physical impacts

Water Resources Issue 1. *Variations in water quantity.*

***Location*:** B.C. and Yukon

Primary impacts: Precipitation patterns will change temporally and spatially. The hydrologic cycle will be altered throughout, resulting in changes in flows, in stored water, and the timing and releases of stored water.

Secondary impacts: Rapid glacier melt will affect the total flow and timing of flows in rivers and streams, and add to summer low flow periods. Increased sedimentation will be associated with increased glacier melting.

Knowledge gaps:

- In southern B.C., how are the frequencies and timing of high and low flows going to change? What is the outlook for flood frequency and severity?
- In the north, ice jams are a poorly understood phenomenon. How would the effects of climate change influence the size and timing of jams?
- In the north, what changes in the extent and behaviour of permafrost will occur because of the widespread and numerous effects which are resulting from climate warming?

Water Resources - Impacts on managed and unmanaged ecosystems

Water Resources Issue 2. *Impacts on storm-water infrastructure*

Location: Urban areas

Primary impacts: Increased runoff, overflows, and flooding of the system.

Secondary impacts:

- Increased cost for design of the storm and sewer infrastructure to handle extreme events. A related impact is that minimum flows in the system have different requirements and this complicates the quest for efficient and effective design.
- Increased pollution pulsing in dry/wet cycles bringing accumulated pollution to the system and receiving environments during wet periods.
- Increased need to treat storm-water for pollution control if upstream pollution control is ineffective.

Knowledge gaps:

- How can infrastructure planning and operations be tailored to handle swings in storm-water pollution concentrations?
- What needs to be done to analyze the probability and characteristics of extreme events to determine the need for both redesigned infrastructure and operations and for new construction?

Comment: Policy development does not presently assign a priority to the costs of accepting major pollution events, and hence funding is not afforded a priority.

Ecosystems and Biodiversity

Ecosystem and Biodiversity Issue 1: *Changes in alpine plant communities.*

Location: Coast Range and Interior mountains.

Primary impacts: Changes in precipitation patterns and snowpack extent. Frequency and nature of extreme events including convective storms and high winds.

Secondary impacts: Reduction or loss of some alpine plant species with attendant alteration of plant/forest communities upon which animal species are dependent.

Knowledge gaps:

- What plant and animal species currently occupy the alpine area?
- How will climate change affect snow-pack behaviour? (Field experiments in snowpack manipulation exist in Alaska.)
- What are the characteristics of precipitation in alpine areas? How can these effects be incorporated into regional models?

Ecosystem and Biodiversity Issue 2. *The impact of change in sea level and_storm surges on tidal and estuarine ecosystems.*

Location: Estuaries.

Primary impacts: Sea level rise continues. Tides and storm surges continue.

Secondary impacts:

- Slow and permanent marine flooding of habitat and recurrent flooding during high tides and storm surges, resulting in changes in habitat characteristics and extent.
- Dyke construction further alters the natural estuarine environment.

Knowledge gaps:

- What are the combined effects on tidal/estuarine ecosystems of increased river flow and rise in sea level?
- What is the present and predicted rate of sea level rise (time and increments) for selected sites on the B.C. Coast?
- What is the potential loss of waterfowl habitat?
- What will be the impacts of habitat change on marine mammals in this environment?

WORKSHOP REPORTS - DAY 2

Introduction

Each group worked to draft a list of up to 10 of the most important plain language messages pertaining to climate change impacts, mitigation and adaptation, specific to a given geographic area, that policy makers, the public and other stakeholders should know. These could include information in which we have some confidence as well as details on what further research is needed. The "deliverable" was a list of plain language climate change impact messages.

Also, each group prepared a list of educational and communication activities that will best inform the public, policymakers, industry and other stakeholders on climate change issues so that they consider climate change in their decision making.

South Coast - Natural ecosystem impacts.

***South Coast Message 1**.* Climate changes on the South Coast will likely entail:

- Increase summer drought with attendant water shortages and competition for available water for drinking, irrigation and other uses. Natural ecosystems (terrestrial and aquatic) are stressed. Water storage (reservoirs) patterns change.
- Increased frequency of extreme events (storms, winds, snow).
- Increased frequency and severity of river and stream flooding and gradual increase in marine flooding.
- Changes in air and water temperatures, and reduced air quality.

Communication activities

- Encourage governments to implement water meter systems and other demand-side management tools, and to improve the existing water supply infrastructure.
- Request better use of existing authority under by-laws to enforce water conservation.
- Strengthen current public education campaigns on water conservation, and link messages to climate change.
- Seek the use of effective water quality protection measures now, given the anticipated stresses on water quality in the future.
- Inform the public and industry on the cause/effect of climate change and the value of conserving water rather than expanding the supply system, including the need to allocate water use for domestic, industrial, and agriculture use (which benefits wildlife).

South Coast - Human and infrastructure impacts.

South Coast Message 2: Climate change elsewhere will increase human population here and will stress the environment upon which ecosystems and human well-being depend.

Communication activities.

- Encourage long-term proactive planning strategies to bring the inevitable climate change-induced alterations into decision-making.
- Encourage school, government, municipal, and media program visits by experts. Develop teaching resource packages to inform and to promote awareness.
- Promote the concept of an Ecological Investment Portfolio and Safety Net to link present and future generations` security to the climate change phenomenon.

South Coast Message 3: There is a need to create protected areas for marine and aquatic species, including migratory birds, commercial fish, and vulnerable plant life of salt marches.

Communication activities: Encourage environmentally friendly zoning to achieve a protected areas program which takes into account the long term effects of climate change. Tax breaks and market incentives may encourage shoreline and estuary property owners to collaborate.

Southwest Interior

***Southwest Interior Message** :* Climate change is causing altered hydrographs and shifts in peakflows, water levels, supplies and use leading to conflicts. Water quality and fish are affected. Natural biodiversity and patterns (forest fires and pests) are changing and fish and wildlife species are vulnerable to decline and regional extirpation (elimination). Human activity is being displaced, including recreational pursuits.

Communication activities:

- Integrated communication campaigns for communities with shared goals. Annual

events with lead up and follow up activities which are goal focussed.
- Prepare compelling political briefings.
- Empower communities through self-education forums for local discussion of issues/problems and solutions. Package solutions with problems. Piggy back/leverage the message on existing activities.
- Develop visual posters, CD ROM, and videos and utilize teacher training modules.
- Communicate the actions here which affect society globally, at international conferences, such as the Kyoto, Japan meeting.

What to communicate in the messages?

- Clear plain language of the effects of climate change to a personal level. That is, deliver "the facts". Link the cause with the effect and stress the fact that we all own the problem because we are contributing to the production of green house gases.
- Some of the effects are land use zoning (floodplains), lost recreational opportunities, competition for and degradation of water supply, prospects of tax and insurance cost increases, water supply metering, and the uncertainties passed on to future generations. The prospects are for costly water conservation and demand management programs for irrigation districts and water boards, reworked flood damage prevention and reduction work at the regional district level, and capital investment in water distribution technologies for governments, with some focus on watershed management as a trade-off to structures.
- There is a window of opportunity now to avoid future disbenefits. A shared proactive multi-stakeholder effort now will reap benefits now and in the future.

Who needs to be targeted with the message?

The audiences are Provincial and Federal Government agencies and elected officials, Regional Districts, Municipalities, Water Boards, the voting public and the next generation of voting publics of pre-voting age.

Seek out and target the audiences with a multiplier effect through their constituencies, such as NGO`s, media, educators, First Nations, industrial associations, community champions and opinion leaders.

Southeast Interior

***Southeast Interior Message 1**.* Climate change effects will continue to bring extremes of temperature and precipitation and storm impacts with costly impacts on infrastructure, property, human well being, tourism, and ecosystems upon which plant and animal species and human society depend. River flows on the Columbia and the Kootenay Rivers will be altered, thereby complicating agreements on water management.

Communication activities: Prepare briefing notes and technical backgrounders for each type of stakeholder (elected official, each level of government, industry sectors, public media, the education system, emergency response agencies, as well as participants in the river flow agreements specific to the region).

***Southeast Interior Message 2**.* The Columbia River Treaty was signed 25 - 30 years ago and it is currently being renegotiated. The new agreement may take a different form from the existing one, although it has not been finalized.

Communication activities: Prepare a briefing note and technical backgrounder showing that future climate change will need to be taken into account, particularly if the agreement is a long-term one. The treaty with the U.S.A. and arrangements with the Canadian levels of government need to consider that control of the Columbia River may result in local residents having to move away to accommodate new river flows. This may require compensation for community displacement, retraining and other costs. Some of the agencies which could be involved in this matter are B.C. Utilities. Commission, B.C. Ministry of Employment and Investment, B.C. Hydro, and West Kootenay Power.

Northern British Columbia

***Northern British Columbia Message**:* Changes will take place in natural resource distribution and availability. Fisheries, forestry, agriculture, and other lands uses will be altered further*.*

Communication activities:

- Prepare a plain language description of the expected climate changes over a given time span (2050 A.D.) and join with each sector to produce specific facts and strategies to ensure that climate change reality is integrated into present and future resource management planning, including coping with extreme events.
- Priority sectors are forestry (timber supply analysis), fisheries and aquaculture, estuarine habitat management and protection, and soil, land use and agriculture. Municipal governments, regional districts, First Nations and other parties responsible for public safety and security of infrastructure all need to involved on an ongoing basis.

Yukon

Yukon Message 1*.* The water resources sector will continue to be impacted under the scenario of doubling of carbon dioxide in the atmosphere and Yukon will be more affected than southern and central B.C. A 40% increase in runoff and a 30 % increase in peak flows are projected. Thus extreme flood events will be more frequent and of greater magnitude. Infrastructure will be stressed and natural systems will be disturbed more than at present, putting stress on fish and wildlife and human well being, particularly during and after extreme weather events (heavy snow, flooding, fires).

Communication activities:

- Produce a plain language message on water resources impacts and join with each sector (Yukon Energy, Public Works, Federal, Territorial and local governments, First Nations, forestry) to incorporate the projections into design and maintenance of culverts, bridges, road, and other infrastructure, and of emergency planning and operations (floods, fires). Utilize Yukon examples such as breakup on the Yukon River at Dawson (100 year record).
- Provide the information in a variety of forms and in readily understandable language. For elaboration, see the communications points in the Southwest British Columbia section above.

Yukon Message 2. Projected temperature increases will melt permafrost in the permanent and discontinuous permafrost zones of Yukon (and northern B.C.) with resulting instability of terrain and changing hydrology. Community, Territorial Government and industry infrastructure will be stressed and threatened. Natural systems (northern wetlands, water systems, and plant communities) will continue to be altered. Waterfowl, caribou, muskrat and other resources will be changed bringing an impact on native lifestyles.

Communication activities:

- Produce a plain language illustrated description of permafrost degradation for Yukon and engage the sectors in producing customized advice on how to build adaptive measures into planning and operations in each sector.
- Include the government sector, an example being the need to understand permafrost degradation in environmental assessment and in the current preparation of the Development Assessment Process by the Yukon Territorial Government.

RECOMMENDATIONS

South Coast Recommendations

- To communicate the need to increase the action by the individual and organized groups on present and future climate change, co-ordinate the communication through a "Regional Climate Change Roundtable" comprised of sector representatives.
- To reinforce the importance of long term investment and commitment to insure that the ecological safety net is secure now and for future generations, set as a goal the development of the "ecological citizen" who makes informed decisions with respect to

quality of life and standard of living. The concept of a "Registered Climate Change Savings Plan" may be a useful framework to convey appropriate individual and community action. This concept is in its early stages of development and good examples with positive incentives are being sought.

Northern British Columbia Recommendations

- Promote research on the sensitivity of ecosystems to climate change impacts.
- Bring First Nations into the process of assessing climate change impacts and adaptation.

Southwest Interior Recommendations

- The Federal and Provincial governments should formulate an action plan involving the appropriate jurisdictions and focus on regulation and education initiatives to further prepare for the ongoing effects of climate change in the region.
- A specific action is recommended, namely to plan and fund the Water Resources Branch of the B.C. Ministry of Environment, Lands and Parks to carry out a climate change hydrological assessment for the Southwest Interior with recommendations for remedial action.

Yukon Recommendations

- It is recommended that a public process of explanation, consultation, and dialogue be carried out under the auspices of the government agencies with responsibility for the subject, and including the public throughout.
- Ensure that the environmental assessment and permitting processes (e.g. the new Yukon Development Assessment Process) include consideration of climate change implications such as permafrost alteration and the effects on power generation.
- Because of the more rapid warming taking place in Yukon, compared to southern and central B.C., install and maintain long term monitoring of climate change data in Yukon and the observed effects in the field.

Southeast Interior Recommendations

- Given that water flows on the Columbia River may increase or decrease because of climate change and this will affect power generation, flood control, irrigation, domestic use, including potable water, it is recommended that the Federal and Provincial Governments work to responsibly manage the Columbia Basin River waters, incorporating potential climate change impacts of altered water flows, to maintain its value to the Region and the Province.

Part 2

CLIMATE VARIABILITY AND CHANGE

Chapter 2

THE SCIENCE OF CLIMATE CHANGE

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OVERVIEW

Humanity appears to be embarked upon an uncontrolled, global-scale experiment with the global climate system that threatens to dramatically alter the earth's weather patterns and hence global ecosystems as we know it today. While such human-induced climate change will take place against a background of natural climate fluctuations and variability, best scientific estimates suggest that it will be more rapid and significant than any natural change experienced in the last 10,000 years.

The following estimates for possible climate change under 2xCO_2 scenarios, representing the range of projections from a number of models, are illustrative of how the climates of British Columbia and Yukon may change under global warming scenarios.

- Temperature: Equilibrium models project winter warming due to increased concentrations of greenhouse gases equivalent to a doubling of carbon dioxide to be about 3-4°C along coastal British Columbia, increasing to 4-6°C in eastern regions. Yukon winter temperatures are projected to increase by 2-5°C in the southern regions, increasing to as much as 8°C along its north shore. Equivalent summer warming is estimated at a fairly uniform 3-6°C for BC and the southern Yukon, decreasing to 2-4°C in the northern Yukon.
- Precipitation: Since precipitation patterns are significantly influenced by changes in global circulation patterns induced by climate change, regional projections for changes in precipitation under doubled CO_2 scenarios remain very uncertain. However, in general, the model results range from little change to significant increase in winter precipitation for most of both British Columbia and the Yukon. In summer, most scenarios suggest little change for the Yukon, but a tendency for less rain in southern British Columbia.
- Extreme Weather: Warmer temperatures are expected to increase the frequency of mild winters and warm summers, with a corresponding decrease in cold events. Increased poleward transport of moisture, as well as more intense summer heating of convective clouds should increase the frequency of both intense winter storms and heavy summer rainfall events. More intense thunderstorms may also increase hazards due to lightning, wind and hail.

WHAT CAUSES CLIMATE CHANGE?

Climate is commonly defined as average weather. Hence, the climate of a particular region describes the average annual, seasonal and monthly and daily values and variability of its temperature, precipitation, cloud cover, wind and other weather features, as observed over a number of years. However, although this notion of climate assumes a long-term consistency and stability, climates also vary and change with time as a result of external forces upon and internal processes within the global climate system.

The global climate system is heated and hence driven by energy from the sun. This energy also drives the hydrological cycle, causes the earth's atmosphere and oceans to circulate, and helps generate weather storms. The atmosphere, in turn, both reflects part of the sunlight back to space and functions as an insulating blanket around the earth that prevents much of heat energy absorbed from the sun's rays from escaping back to space. This insulating effect helps keep the planet liveable. Whenever changes occur that affect the flow of energy into, within and out of the climate system, climate change occurs. Examples of causes of climate change or variability include changes in: the intensity of incoming sunlight; the composition of the atmosphere and hence its light scattering and insulating properties; the extent and reflective properties of snow, ice and vegetation on the earth's surface; and ocean circulation and hence its ability to take up heat energy from the sun and atmosphere.

On a global scale, some variations in climate can be of relatively short duration (years to decades). These fluctuations are caused by such factors as rapid oscillations in the ocean circulation or by other short-lived phenomena such as the injection of highly reflective sulphate particles into the atmosphere by explosive volcanoes. However, at the other extreme, factors such as slow changes in the earth's orbit around the sun are capable of triggering very large fluctuations in climate on time scales of tens and hundreds of thousands of years.

On regional scales, climates are not only influenced by changes in atmospheric circulation and radiative forcing caused by global scale changes, but can also be further altered in complex ways by the effects of local changes in snow and ice cover, ocean conditions, vegetation cover and other factors.

The effects of climate variations on global and regional ecosystems can be dramatic. Along the west coast of North America, for example, during the last deglaciation grass-sedge tundra type vegetation was gradually replaced by a succession of other ecosystems until the emergence of fully closed forests during the peak of the Holocene (Heusser, 1995). Temperature, moisture, snow, ice and other regionally specific variables play an important part in these fluctuations in climates and vegetation. Because of the inertial influence of the Pacific Ocean, the fluctuations of coastal climates such as that of BC are, in general, more modest than those of interior continents. By contrast, at higher latitudes such as those of the Yukon, positive feedbacks involving snow and ice can significantly amplify the effect of global climate change, particularly during winter seasons. Both studies of indicators of earth's past climates and analyses of instrumental climate records collected over the past century in general confirm this attenuation of coastal response and amplification of high latitude response to global temperature fluctuations (IPCC, 1990).

THE ISSUE OF CLIMATE CHANGE

Over the past two centuries humans have introduced a new element into the variable behaviour of both global and regional climates. One century ago, some scientists had already hypothesized that increases in concentrations of carbon dioxide in the atmosphere could significantly enhance the atmosphere's natural insulating properties (the so-called "greenhouse effect"). This enhanced greenhouse effect would in turn induce a large and global scale increase in average global temperatures that could alter climate and weather patterns around the earth (Arrhenius 1896). By the 1950s, scientists recognized that such changes were already taking place, primarily as a result of the accelerating release of carbon dioxide through the combustion of fossil fuels for energy.

Measurements of the composition of the atmosphere over the past several decades have indeed confirmed that average atmospheric concentrations of carbon dioxide (the most significant of the "greenhouse gases") are already approximately 30% higher today than those of pre-industrial times (Neftel, 1988;

Barnola,1995). Furthermore, the concentrations of other secondary greenhouse gases, such as methane and nitrous oxide, have also reached levels unprecedented during at least the past 10,000 years (Chappelaz 1993; Machida et al 1994). New, powerful greenhouse gases unknown in nature (such as the ozone-depleting CFCs) have also been introduced into the atmosphere. Scientific studies clearly link these increases in concentrations of greenhouse gases to rapidly escalating emissions from human activities. Projections for future emission rates suggest that concentrations of carbon dioxide are likely to double, and could triple, within the next century (IPCC 1995). In other words, humanity appears to be embarked upon an uncontrolled, global-scale experiment with the global climate system that threatens to dramatically alter the earth's weather patterns and hence global ecosystems as we know it today. While such human-induced climate change will take place against a background of natural climate fluctuations and variability as already described, best scientific estimates suggest that it will be more rapid and significant than any natural change experienced since the last deglaciation, and hence of major concern to scientists and to governments around the world. To policy makers, this concern is often referred to as the <u>issue</u> of climate change.

CLIMATE CHANGE IN THE 21st CENTURY

Scientists in general agree that the projected increases in greenhouse gas concentrations in future decades will cause a large and potentially dangerous change in global climate (IPCC 1995). However, there is still considerable uncertainty as to the rate of such change, how it will affect precipitation and the frequency and severity of extreme weather events, and how it will influence the climate of one region versus that of another.

Much of the research into such changes are conducted with the help of mathematical models that simulate the earth's climate system and its processes. These "climate models" are based on fundamental principles of physics and biogeochemistry, and experiments with them are run on some of the world's largest computers. The most advanced of these, known as coupled ocean-atmosphere general circulation models (O-AGCMs), simulate these processes in three dimensional space and allow the system to change with time in a fully interactive, "transient" manner. Before using them for climate change experiments, investigators test the competence of these models in approximating the climate system by ensuring they can simulate both today's climate and those of the past (such as the last glacial maximum) with reasonable accuracy. However, despite the very complex nature of some of these models, poor physical understanding of important processes such as cloud behaviour and ocean circulation processes, as well as computational limitations, mean that even the advanced models are as yet still crude reproductions of the real climate system. Hence, modellers advise caution in using the results of model experiments into the possible effect of an enhanced greenhouse gas effect on climate and weather, particularly on a regional scale.

Model Projections for Global Climate Change

Despite these uncertainties, a large number and variety of climate model experiments have provided some important and consistent clues with respect to some of the large scale features of future climate response to projected increases in greenhouse gas concentrations. Some of the most recent experiments have also included the regional climate influences of anthropogenic emissions of sulphate aerosols (primarily a by-product of coal combustion and metal smelting), which can have an important modifying effect on both regional temperatures and larger scale atmospheric circulation. Following are some of the broad conclusions of investigators (IPCC 1995):

- over the next century, average surface temperatures are likely to increase by 0.1 to 0.4°C per decade. Such rates of increase are believed to be unprecedented in recent millennia;

- surface temperatures will increase more rapidly over land than over oceans;

- winter temperatures will increase much more rapidly in polar regions than at lower latitudes. Some Arctic regions could encounter winter warming of up to 1°C/decade. However, summer Arctic temperatures will increase more slowly than global averages because of the offsetting effects of cold oceans and melting ice.

- small changes in mean temperatures can result in very large changes in the severity, duration and frequency of temperature extremes. Hazards related to extreme cold events should, in general, decrease, while those linked to extreme heat events will become more serious.

- global precipitation will increase, and precipitation patterns will change significantly. Increased poleward flux of moisture will cause a significant increase in precipitation in most high latitude regions. Some models suggest the number of intense Northern Hemisphere winter storms will increase. Summer convective storms are also likely to become more intense, resulting in increase in the number of intense rainfall events;

- Warmer temperatures will significantly decrease the volume and extent of sea ice, and will result in shorter snow and ice cover seasons in polar regions.

- By 2100, average sea levels are expected to rise by between 15 and 95 cm.

Implications for the Climates of British Columbia and the Yukon

Modellers caution that projections of future climates at the regional scale have a low level of confidence. This is illustrated by significant regional differences between projections of different modelling groups for a $2xCO_2$ climate. Along the Pacific coast of Canada, this is further complicated by strong topographical influences which remain poorly parameterized in all GCMs. The following estimates for possible climate change under $2xCO_2$ scenarios, representing the range of projections from a number of models, are therefore illustrative only of how the climates of BC and the Yukon may change under global warming scenarios, and should be used with caution and appropriate caveats.

Temperature

On average, equilibrium models project winter warming due to increased concentrations of greenhouse gases equivalent to a doubling of carbon dioxide to be about 3-4°C along coastal British Columbia, increasing to 4-6°C in eastern regions. Yukon winter temperatures are projected to increase by 2-5°C in the southern regions, increasing to as much as 8°C along its north shore. Equivalent summer warming is estimated at a fairly uniform 3-6°C for BC and the southern Yukon, decreasing to 2-4°C in the northern Yukon. Transient models experiments suggest that about two-thirds of that could be realized at actual time of equivalent doubling, estimated at around 2040. Masking effects of sulphate aerosols, although strongest in heavily industrialized regions, are also likely to affect global circulation patterns and hence could also mask up to 25% of the effects expected for the western Canada.

Precipitation

Since precipitation patterns are significantly influenced by changes in global circulation patterns induced by climate change, regional projections for changes in precipitation under doubled CO_2 scenarios remain very uncertain. However, in general, the model results range from little change to significant increase in winter precipitation for most of both BC and the Yukon. In summer, most scenarios suggest little change for the Yukon, but a tendency for less rain in southern BC.

Extreme Weather

Warmer temperatures are expected to increase the frequency of mild winters and warm summers, with a corresponding decrease in cold events. Increased poleward transport of moisture, as well as more intense summer heating of convective clouds should increase the frequency of both intense winter storms and heavy summer rainfall events. More intense thunderstorms may also increase hazards due to lightening, wind and hail.

RECENT CLIMATE TRENDS

Analyses of instrumental temperature records indicate that the globally-averaged surface air temperatures have increased by between 0.3 and 0.6°C over the past century. Based on evidence from proxy climate indicators, the average temperature during the 20th century is at least as warm as that of any other previous century since at least 1400 AD (Bradley & Jones 1995; IPCC 1995). Furthermore, the geographical pattern of changes in temperature appear to be increasingly consistent with climate model projections of expected changes due to past increases in greenhouse gases and sulphate aerosols. This pattern appears unlikely to have occurred by chance due to internal natural climate variability or to be due to volcanic or solar forcing (Santer 95b). Despite significant uncertainties about how to attribute these changes to specific causes, these results have led to a general consensus among scientists that there now appears to be "a discernible human influence on global climate" (IPCC 1995).

The geographical pattern of recent trends in global climates is quite complex. In recent decades, for example, average increases in temperature in the Northern Hemisphere, primarily in winter and spring, have exceeded 0.5°C/decade in some regions such as parts of Siberia and the Yukon. By contrast, parts of the North Atlantic and North Pacific regions have cooled, with large cooling of about 0.2°C per decade over western Greenland (Jones 1994).

In western Canada, analysis of annual temperature trends for the past century indicate a warming of 0.4°C along coastal BC, 0.6°C in the southern BC mountains, and 0.8°C in northern BC and the Yukon. Of these, only the warming in the BC mountains appears to be statistically significant. Most of the warming in these regions was caused by an increase in daily minimum temperatures, and occurred in winter and spring (reaching a statistically significant 1.5°C spring warming in the Yukon).

Global precipitation has increased slightly during the 20th century (about 1%), but increases in the mid to high latitudes of the Northern Hemisphere have been significantly larger (4% for latitudes 30N to 55N, increasing to more than 10% for higher latitudes). However, increases appear to have been greater in eastern regions of North America than in western regions. The Yukon and coastal BC regions, for example, appear to show only slightly increasing precipitation over the past 50 years, while that in the mountainous regions of southern BC have actually decreased slightly over the same time period (IPCC 1995; Environment Canada, 1995).

While it is very difficult to estimate trends of extreme events (since, by definition, they occur very rarely), analyses of extreme low pressure events in the Northern Hemisphere winter season (a useful proxy for extreme storm events) indicate insignificant trends during most of the past century, but a significant increase in the number of such events in recent decades (Lambert, 1996).

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Chapter 3

THE CLIMATES OF BRITISH COLUMBIA AND YUKON

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OVERVIEW

The climates of British Columbia and Yukon are greatly influenced by the proximity of the Pacific and Arctic Oceans, the rugged topography, and the large latitudinal variation from 49°N to 70°N. British Columbia and Yukon lie in the westerlies, a belt of upper winds that blow from west to east. The jet stream that undulates across North America throughout the year carries with it the Pacific weather systems that bring waves of cloud and precipitation to much of British Columbia. In summer, the jet stream tends to be weaker and usually lies across northern British Columbia and Yukon. The weather systems accompanying the jet stream are also generally weaker in summer. South of this summer jet stream, a surface ridge of high pressure often builds over the eastern Pacific and southern British Columbia, bringing prolonged periods of warm dry conditions. In northern Yukon, smaller weather systems often migrate eastwards along the Arctic Ocean coast, bringing surges of wind and precipitation in summer.

British Columbia and Yukon may be conveniently divided into four climate regions which are briefly described as follows:

- Pacific Coast - This narrow coastal strip is characterized by moist mild air from the Pacific. Frequent winter storms produce abundant precipitation as they encounter rising mountain slopes. In summer, large high pressure areas off the coast produce prolonged spells of fine weather.
- South BC Mountains - The southern interior, consisting of mountains, valleys, highlands and plateaus, has a typically continental climate with highly variable precipitation and marked extremes of temperature. Some of the driest regions in Canada are located in western sections. Winters are cold and summers are warm and dry with frequent hot days.
- Yukon/North BC Mountains - This northern region is characterized by alpine, sub-alpine and lowland terrain. It is dominated by widespread and continuous permafrost. Winters are long and very cold. Summers are short and cool. Precipitation is light to moderate.
- Northwestern Forest - This northern region to the east of the Rockies is typically flat and under the influence of cold, dry Arctic air. Summers are short and cool while winters are long and cold with persistent snow cover. Annual precipitation is light.

INTRODUCTION

The climates of British Columbia and Yukon, like their geography, are varied and complex. Spanning nearly 20 degrees of latitude, or 2200 kilometres, this region experiences a huge range in the distribution of the sun's energy. Mountain ranges play a dominant role in controlling the climate by blocking or modifying air masses originating outside the region. Significant climate variation with elevation exists, and the open ocean, being a source of both heat and moisture, also impacts on the climate. It is not surprising that this geographically diverse region has some of the hottest, coldest, driest, and wettest climates in Canada.

The purpose of this chapter is to characterize the past, present and possible future climate regimes of British Columbia and Yukon. Other topics include the nature of climate observations and climate data, a discussion of climate controls, and the identification of climatic sub-regions. Due to space limitations, only temperature and precipitation regimes are described in detail. The reader is referred to the Canadian Climate Normals (Environment Canada, 1993) for a fuller range of climate elements.

CLIMATE DATA

Reliable climate observations in British Columbia and Yukon date back to the late nineteenth century. The pace of early development of the climate network was geared to aviation and economic requirements for weather data. Most of the Environment Canada climate network was put in place during the 1960's and 70's. The network consists of two types of climatological stations: principal and ordinary. In the past, principal climate stations were staffed by professional weather observers. Most of these climate stations are now being automated. Ordinary climate stations are operated by trained volunteer observers. Climate data are quality controlled and archived under World Meteorological Organization guidelines. However, changes in instruments, local conditions, sites, and procedures, and urban encroachment, as well as missing data can all affect the accuracy and completeness of the data.

As of 1996, there were approximately 500 ordinary climatological stations in British Columbia and Yukon and roughly 40 principal stations. A number of other agencies such as BC Hydro and the BC government routinely collect climate information for their own purposes.

Climate data are summarized and published by Environment Canada as the Canadian Climate Normals (Environment Canada, 1993) for such applications as agriculture, building codes, forest management, tourism, and so on. Normal climate values are 30 year averages, a period considered sufficiently long to account for the year to year variability of the climate. The current 30 year period spans 1961 to 1990 and the publication is updated every ten years. Extreme maximum and minimum climate values are the highest and lowest occurrences, respectively, from the entire period of record. Climate parameters include temperature, precipitation and wind, as well as some derived values including growing- and heating- degree days.

CLIMATE CONTROLS

The major physical and physiographic influences on the climates of British Columbia and Yukon have been well documented (Chapman, 1952; Chilton, 1981; Hare and Thomas, 1974; Janz and Storr, 1977; Kendrew and Kerr, 1955; Phillips, 1990; Wahl et al, 1987). The climates of British Columbia and Yukon are greatly influenced by the proximity of the Pacific and Arctic Oceans, the rugged, mountainous topography, and the large latitudinal variation from 49°N to 70°N. Temperatures have plunged to -63°C in Snag, Yukon and surged to 44°C in Oliver in southern British Columbia.

Like most of Canada, British Columbia and Yukon lie in the westerlies, a belt of upper winds that blow from west to east. The strong core of these winds, called the jet stream, undulates across North America throughout the year, often breaking into two or three branches. The jet stream carries with it the Pacific weather systems that bring waves of cloud and precipitation to much of British Columbia.

In summer, the jet stream tends to be weaker and usually lies across northern British Columbia and Yukon. The weather systems accompanying the jet stream are also generally weaker in summer. Evaporation from subtropical areas of the Pacific is the source of much of the atmospheric moisture in these weather systems. South of this summer jet stream, a surface ridge of high pressure often builds over the eastern Pacific and southern British Columbia, bringing prolonged periods of warm dry conditions. In northern Yukon, smaller weather systems often migrate eastwards along the Arctic Ocean coast, bringing surges of wind and precipitation in summer.

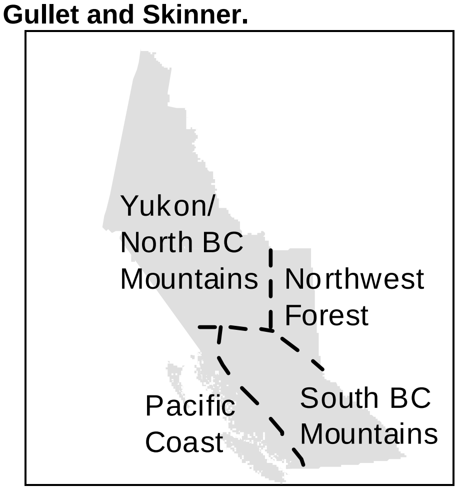
During the winter, the Pacific jet stream intensifies and sags further south. Weather systems also intensify, with October through to January being the wettest and windiest months over much of central and southern British Columbia. The coast mountains squeeze much of the precipitation out of the atmosphere such that the west coast of British Columbia records by far the most annual precipitation. The Rocky Mountains continue this process, producing a wide band of precipitation in the eastern interior of British Columbia. As the jet stream sags southward in winter, cold dry arctic air invades from the north, bringing frigid winter temperatures to Yukon and northern British Columbia. This results in the winter months in northern areas being the driest of the year. This arctic air frequently spills into the southern interior of British Columbia in winter and occasionally onto the south coast. In winter, precipitation at low elevations falls as snow when the arctic air is present, and precipitation in the mountains is generally always snow. This mountain snowpack reservoir is a vital to ecosystems and the socio-economic fabric of British Columbia, since it is the natural source of fresh water throughout the summer.

In mountainous terrain, the effects of elevation on climate can overwhelm the influence of other climate controls. Slope, aspect and elevation play a significant role in temperature variation and the distribution of precipitation as well as other climate elements including wind. Mountains are measurably wetter and cooler with increasing elevation. Windward slopes are usually much wetter than leeward slopes. Given the proximity of the ocean and the orientation of the mountains to the prevailing winds, areas of heavy precipitation along the British Columbia coast and southwestern Yukon can change abruptly to much drier regimes on the lee side of the mountains.

CLIMATE REGIONS

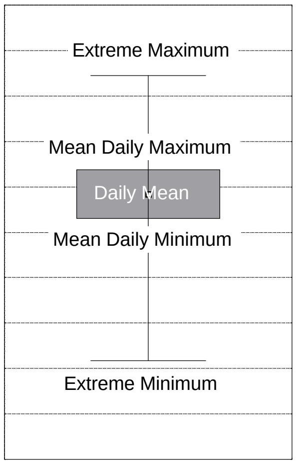
A number of climate classification schemes have been applied to British Columbia and Yukon (Ecological Stratification Working Group, 1995; Gullet and Skinner, 1992; Hare and Thomas, 1974; Wahl et al, 1987). Gullet and Skinner (1992) identified 11 climate regions for Canada as a basis for detecting temperature change in Canada over the past century. Divisions were based on a combination of the six climate regions of Thomas and Hare (1974) and the 15 ecozones defined under the National Ecological Framework for Canada (Ecological Stratification Working Group, 1995). Since many different spatial structures are possible and justifiable on climatological grounds, the number of regions and the exact placement of boundaries are somewhat arbitrary (D. Gullet, pers. comm.). Figure 1 shows four climate regions defined by Gullet and Skinner that lie within the bounds of British Columbia and Yukon as follows: Pacific Coast, South British Columbia Mountains, Yukon/North British Columbia Mountains, and Northwestern Forest, only a portion of which covers the northeastern corner of the province.

Figure 1. Map of British Columbia and Yukon showing four climate regions defined by Gullet and Skinner.



For each of the four climate regions characterized below, the geography is depicted and the climate is described in terms of its seasonal average as well as its variability, Climatic variations within each region, are also given. As shown in Figure 2, the average seasonal temperature is represented by the daily mean temperature, the mean daily maximum, and the mean daily minimum temperature for each season. Also shown are the extreme daily maximum and minimum temperatures. The standard deviation is a measure of the day to day variability of the temperature. Roughly 65% of all occurrences of a given parameter lie within one standard deviation of the mean value. For precipitation, total seasonal rain (millimetres) and snowfall (in centimetres) are given.

Figure 2. Legend for temperature profiles that appear in the following sections for each climate region.



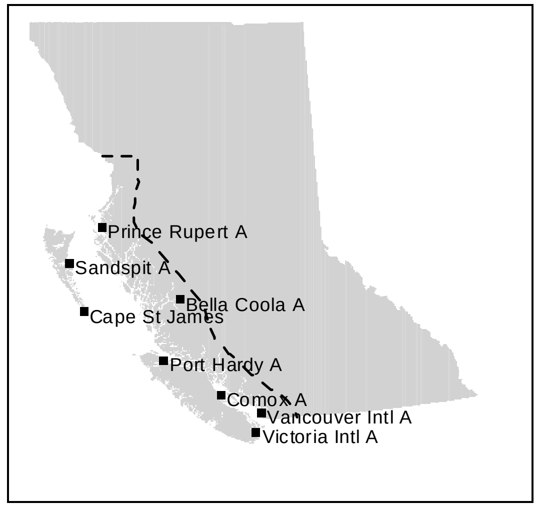
Temperatures and precipitation are significantly affected by mountains. However, the existing network of climate stations tends to be concentrated in valley floors and populated areas so that the climate record of British Columbia and Yukon is biased towards the drier valley climates. Measures of temperature and precipitation are relatively sparse in the rugged mountainous regions of British Columbia and Yukon, particularly in the north. To define the climate of British Columbia and Yukon fully would require a much denser climate station network than exists today. The climate descriptions which follow, therefore, are only representative of the more populated areas where climate stations are situated.

Pacific Coast Climate Region

Geography

This region includes Vancouver Island and the Queen Charlotte Islands, plus a narrow strip of the coastal mainland consisting of the highlands and western slopes of the Coast Mountains. The topography is characterized by narrow coastal fjords and deep inlets extending well into the mountains, as well as highlands and mountain slopes rising on average to approximately 2500 metres. (Figure 3)

Figure 3. Pacific Coast climatic region showing a selection of climate stations.



Temperatures

The Pacific Ocean is warmer than the land in winter and cooler in summer, moderating temperatures year around. The mean annual temperature is between roughly 7 and 10°C. The Pacific Coast has the least seasonal temperature variation of all the regions and shows almost only slight variation from north to south. Daily minimum temperatures usually stay above freezing during the winter at low elevations along the south coast. January mean daily maximum temperatures average about 5 °C, and the mean daily minimum is near zero. Variability is low with standard deviations for January temperatures between 1 and 3 degrees. Somewhat cooler temperatures are found to the north and further inland. For example, the mean daily temperature for January at Prince Rupert is 0.8°C. Extreme minimum temperatures are due to the occasional outbreak of arctic air during which daily minimums drop below zero and the skies become clear. Summers are typically warm and dry under the influence of high pressure, although seldom hot due to the moderating influence of the ocean. July mean daily maximum temperatures average 17 to 23 °C and mean daily minimum temperatures average near 10 °C. Variability is very low with July standard deviations being less than 1.0 degree. (Figure 4).

Figure 4. Daily temperature range (mean and extreme) by season for the Pacific Coast climate region.

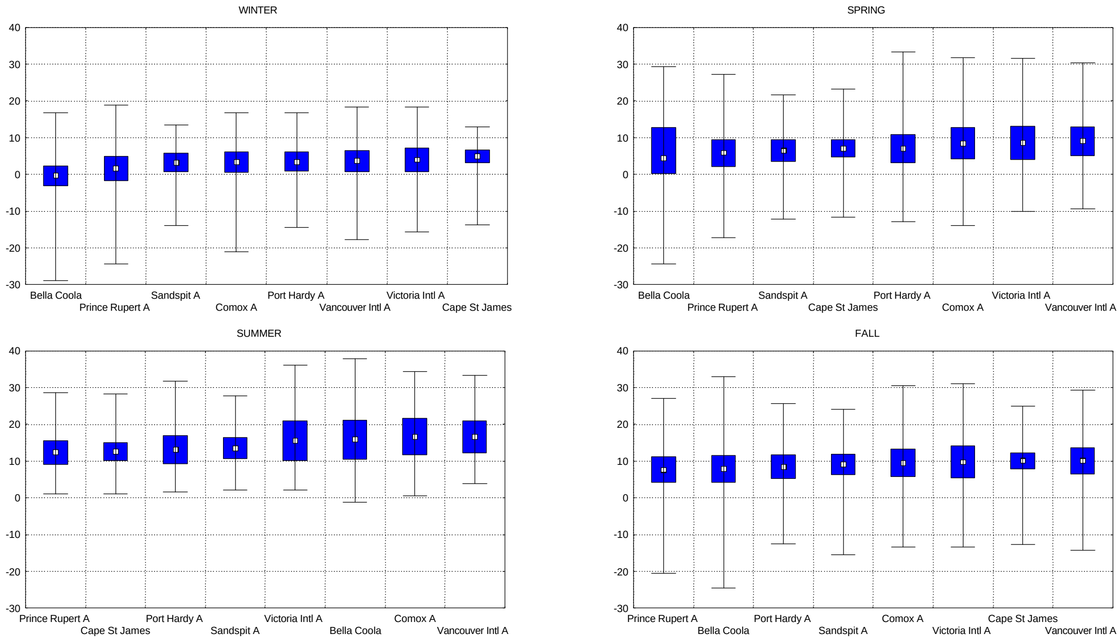
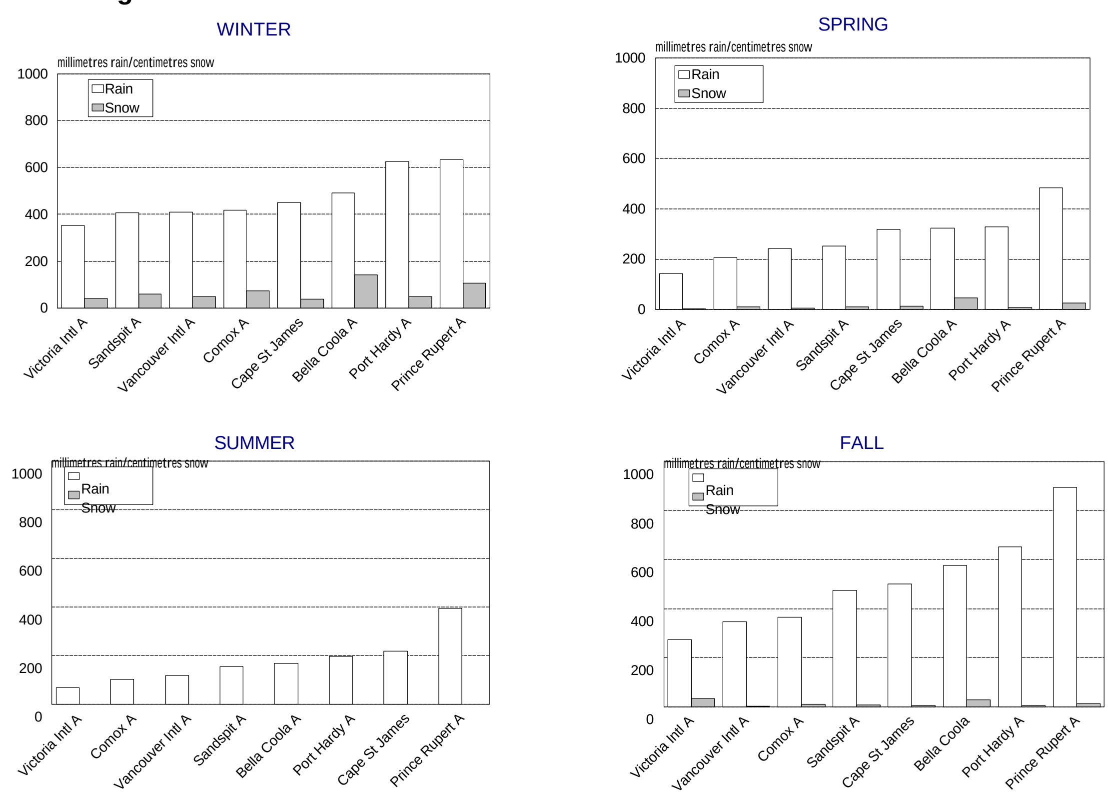


Figure 5. Seasonal total rainfall (millimetres) and snowfall (centimetres) for the Pacific Coast climate region.



Precipitation

Precipitation patterns vary considerably in response to topography. Windward slopes receive in excess of 3500 millimetres of precipitation annually, while the Gulf Islands and southeastern Vancouver Island may receive less than 1000 millimetres. Cloudy, wet weather that lasts from October through April. Most of this precipitation falls as rain. When snow occurs, it does not stay on the ground long with the return of warmer conditions. Vancouver International Airport, for example, receives on average over 1100 millimetres of rain and only 55 centimetres of snow annually. July mean rainfall ranges from roughly 20 millimetres in the south to about 100 millimetres in the north. (Figure 5)

Climatic Variations

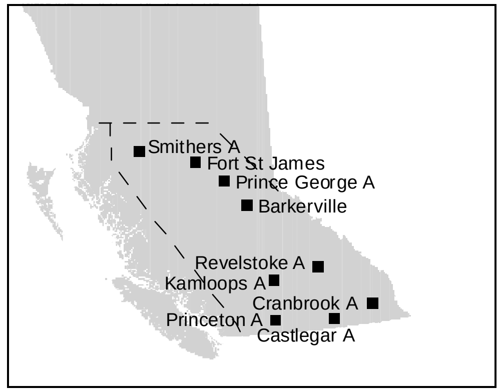
The west facing slopes of Vancouver Island, the Queen Charlottes, and the Coast Mountains are the wettest part of this region with prolonged and sometimes heavy rain during winter. The eastern slopes of the island mountains experience less rainy weather due to the sinking motion and subsequent drying of the air. The Gulf Islands and Saanich Peninsula of Vancouver Island, which lie in the rain shadow of the Olympic Mountains of Washington, receive the least amount of rain. Prince Rupert receives more than 2500 millimetres of precipitation annually. Victoria, by contrast, receives on average less than 900 millimetres.

South B.C. Mountains Climate Region

Geography

The South British Columbia Mountains region lies between the crest of the Coast Mountains and the continental divide of the Rockies, and includes the plateaus, highlands, valleys and mountains south of roughly 56° latitude. It includes the basins of the Fraser, Thompson, Columbia and Kootenay Rivers as well as the Selkirk, Purcell and Monashee ranges whose heavy winter snows are the source of runoff for the major rivers of these basins. Between the Selkirk-Purcell ranges and the Coast Mountains lie the Fraser and Columbia River basins, characterized by valleys, rolling plateaus and highlands. To the south are the arid Okanagan and Thompson valleys, and to the north, the Cariboo mountains and the Interior Plateau.

Figure 6. South BC Mountains climate region showing a selection of climate stations.



Temperature

The region experiences marked extremes of temperature. January mean daily maximum temperatures remain a few degrees below zero and mean daily minimum temperatures range between -8 and -16 °C. Variability is high in winter with standard deviations of 3 to 5 degrees for January. In summer, July mean daily maximum temperatures average in the low to mid twenties and mean daily minimums are between 8 and 11 °C. July variability is low with standard deviations of around 1 degree (Fig. 7).

Precipitation

Pacific maritime air brings only moderate precipitation to the interior mountains and high plateaus. As this modified moist Pacific air sinks into the valleys of the interior, it compresses and becomes warmer and drier. Kamloops, for example, reports an average of less than 300 millimetres of precipitation annually. Moisture is fairly evenly distributed throughout the year, although spring is the driest season. The western slopes of the interior mountains receive substantially more precipitation than the eastern slopes, and this is usually in the form of snow. Some of the driest climates in Canada are located here in the valley bottoms and on the east-facing slopes in the rain shadow of the Coast Mountains. Average annual precipitation is generally between 500 and 1000 millimetres except in the southern interior valleys where it is less than 350 millimetres. (Figure 8)

Figure 7. Daily temperature range (mean and extreme) by season for the South BC Mountains climate region.

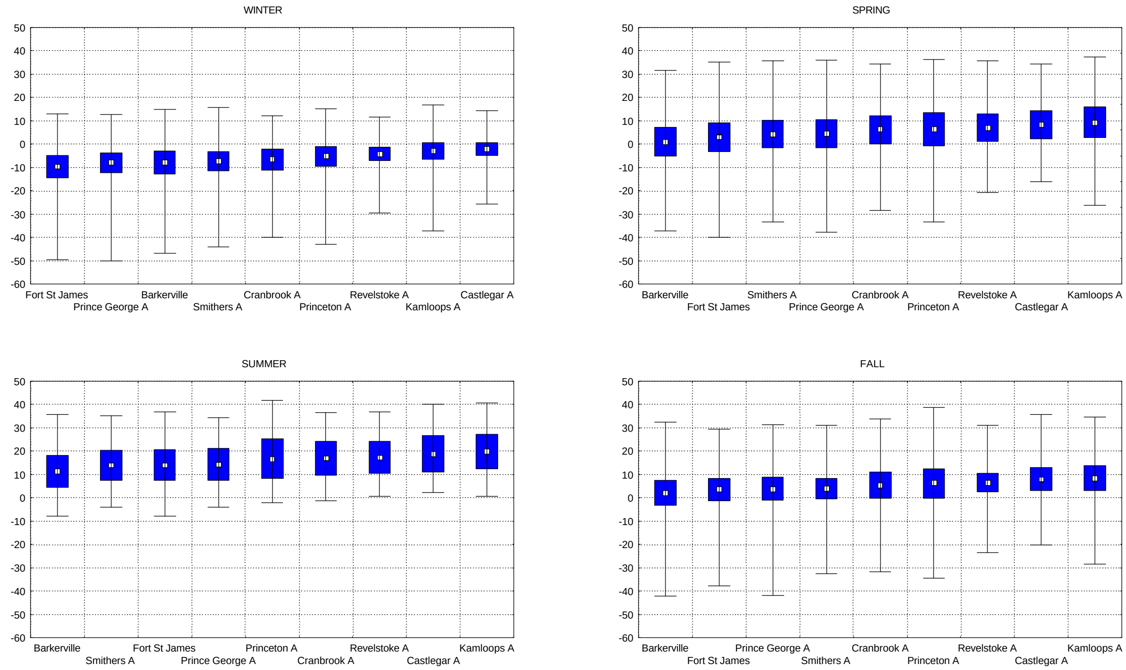
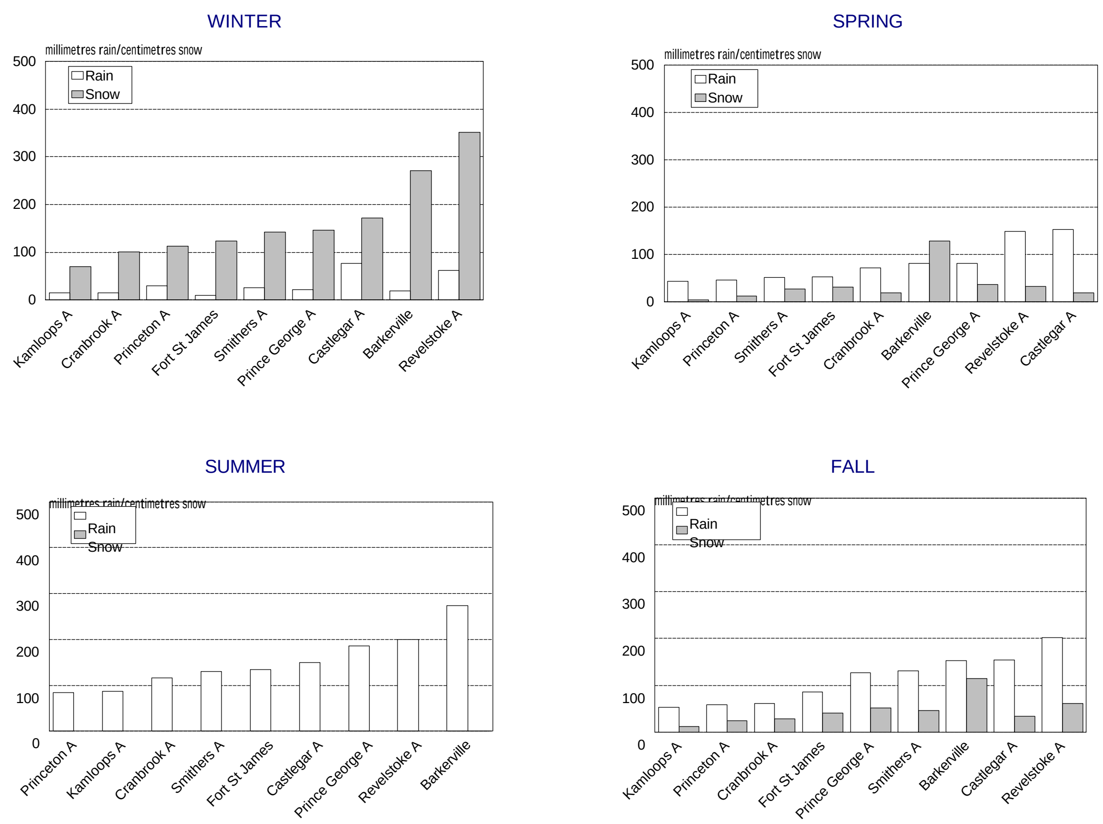


Figure 8. Seasonal total rainfall (millimetres) and snowfall (centimetres) for the South BC Mountains climate region.



Climatic Variations

The southern interior valleys and leeward slopes including the Okanagan Valley and the area to the west and south of Kamloops are noted for their hot, dry summers. One of the driest places in British Columbia is the area along the Thompson River between Litton and Ashcroft. By contrast, one of the deepest and most prolonged snow covers is in the eastern portion of the southern interior over the Selkirk-Purcell-Monashee ranges which produces substantial runoff in the spring and summer. Northern interior summers are cooler and wetter than the south. July daily mean temperatures for Fort St. James and Prince George average 15 °C while Castlegar and Cranbrook average closer to 20 °C. In the winter, average January temperatures of the northern interior run about 5 degrees colder than in the south.

Yukon/North BC Mountains Climate Region

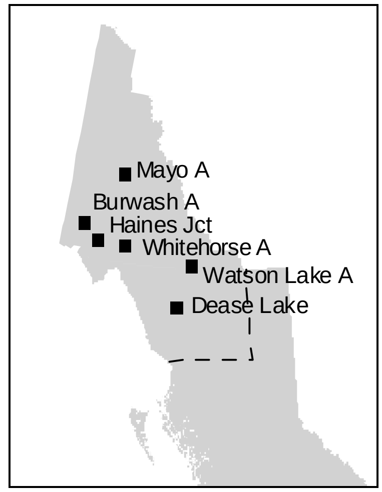
Geography

This region consists of the entire Yukon Territory and the northern portion of British Columbia north of roughly 56 degrees latitude. Most of it comprises a large terrestrial ecozone known as the Boreal Cordillera. The northern portion of British Columbia, situated between the Coast mountains to the west and the Rocky Mountains to the east, is characterized by very rugged terrain consisting of mountains and plateaus. In Yukon, the imposing St. Elias Range continues where the Coast Mountains leave off posing an enormous barrier to Pacific storms. To the east, the Rockies extend northward into the Mackenzie-Selwyn-Richardson complex. Much of the interior of Yukon consists of rugged mountains, plateaus, steep valleys and narrow glacier-fed lakes. (Figure 9)

Temperature

Despite its proximity to the oceans, and owing to its high latitudes, the climate of this northern region is characterized by long cold winters and short summers. High latitudes affect the hours of daylight in both winter and summer. In winter, extreme cold is usually the result of a temperature inversion where cold air becomes trapped in depressions surrounded by mountains. Snow on the ground acts as an

Figure 9. Yukon/North BC Mountains climate region showing a selection of climate stations.



insulator from the warmer ground beneath and also as a radiator under clear skies. The lack of cloud cover and the reduced hours of sunlight lead to a large loss of radiation which is not compensated by sunshine due to the low sun angle. January daily maximum temperatures are in the -15 to -22 °C range. Daily minimum temperatures average in the range of -23 to -32 °C. Temperature variability is high with standard deviations of 6 to 8 degrees for January. In summer, the extended days provide longer hours of radiation. Summers in Yukon, although short, can sometimes be quite warm, resembling those in northern British Columbia. July daytime maximums average 19 to 23 °C and minimums average between 6 and 8 °C. The July standard deviation is about 1 degree (Figure 10).

Precipitation

Yukon receives very little precipitation compared to British Columbia and most of it occurs during the summer months as showers. Average annual precipitation is less than 500 millimetres. The spatial pattern of precipitation reflects the topography with windward slopes receiving more precipitation than leeward slopes, and higher elevations receiving more precipitation than lower elevations. (Figure 11)

Climate Variations

The wettest part of this climate region is found on the windward slopes of the Coast

Figure 10. Daily temperature range (mean and extreme) by season for the Yukon/North BC Mountains climate region.

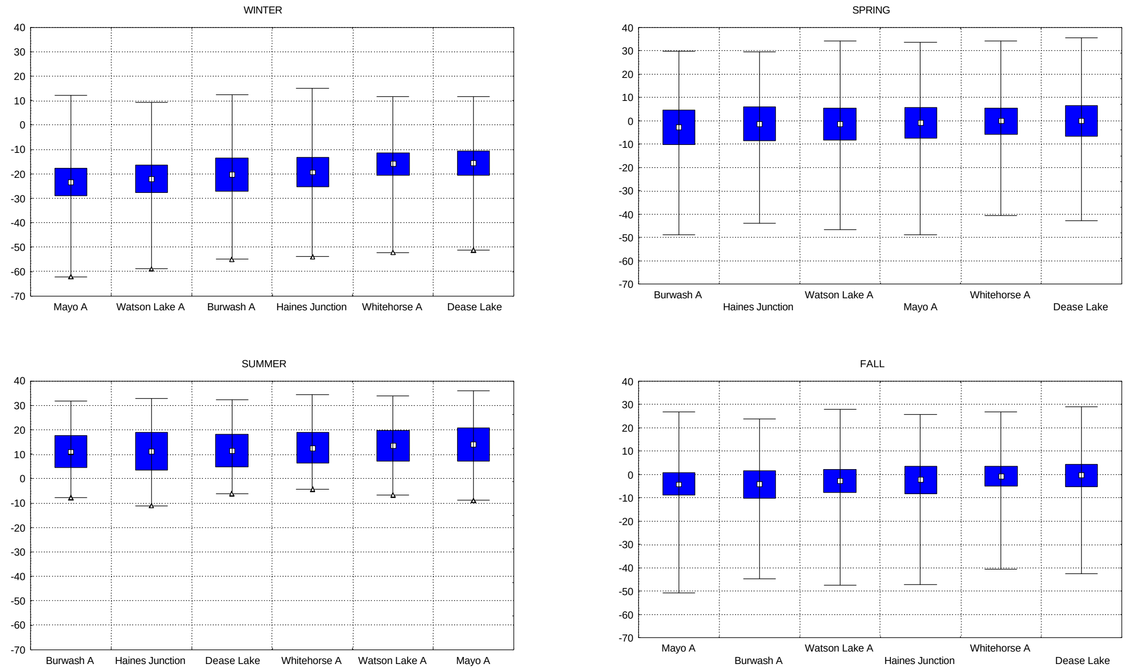
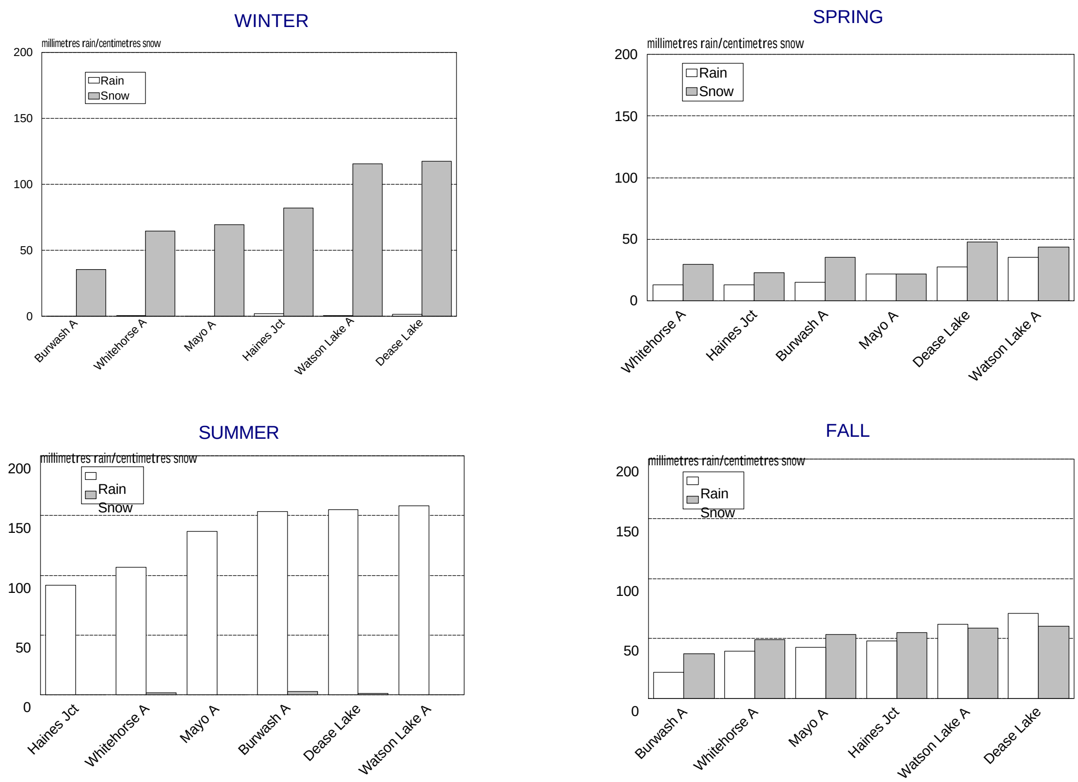


Figure 11. Seasonal total rainfall (millimetres) and snowfall (centimetres) for the Yukon/North BC Mountains climate region.



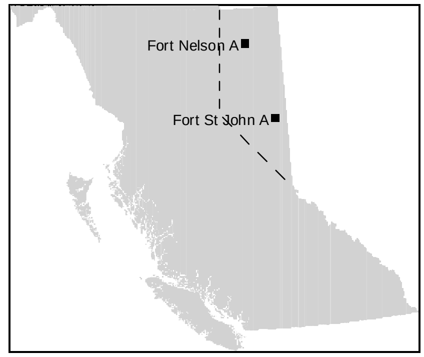
Mountains and St. Elias Range where huge deposits of snow nourish an extensive network of glaciers. The climate becomes much drier on the leeward slopes of this range. Despite the natural barrier of the St. Elias Range, some Pacific maritime air penetrates into southwest Yukon which has a moderating effect on both summer and winter temperatures. The interior basin experiences a continental climate marked by low precipitation and a large range in temperature. Average monthly winter time temperatures in the interior remain below zero for six to eight months, and the area is also noted for temperature extremes. The coldest temperature ever recorded in Canada (-62.8°C) was in this region at Snag, Yukon in 1947. Northern Yukon is characterized by prolonged and cold winters. Average daily January temperatures for Mayo are around -25°C. Inversion effects keep low elevations very cold, whereas the high elevations of the British and Richardson Mountainous regions tend to be milder. Summers are short and variable. Annual precipitation is low and results mostly from summer convection. The Arctic slope, a narrow zone lying between the British Mountains and the Arctic Ocean, receives very little precipitation. Winters are cold and prolonged, but not quite as extreme as the interior due to the influence of the Beaufort Sea. Summers are cool and changeable depending on whether the wind is from the sea or land.

Northwestern Forest Climate Region

Geography

This climate region covers a vast portion of western Canada, but only a small part of it is within British Columbia and none of it is in Yukon. The region includes the northeastern corner of British Columbia to the east of the continental divide, encompassing the eastern slopes of the Rockies and the river basins of the Laird, Fort Nelson and Peace Rivers. This corner of the province is part of the Great Basin of North America characterized by rolling hills, plateaus and plains. Elevations range between 900 and 1200 metres. This northern portion is home to the Boreal Forest consisting of spruce, fir, pine, larch as well as poplar, birch and mountain ash. (Figure 12)

Figure 12. BC portion of the Northwestern Forest climate region showing a selection of climate stations.



Temperature

This region has a continental climate with long, cold winters and short summers. The most striking characteristic of this region is the large seasonal change in temperatures which, like the Yukon, span more than 40 degrees between the January mean daily minimum and July mean daily maximum. The annual mean daily temperature is around or below freezing. Frigid, continental Arctic air dominates winter and spring. January mean maximum temperatures reach-11 to -18°C for Fort St. John and Fort Nelson, respectively, and daily minimum temperatures are in the -19 to -27 °C range. July mean daily maximum temperatures are around 23 °C and mean daily minimum temperatures average 10 °C. (Figure 13)

Precipitation

Precipitation is light in the lee of the Rockies with most occurring in summer as showers. Average annual precipitation is less than 500 millimetres. Arctic air arriving from the north is dry. Pacific maritime air is mild but with most of its moisture gone when it arrives over the mountains. (Figure 14)

CLIMATE CHANGE

The natural variability of the climate is evident in the day-to-day and year-to-year changeability of weather patterns. To determine whether the climate is changing over time, it is necessary to distinguish between short term fluctuations and long term trends in the climate

Figure 13. Daily temperature range (mean and extreme) by season for the British Columbia portion of the Northwestern Forest climate region.

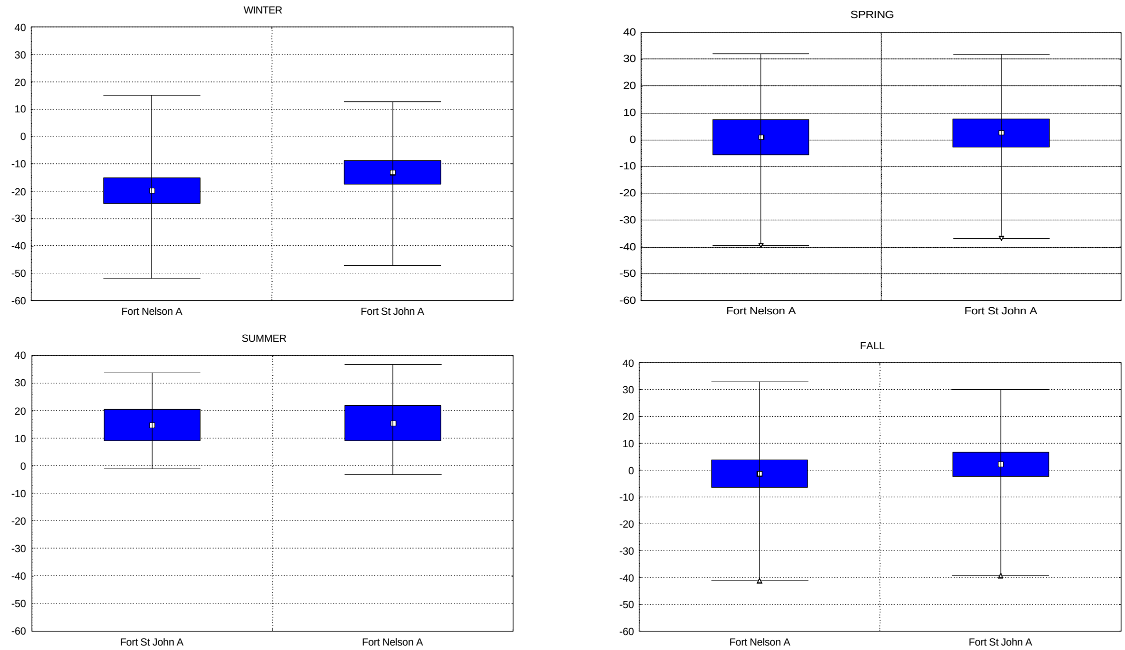
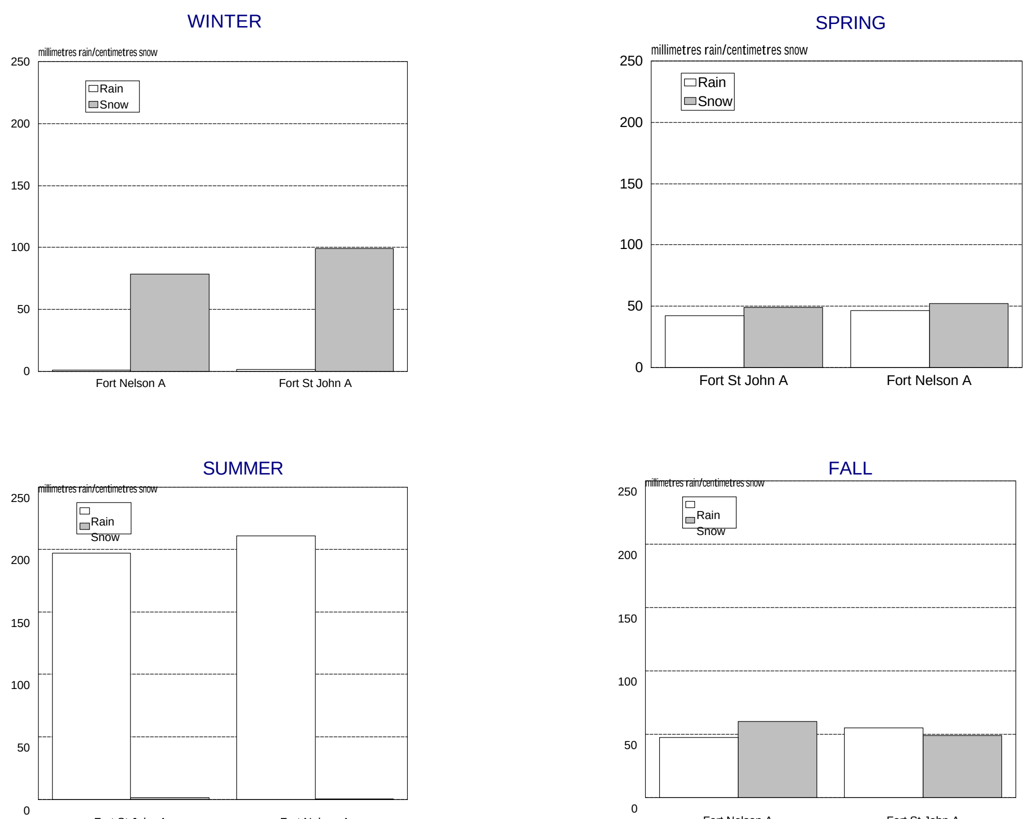


Figure 14. Seasonal total rainfall (millimetres) and snowfall (centimetres) for the BC portion of the Northwestern Forest climate region.



record. Only by studying the climate data over a period of several decades is it possible to detect a climate change such as a warming trend. The Intergovernmental Panel on Climate Change (IPCC) has examined the long term record and has determined that the global average surface temperature has increased by about 0.5 °C over the last century (IPCC, 1995). This warming has not been uniform but has been greatest over the continents at the middle latitudes of the Northern Hemisphere since the 1970's.

Environment Canada (1995) examined the data from more than 100 Canadian climate stations with periods of record dating back to about 1895 to determine the occurrence of a warming trend over Canada. This work began with the creation of the climate regions described earlier in this chapter. Departures in the temperature from the 1951 to 1980 Normals were obtained for each climate region and plotted in a time series to determine any evidence of temperature trends. The results of this study that pertain to British Columbia and Yukon are presented in Table 1 below.

To be statistically significant, a clear trend must emerge from the highly variable year to year temperature measurements for a particular region. Trends for the Northwestern Forest climate region as well as the South BC Mountains climate region are statistically significant. The temperature changes over the past century have shown three distinct phases: a warming trend from the late 1890's to the 1940's, followed by a cooling trend from the 1940's to the 1970's, and a resumption of a warming trend through the 1980's.

In recent years, concern has been expressed that the world may be on the brink of unprecedented climate change due to rising levels of greenhouse gases in the atmosphere (IPCC, 1995). Considerable research has been dedicated to the development and enhancement of General Circulation Models (GCMs). These are physically-based computer models designed to simulate the radiative effects of various concentrations of greenhouse gases on the global climate. There are many reputable GCMs, each producing somewhat different climate change scenarios depending on their unique mathematical and physical formulations. The fact that different GCMs produce different results, particularly on a regional scale, is an indication of the uncertainty inherent in the ability of these models to predict the future climate.

Recent GCM estimates of the projected rise in long term global average annual surface temperature are between 1 and 4.5 Celsius degrees under simulated doubled CO2 conditions (IPCC, 1995). On the sub-continent scale there is considerable uncertainty in the model results and it is not possible to know with confidence the fine details of how the climate will change regionally. Since the resolution of GCMs is usually too coarse to reliably estimate regional climates, it is customary to use observational data as a baseline and adjust these data by the GCM scenarios.

Figures 15 and 16 show the GCM-projected changes in seasonal temperature and precipitation produced by the three different GCMs for the four climate regions of British Columbia and Yukon for the latter half of the twenty-first century. The horizontal bars represent the spatial variability in the projected changes in temperature and precipitation. To apply these scenarios, temperature data for a particular climate region are adjusted by adding the temperature change shown in the figure, and precipitation data are adjusted by the percentage change shown.

The three models are: the CCC GCMII, prepared by the Canadian Centre for Climate Modelling and Analysis (Boer et al., 1992); the GFDL GCM from the Geophysical Fluid Dynamics Laboratory at Princeton University (Manabe et al, 1991), and NASA's GISS GCM produced by the Goddard Institute for Space

Table 1. Regional trends in annual average temperature from 1895-1992 for four climate regions in British Columbia and Yukon. (Environment Canada, 1995)

Climate Region	Temperature Change	Statistically Significant
Pacific Coast	0.4 °C	NO
South BC Mountains	0.6 °C	YES
Yukon/North BC Mountains	0.8 °C	NO
Northwestern Forest	1.4 °C	YES

Figure 15. Projected seasonal temperature changes (degrees C) for climate regions of British Columbia and Yukon for the latter half of the twenty-first century.

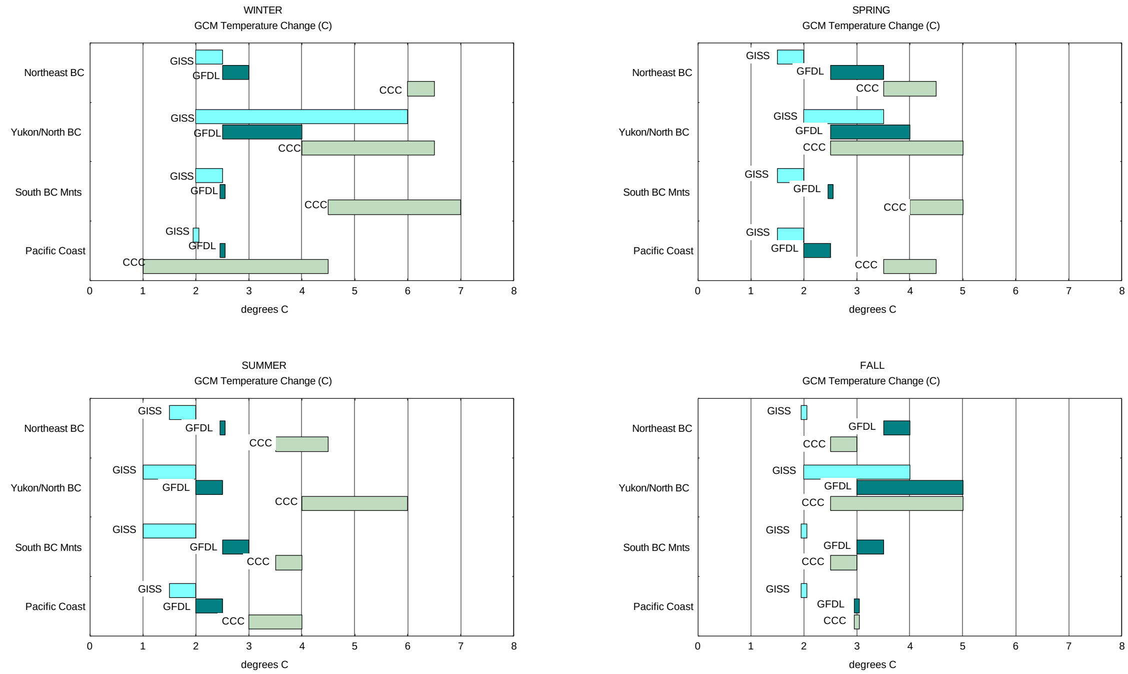
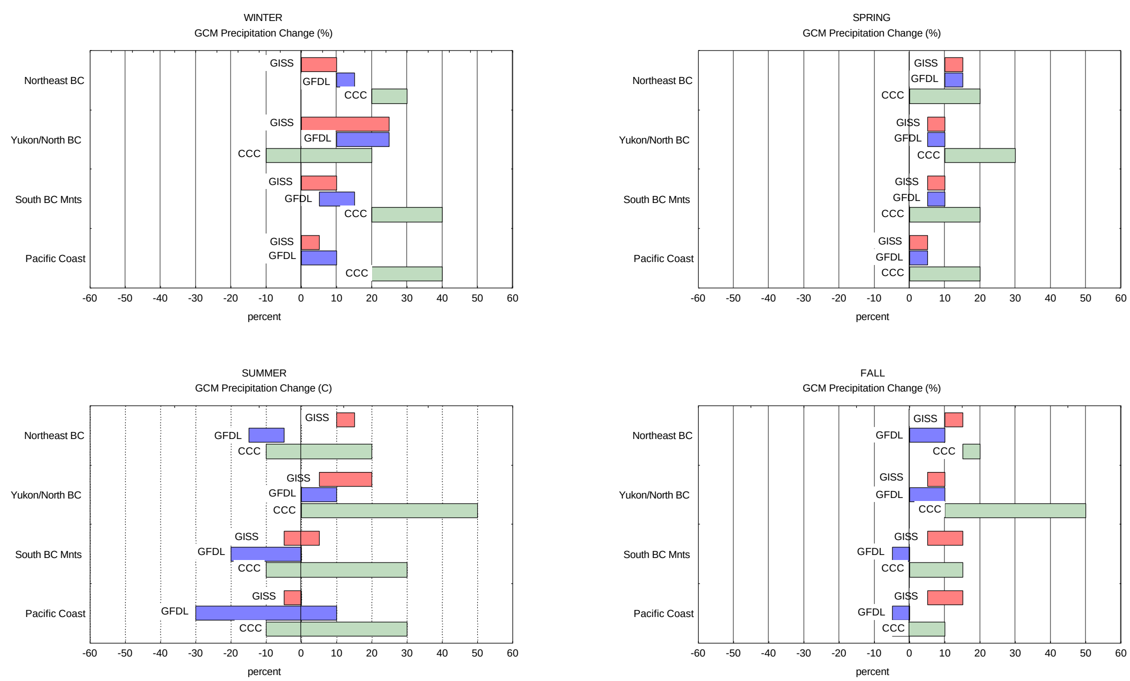


Figure 16. Projected seasonal precipitation changes (percent) for climate regions of British Columbia and Yukon for the latter half of the twenty-first century.



Studies (Russell et al., 1995; Hansen et al., 1983). The GFDL and the GISS GCMs are transient models whose CO2 is increased by 1% per year until CO2 concentrations are doubled. These atmospheric models are coupled to fully circulating ocean models in order to simulate the oceans' effect on the climate as it changes very gradually over time. The CCC GCMII is called an equilibrium model whose results represent the full response of the atmosphere and ocean to an instantaneous doubling of CO2 concentrations. More information concerning these models and their application may be found in the appendix of this publication. The expected timing of a doubling of CO2 depends on our assumptions about the future rate of greenhouse gas emissions as well as the base period chosen. When used in conjunction with the 1951-80 or 1961-90 Normals and a standard IPCC emission scenario, IS92a, (IPCC, 1995) the valid period for the climate change projections shown here is for the latter half of the twenty-first century.

CONCLUSION

This chapter summarizes what is currently known about the climates of British Columbia and Yukon. In addition, the sources and nature of climate data are described and the climate controls of the region are discussed. The climate of this region is complex and only the most salient features of four general climatic regions are described. Many publications on this subject exist, and the reader is directed to the references provided for more information.

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Part 3

THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON PHYSICAL ENVIRONMENT OF BRITISH COLUMBIA AND YUKON

Chapter 4

PROCESSES AFFECTING SEA LEVEL CHANGE ALONG THE COASTS OF BRITISH COLUMBIA AND YUKON

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OVERVIEW

This report quantifies the principal mechanisms affecting relative sea level rise along the coasts of British Columbia and the Yukon. Although global climate change can be expected to have a profound influence on long-term sea level, it is only one of several factors affecting coastal sea level variations. Accurate estimates of present and future sea level change also require a thorough understanding of regional phenomena such as glacio-isostatic rebound, plate tectonics, hydrological processes, and the variability of prevailing atmospheric pressure and wind systems.

Relative sea level is rising between 1 and 2 millimetres per year due to thermal expansion of the ocean (steric processes) and ocean volume increases resulting from the melting of land based glaciers and ice sheets (eustatic processes). The analysis indicates that there are major differences in the rates of sea level rise at the southern and northern sectors of the British Columbia coast due to uplift along the southern coast caused by the frictionally-locked subducting plate under Vancouver Island. Major differences exist in the rates of sea level rise along the inner and outer coastal waters of British Columbia as a result of spatial differences in glacio-isostatic rebound. Expected sea level rise rates for British Columbia range from -1 to +2 mm/yr on the south coast to -1 to +6 mm/yr on the north coast. For Yukon, there is a large component of sea level rise from isostatic rebound. Predicted sea level rise rates for the Yukon coast vary from 3 to 9 mm/yr. Sea level rise from oceanic and coastal winds is poorly known but is probably within a maximum range of ±20 cm for the next few hundred years for both British Coumbia and Yukon.

INTRODUCTION

The effects of possible sea level rise are a prominent consideration in any discussion of the consequences of future climate change and "global warming". Two decades ago, speculation about the possible rapid collapse of the West Antarctic Ice Sheet, with a resulting 5 m rise of sea level, attracted considerable scientific attention (e.g. Mercer, 1978). However, when scientists in the field began to examine the West Antarctic Ice Sheet question more closely, they concluded that its rapid collapse was highly improbable. It is now generally agreed that a climate-induced rise in global sea level over the next century is unlikely to reach 1 m and will probably be only a fraction of that (IPCC, 1990). Moreover, it is clear that climate change is only one of a variety of processes that can bring about long-term variations in relative sea level. Other factors that affect oceanographic, meteorological and geological conditions also must be taken into account. These contributions result in a complex sea level signal in which large amplitude interannual and decade-scale fluctuations in relative sea level easily mask small amplitude secular changes associated with global climate change (Fig. 1).

The study of long-term global sea level change has recently advanced from the stage of simple data processing and manipulation, to sophisticated data calibration and selection, to numerical modeling and satellite measurement. Much use has been made of the tide gauge data bank created in 1933 at the Permanent Service on Mean Sea Level in England (Pugh et. al., 1987). Tide gauges measure the level of the sea relative to the land (local bench marks) so that what is measured is as sensitive to changes in land level as to changes in sea level. Hence the use of the term "relative sea level" rather than just "sea level". Moreover, the sea itself is not "level". There is a hypothetical surface called the geoid, which would be the level of the sea surface if there were no winds, no ocean currents and no variations in atmospheric pressure. Because of these other factors, the actual level of the sea at any location, even averaged over long periods, differs from the geoid by as much as a metre. As a result of the irregular distribution of mass within the earth, the geoid is itself an irregular surface relative to the centre of mass of the earth. It is this latter factor which limits the ability of satellite altimetry and the Global Positioning System to provide precise measurements of absolute sea level.

The purpose of this report is to define the principal mechanisms affecting relative sea level rise along the coasts of British Columbia and the Yukon. Global climate change can be expected to have a profound effect on long-term sea level variations, but this is only part of the story. Accurate estimates of present and future sea level change also require a thorough understanding of regional phenomena such as glacio-isostatic rebound (the slow visco-elastic recovery of the solid earth to the deformation imposed by the Laurentide ice sheet during the last ice age), plate tectonics (motion of the earth's crust associated with seafloor spreading), hydrological processes (storage and transport of ground water and compaction of sediments), and the variability of prevailing atmospheric pressure and wind systems. These factors will be addressed in this report and estimates given for the anticipated annual sea level rise for the coasts of British Columbia and Yukon.

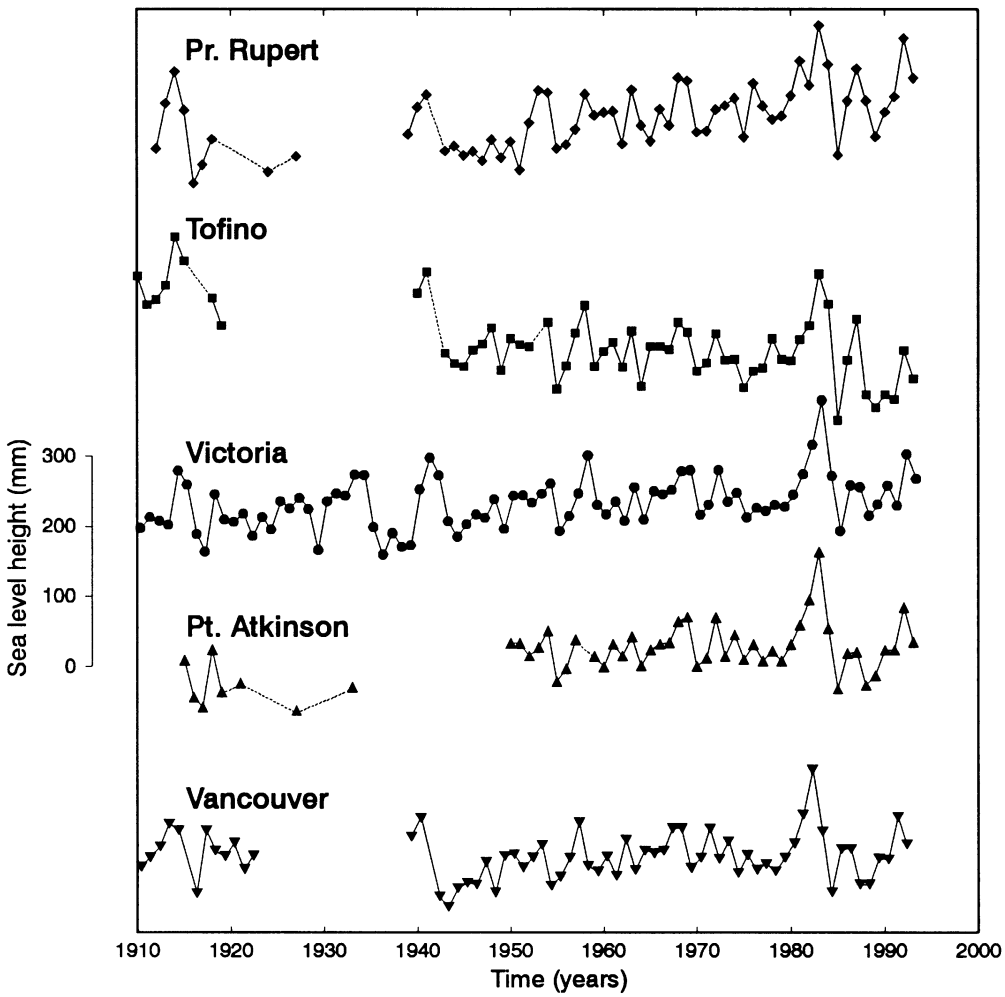
GLOBAL SEA LEVEL CHANGE

In addition to regional and site-specific processes, all oceanic locations will be affected by a global change in sea level caused by changes in the mass and volume of water in the world ocean. This topic of research is of prime importance to all nations bordering the sea, especially low lying areas like Bangledesh and the east coast of United States. Low lying regions of British Columbia such as the Fraser River delta also are susceptible to increased global sea level.

Eustatic and Steric Effects

On a global scale, the factors contributing most to long term climate-induced sea level variations are: (1) Eustatic changes associated with the amount of water in the ocean due to melting or growth of land-based ice sheets and glaciers, and (2) Steric changes caused by changes in the density of seawater associated with heating or cooling of the world ocean. These two processes are not distributed uniformly over the globe, but vary from ocean basin to ocean basin according to the spatial variability of the atmospheric heating and the ocean currents responsible for redistributing the

Figure 1. Monthly averaged sea level heights from tide gauge records for five ports in British Columbia. For plotting purposes the records have been offset from one another. The scale on the left gives variations in millimetres.



mass and volume within the ocean. Setting aside regional differences, Revelle (1983) predicts that global sea level will rise 0.7 m over the next century (for an average rate of 7 mm/yr) and that 0.4 m of this will be due to melting of the world glaciers (a change in the oceanic water mass) and 0.3 m to thermal expansion of the ocean (a change in the oceanic volume). Because the prediction of sea level rise is not an exact science, somewhat different estimates of the net sea level change and the relative contributions from the eustatic and steric components can be found in other reports (e.g. Thomas, 1985).

The quantity of water in the ocean depends mostly on how much ice is supported by land and how much water is stored in lakes, reservoirs and aquifers. Over periods of hundreds of thousands of years, by far the most important influence on global sea level has been the amount of ice stored in continental glaciers, variations of which have led to sea level changes of over 100 m on the coasts of British Columbia and the Yukon. World-wide sea level fall during the height of the last ice age some 15,000 years ago was about 100 m. Approximately 6,000 years ago, the great Northern Hemisphere continental ice sheets of the last ice age had diminished to a few remnants. The remaining ice sheets in Greenland and Antarctica appear to have become stable (e.g. Emery and Aubrey, 1991).

Thus, for the past several thousand years and probably for the next century or so at least, ice melting effects have been, and are anticipated to be, much less dramatic than during the deglaciation period. Global warming might be expected to lead to a reduction of the volume of ice in mountain glaciers and small ice sheets. However, warming is also expected to increase precipitation, which will add to the amount of ice. Kuhn (1993) concludes that small glaciers will diminish in the next century contributing 20 ± 10 mm of global sea level rise for an average rate of 0.20 ± 0.10 mm/yr.

Other global scale influences are of comparable importance to ice melt contributions. Probably the largest of these other influences is the change in temperature of the ocean associated with global warming. The thermal coefficient of expansion of sea water varies with temperature and pressure, but except for the small fraction of the ocean water which is either very hot or both very cold and near-surface, the coefficient does not vary greatly from 2×10^{-4} per degree Celsius. Thus, 1 megajoule (MJ) of heat added to a volume of water increases that volume by about 50 cm^3. (The same 1 MJ would yield about 3000 cm^3 of water if applied to ice at its melting point.) An increase in the heat content of the ocean of $1W/m^2$ would lead to a relative sea level rise of about 1.5 mm/yr. For comparison, changes in the composition of the atmosphere over recent decades are calculated to increase the net radiative heat flux to the surface by about 2.5 W/m^2 (IPCC, 1994). The amount of sea level rise associated with global warming depends upon what proportion of this 2.5 W/m^2 is stored in the ocean, and how much net melting there is of land-supported ice. A net flux increase of $1W/m^2$ provides an average ocean warming of about 0.002 °C/yr. Measuring warming of such magnitude at an individual site is within contemporary instrumental capability but it is difficult to extrapolate such warming to an entire globe (Stewart et al., 1996).

Sea Level Rise derived from Tide Gauge Data

Although many scientists remain uncertain about the degree of global warming, the Intergovernmental Panel on Climate Change (IPCC, 1990) had sufficient confidence in the secular trends seen in atmospheric time series measurements to state that "Nevertheless, the balance of evidence suggests that there is a descernible human influence on global climate". One of the reasons for a consensus on this subject among oceanographers is that, regardless of how the global tide gauge data are smoothed, prodded and massaged, they appear to contain a long-term positive trend. Estimates of the long-term sea level rise due to eustatic and steric effects typically range between 1 and 3 mm/year (Table 1) and vary according to which tide gauge stations are used in the analysis and the methods used to estimate the trend.

There are over 500 worldwide tide gauge records that are available for long-term sea level studies. Until recently, there was something of a "black art" to the process of selecting those records that are most reliable for global sea level analysis. The increased

Table 1. Predicted rate of sea level rise (mm/yr) for the coast of British Columbia and the Yukon for the next century. Sea level rise (+), sea level fall (-). Additional regions are needed for British Columbia because of impact of local tectonic effects. The impact of changes in winds associated with future ENSO events is assumed to either stay the same or increase slightly.

	South B.C. outer coast	North B.C. outer coast	South B.C. inner coast	North B.C. inner coast	Yukon
Eustatic Sea Level	+1 to +2	+1 to +2	+1 to +2	+1 to +2	+1 to +2
Steric Sea Level	0 to +1	0 to +1	0 to +1	0 to +1	0 to +1
Oceanic Winds	0 to +1	0 to +1	0 to +1	0 to +1	0 to +1
Coastal Winds	0 to +1	0 to +1	0 to +1	0 to +1	0 to +1
Isostatic Rebound	-1 to +1	-1 to +1	-2 to -3	-2 to -3	+2 to +4
Tectonic Processes	-1 to -4	0	0	0	0
Total Change	-1 to +2	0 to +6	-1 to +2	-1 to +2	+3 to +9

confidence that now enables investigators to justify selection of certain gauge stations is due, in part, to numerical models of the phase and amplitude of the post glacial rebound for a visco-elastic earth (Lambeck, 1980; Peltier, 1986; Peltier and Tushingham, 1989; Peltier, 1996). These numerical models provide an independent estimate of how the earth's mantle is expected to respond to ice-loading which, in turn, enables us to "calibrate" the longer coastal sea level records and remove that component of variability directly linked to the effects of glacio-isostatic deformation. Peltier and Tushingham (1989) used their ICE-3G model to calculate a global sea level rise of 2.4±0.9 mm/year. This trend is large compared with previous estimates and it was clear that more conservative values would soon be forthcoming. These authors' statement that only 25% of the total change was due to steric effects is difficult to accept in view of the steric sea level trend of 1.1 mm/year reported by Thomson and Tabata (1989) for a region of the northeast Pacific where weak currents and small temperature changes over the region introduce few complications in the trend.

The most recent analysis of global tide gauge data (Douglas, 1991) incorporates the model results of Tushingham and Peltier (1991) and a knowledge of tectonic plate distributions. According to Douglas, the disparity between the various trend calculations in the literature results from the use of tide gauge data from convergent plate boundaries. Using the ICE-3G model of Tushingham and Peltier to correct for postglacial rebound and eliminating tide gauge records in areas of converging plate boundaries, Douglas finds a consistent trend of 1.8±0.1 mm/year for selected regions of the Northern Hemisphere for the period 1880-1980. This trend is consistent with previous estimates but is bounded by a much smaller error. If such a small error proves to be credible, it becomes increasingly more difficult to refute the case for rising sea level.

Douglas (1991) is yet another step in the continual refinement of the sea level trend estimate derived from the data bank of monthly mean tide gauge data. The notion that tectonic processes contaminate tide gauge records is certainly not new. In fact, tide gauge data have long been used to examine the rebound of the earth to earthquake deformation and to study relative changes in coastal elevation at plate boundaries (e.g. Dragert, 1989; Hyndman et al., 1995). Moreover, not all plate boundaries are undergoing differential change in elevation. Hannah (1990) finds a mean trend of 1.7 mm/year for New Zealand, similar to that of Douglas for the Northern Hemisphere stations, but no indication that there is differential vertical motion across the boundary of the Australian and Pacific plates. This brings us back to the problem of which coastal tide gauge stations can be trusted to accurately reflect long-term sea level change in the ocean. It is doubtful that we have seen the last "best" estimate of global sea level change. The richness of the sea level data bank is too attractive to be ignored. However, the problem with all trend estimates is that there is not much more that can be done with the present data sets other than improve the data selection-rejection process and refine the correction factors that account for tectonic processes and glacio-isostatic rebound. (However, see the discussion on satellite altimetry in the section on future sea level measurements.) The annual fractional lengthening of each time series is not enough to increase significantly the statistical significance of the calculated trends over the next few decades. The records need to be doubled in length, which typically means a wait of 50 to 100 years.

Sea Level Rise Derived from Oceanic Temperature and Salinity Data

In comparison to coastal sea level research, there have been few investigations of changes in oceanic sea level based on steric sea level and geopotential thickness (changes in sea level due to changes in the water density resulting from changes in water temperature and salinity). The main problem is that there are few long-term time series of subsurface temperature and salinity for the world ocean. Where such time series exist, the trends are masked by large interannual fluctuations and small shifts in the locations of oceanic gyres.

Based on the 35-year time series of temperature and salinity to 1000 m depth at Ocean Station "P" in the northeast Pacific, Thomson and Tabata (1989) found a significant steric sea level trend of 1.1 mm/year, which is consistent with regional trends from nearby land-based tide gauge records. Here, the main contribution comes from fluctuations which have periods less than a decade. Once again, the fluctuations are very large compared with the 35-year trend.

Levitus (1990) compared steric sea level values between 1970-74 and 1955-1959 calculated relative to 1500 m depth in the North Atlantic. In the central portion of the subtropical gyre, levels decreased by 17.5 dynamic centimetres (1 dyn cm ª 1 cm sea level elevation) whereas in the western subarctic gyre, located to the north of the Gulf Stream, levels increased by 7.5 dyn cm (corresponding to a sea level rise of 5 mm/year). A decrease in steric sea level of 5 cm occurred along the eastern boundary of the North Atlantic. Clearly, more work needs to be done on available steric sea level records if this approach is to provide useful insight into long-term sea level change.

A box-advection-diffusion model proposed by Rahmstorf (1991) indicates that, for an equilibrium atmospheric warming of 3 C° for a doubling of carbon dioxide (CO_2), the zonally-averaged ocean temperature will rise 1.5 to 2.0 C° over the hundred year period ending in 2050. Since the ocean acts as a buffer, the oceanic warming lags the atmospheric equilibrium warming by 25 to 50 years. The heat uptake depends strongly on possible changes to the global thermohaline circulation which can therefore affect global sea level rise predictions. A direct estimate of sea level rise caused by ocean thermal expansion has been made by Church et al. (1991) using a surface ventilated ocean circulation model. For a global mean 3 C° rise in air temperature by the year 2050, the model predicts a nearly uniform steric sea level rise from thermal expansion of 0.2 to 0.3 m. Taking the range of global mean temperature increase to be between 1.5 and 4.5 C° by 2050 (based on present climate models), the authors predict a total sea level rise of between 0.15 and 0.75 m, for an average rise of 2.5 to 12.5 mm/year.

BRITISH COLUMBIA AND THE YUKON SEA LEVEL CHANGE

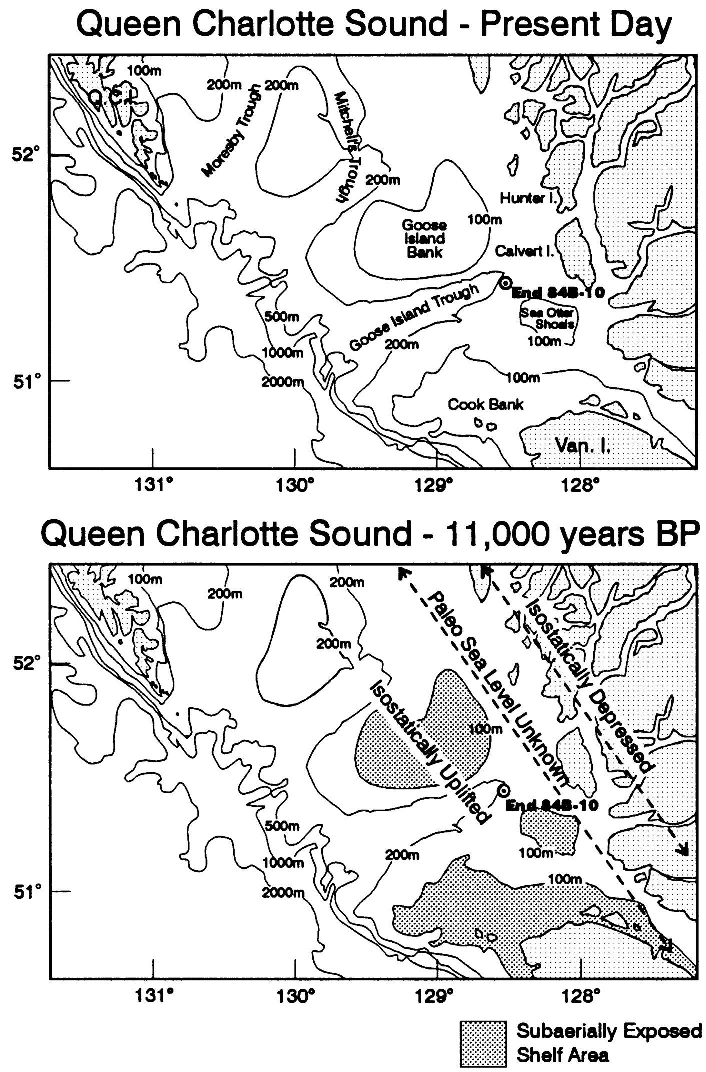
Based on the previous discussion, we estimate that global-scale changes in world sea level, if they were acting alone, would cause sea levels on the coasts of British Columbia and the Yukon to rise by roughly 2 to 3 mm/yr (Table 1). Of this change, 1 to 2 mm/yr would be due to eustatic effects and 1 mm/yr to steric effects. To determine accurately what is going to occur along the coasts of British Columbia and the Yukon, we also need to examine separately the regional effects of tectonic motions, isostatic rebound, and long-term changes to currents and winds.

Contribution from Glacio-Isostatic Rebound

During the last ice age, the great weight of the kilometre-thick ice on the surface of the earth caused a global-scale deformation of the crust and mantle. Land depressed under the ice sheets was squeezed laterally into bulges, called forebulges. These forebulges occupied unglaciated portions of the earth, including the ocean basins. As the ice sheets began to melt, the upper portion of the earth began to re-adjust to the shifting surface load with large forebulges slowly accompanying the retreating ice edges inland on the coast (Fig. 2). The complex problem of how the earth's crust and mantle rebounded to the rapid unloading of the glacial ice during the last ice age has been investigated over the past few decades (e.g. Lambeck, 1980; Peltier, 1996). These studies rely heavily on numerical models which are, in turn, based on assumptions about the physical structure of the mantle and the magnitudes of various visco-elastic parameters affecting the timing and spatial character of the rebound. Peltier (1996) uses an iterative modelling procedure based on a three-layer model of the mantle and lithosphere that is constrained by tide gauge data, site-specific relaxation times for the land masses of northern Europe and Canada, and a series of estimates for the mantle viscosity. Results from this isostatic rebound model (Fig. 3) indicate that the outer west coasts of British Columbia and Alaska are within the transition zone between strong (2 to 4 mm/yr) emergence of the land (sea level fall) and moderate (-2 mm/year) subsidence of the seafloor (sea level rise). The coast of the Yukon is a region of marked (-2 to -4 mm/yr) land subsidence (sea level rise).

A detailed examination of the Peltier (1996) model provides the following picture of present and near-future sea level change for the coast of British Columbia and the Yukon. Specifically, the land is subsiding (sea level rising) in central British Columbia at up to 4 mm/yr. The oblong region of land emergence extending from south-central British Columbia to western Alaska (Fig. 3) coincides with a forebulge that is continuing to move inland toward the northern Canadian shield where the Laurentide ice sheet was thickest during the last ice age. As shown by Figure 2, this forebulge crossed the outer coast some 5,000 years ago

Figure 2. A topographic map of Queen Charlotte Sound showing isostatically uplifted forebulge of the shelf in the late glacial period. (From Patterson et al., 1995).



when it was responsible for a regional fall in sea level that was counter to the rapid rise in world sea level accompanying the ice melt. With the exception of the inner coastal regions where sea level is falling at a rate of -1 to -3 mm/yr, sea levels in the offshore shelf regions are changing at about -1 to 1 mm/yr. Sea levels along the west coasts of British Columbia and Alaska, which straddle the region of high gradient in sea level change, are predicted to change by around -1 to 1 mm/yr. The model predicts that the land is emerging in the inland regions of continental interior. Based on the model, we could state that sea levels along the outer coast are rising by 0 to 1 mm/year while those along the inner coast (Strait of Georgia Depression from Puget Sound to the Alaska Panhandle) are falling at around -1 mm/year. Despite the limited spatial resolution of the model, the results are in general agreement with the observations of Dragert and Hyndman (1995) presented in Figure 4. The model results for the Yukon are more definitive in that they suggest that isostatic rebound, taken alone, is causing relative sea level on the coast of the Yukon to rise at a mean long-term rate of 2 to 3 mm/yr. If the model results are accurate,

Figure 3. Predictions of present-day sea level rise for the regions of North America that were covered with ice at the last glacial maximum. (Modified after Peltier, 1996.)

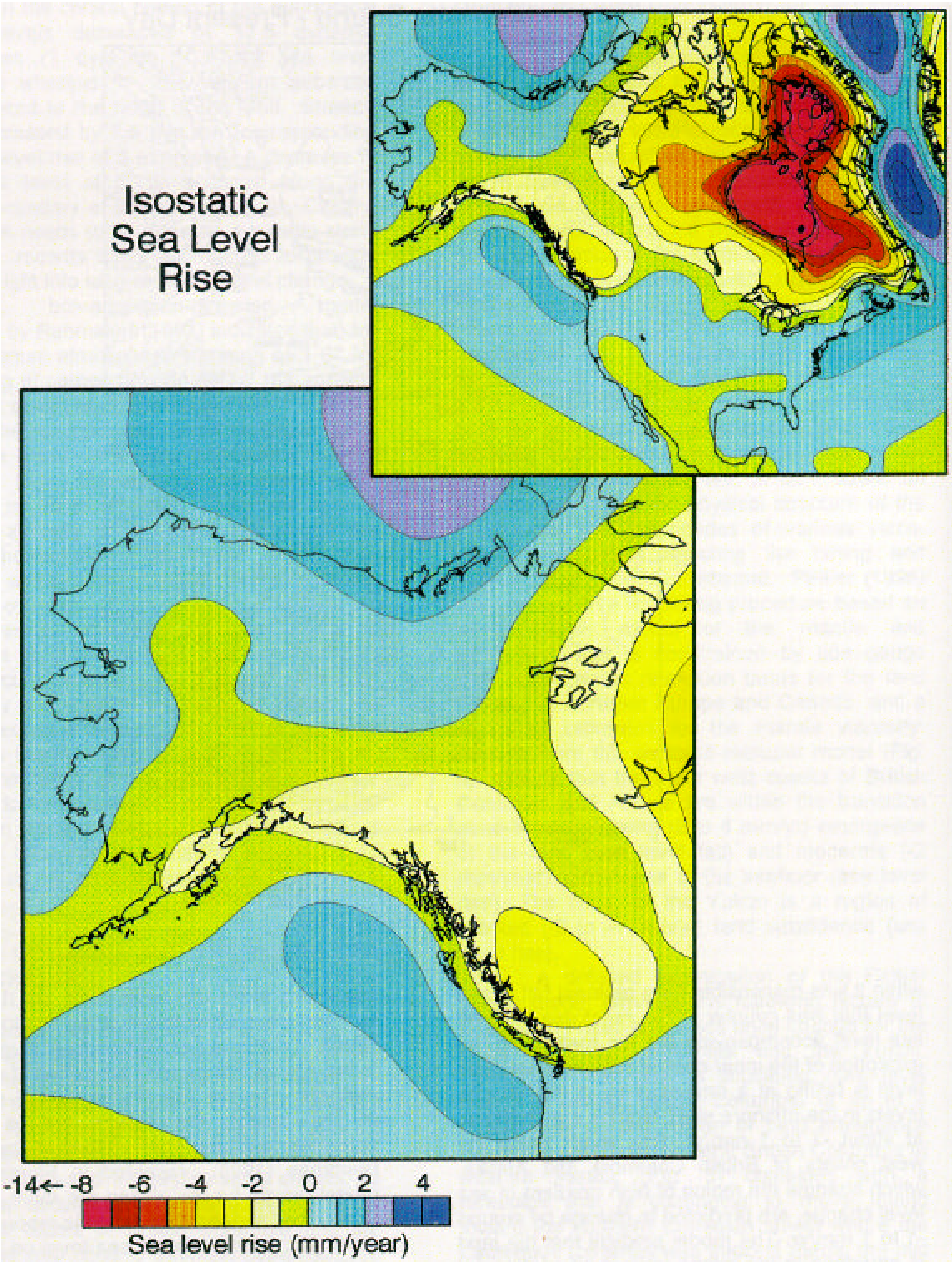


Figure 3

Figure 4. Smoothed contours of vertical velocity (mm/yr) estimated from repeated leveling surveys and regional mean-sea-level trends. The epicentres of two large on-shore earthquakes in central Vancouver Island are shown by stars annotated with the year of occurrence. The Beaufort Range fault zone (BFZ) is shown by a heavy line. The jagged line along the base of the continental margin denotes the Juan de Fuca trench. (From Holdahl et al., 1989.)

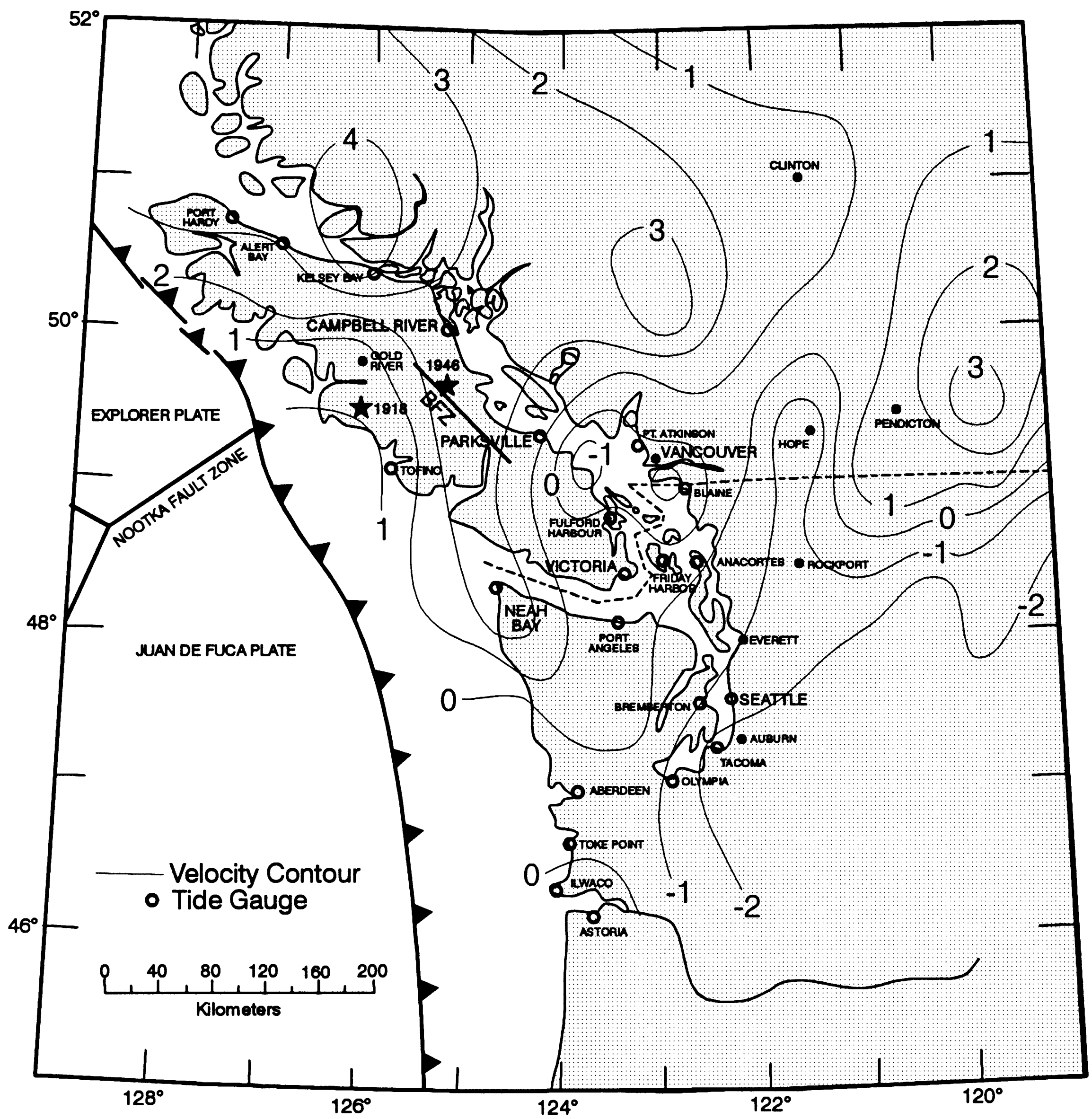
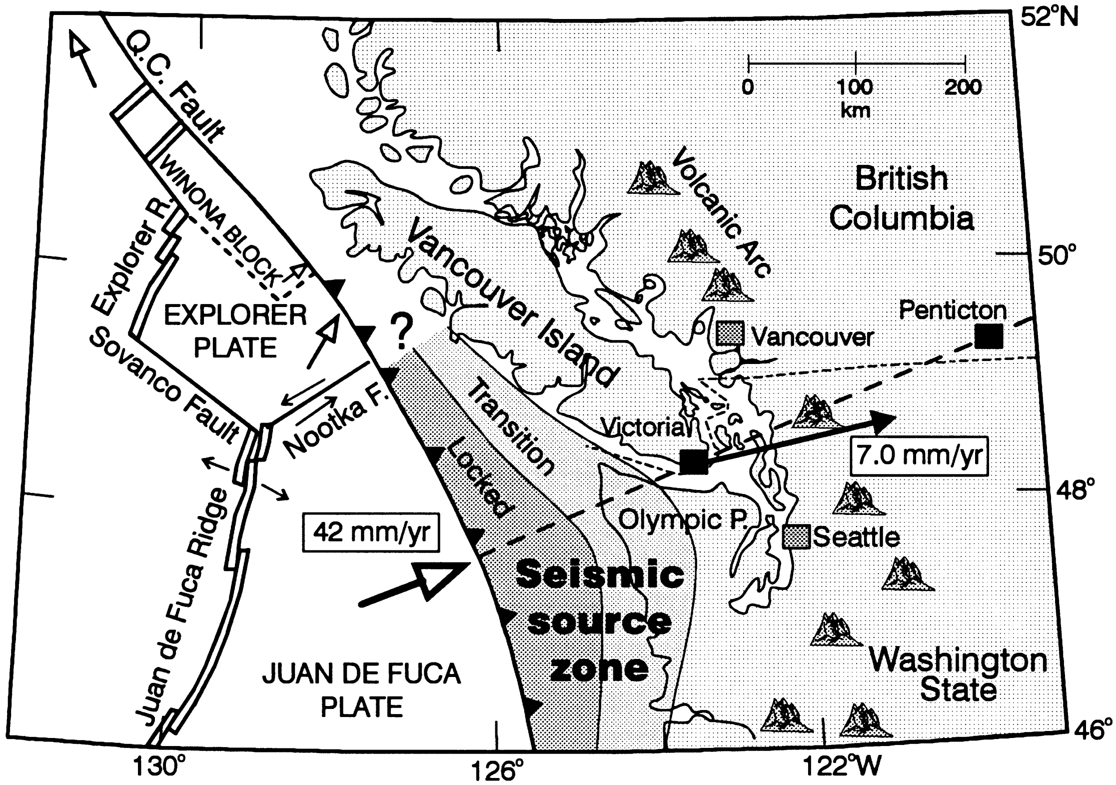


Figure 5. Crustal motions off southwest British Columbia. With the thrust fault locked, the 40 mm/yr convergence of the Juan de Fuca Plate is taken up as elastic shortening across the continental margin. GPS measurements show that Victoria is moving landward at a rate of 7 mm/yr with respect to the North American continent (Penticton site). (From Hydnman et al., 1995).



the Yukon is more vulnerable to glacial adjustment than the west coast of British Columbia.

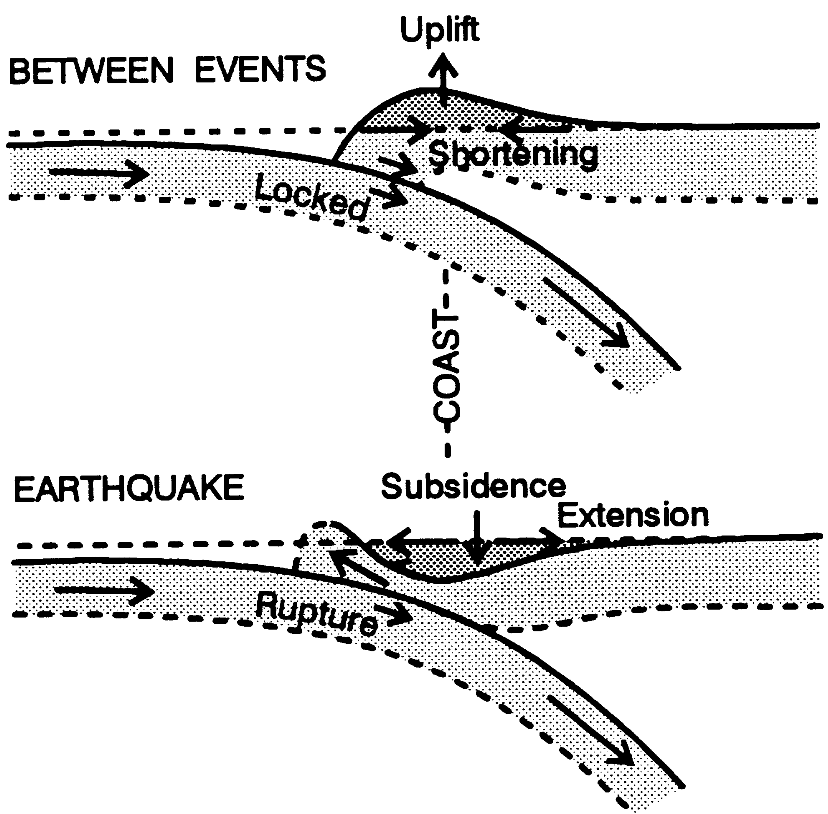
When applying these results, it must be remembered that they are based on a numerical model and that the sea level data used to calibrate the model are contaminated by the very processes the model is attempting to determine. It would not take much for the positions of the model contours to be out by several tens of kilometers. For regions along the Pacific coast lying within the transition zone between sea level rise and sea level fall, this could mean differences in the rates of sea level change of the order of 1 mm/year.

Impact of Tectonic Motions

The Juan de Fuca Plate, which is a fragment of the oceanic Pacific Plate, is subducting under the continental North American Plate along the Cascadia Subduction Zone (Fig. 4). There is now geophysical evidence (e.g. Hyndman et al., 1995; Dragert et al., 1994; Hyndman, 1995) that the subducting oceanic plate is not sliding smoothly, but because of frictional forces is locked in position along the entire continental margin extending from the west coast of Vancouver Island to northern California. This causes shortening of the earth's crust and leads to rapid regional uplift in the form of a bulge (Fig. 5). Gravity measurements and tide gauge data (corrected for isostatic rebound) estimate the uplift to be 1 to 4 mm/yr for this region of the coast. The value is highest (4 mm/yr) along the southwest coast of Vancouver Island (Hyndman and Wang, 1995) but then decreases to near zero some 100 km inland from the point of maximum uplift (see Fig. 3).

The uplift of the coast associated with the arrested plate subduction does not continue indefinitely. If it did, the west coast of North America would be deformed into high mountain ranges greater than those found anywhere on earth. Instead, the interface between the subducting oceanic plate and the continental plate is thought to rupture suddenly, resulting in a massive (magnitude > 8) earthquake. Such events occur on an irregular basis with return times between 300 and 900 years (Hyndman, 1995). According to a reconstruction of events based on geological cores on the west coast of North America and historical Japanese records of tsunamis, the last major earthquake in the Cascadia region may have occured 300 years ago (at 9 p.m. local time on January 26, 1700). Thus, in addition to the crustal uplift of 1 to 4 mm/yr that accompanies the approximately 500-year periods of arrested crustal subduction, there are sudden ruptures of the crust that lead to coastal subsidence of the order of 1 to 2 m and the formation of tsunami waves of the order of 1 to 10 m that flood the coast. According to Hyndman, (1995): "The next great earthquake in Cascadia will generate extremely large seismic waves lasting for as long as several minutes. After the shaking ceases, most coastal areas will be one to two metres lower and 5 to 10 metres seaward of where they started." The Canadian coastal areas referred to by Hyndman lie along the west coast of Vancouver Island.

Figure 6. Coastal uplift associated with the motions in Figure 5. (a) Elastic deformation builds up between great earthquakes if the thrust fault is locked. The seaward edge of the continent is dragged down and a flexural bulge forms further landward. (b) During a great earthquake, there is uplift of the seaward edge and collapse of the flexural bulge. The abrupt uplift generates a tsunami, and the collapse of the bulge causes the subsidence recorded in buried coastal marshes. (From Hydnman et al., 1995).



To add to the earthquake's impact, the 1 to 10 metre tsunami waves are expected to hit the west coast of Vancouver Island minutes after the 1 to 2 m coastal subsidence. These effects would be devastating in comparison to the slow and imperceptible changes in sea level associated with global climate change. For example, Hyndman (1995) mentions the January 1700 earthquake: "Native tradition records that an earthquake struck Pachina Bay on the west coast of Vancouver Island one winter night; in the morning the village at the head of the bay was gone."

Wind and Current Effects

Cyclical sea level fluctuations spanning periods of hours to years are caused by the tides, storm surges, tsunamis, and coastal-trapped wave phenomena, which include the occurrences and propagation of El Niño-Southern Oscillation (ENSO) events along the eastern boundaries of the Pacific Ocean (Johnson and O'Brien, 1990). Relative sea level changes of the order of 10 cm have been correlated with wind-induced variability in large-scale gyre circulation in the Atlantic (Thompson et al., 1986; Thompson, 1990), in wind-induced transport of the Kuroshio near Japan (Kutsuwada, 1988) and wind forcing on the Newfoundland and Labrador shelves (Greatbatch et al., 1990). Ekman and Stigebrandt (1990) have examined the 165-year tide gauge record for Stockholm and find an increase in the amplitude of the annual tidal component from 8 to 10 cm which they associate with meteorologically-induced shifts in the location of the oceanic polar front in the northeast Atlantic. The amplitude (3 cm) of the Pole Tide associated with the earth's Chandler "Wobble" is six times the equilibrium tide and suggests that a meteorological forcing component close to the Chandler period of 14.3 months has changed and added to the variability of sea level at this period.

Coastal sea levels in the Yukon and Northwest Territories are influenced to a greater degree than British Columbia by storm surges associated with shoreward storm-driven winds and waves. Henry (1974) reports surge heights as much as 2 m above normal tidal levels, and negative surges of 1 m below tidal levels in the sea level record at Tuktoyaktuk. Although his numerical model of these surges indicated heights of up to 3 m in Mackenzie Bay on the Yukon coast west of Tuktoyaktuk, there were no gauges to monitor such events. Storm surges strike coastlines where the sea floor of the coastal ocean is shallow, a feature fortunately absent in most British Columbia waters.

Strub et al. (1987) find coastal sea level variations of the order of 10 cm associated with the seasonal current pattern along the west coast of North America. Poleward currents and winds in winter cause mean sea level to rise by 10 to 20 cm on the west coast of British Columbia while equatorward currents and winds in summer cause sea levels to fall by roughly 10 to 20 cm. Superimposed on this roughly 40 cm annual sea level cycle in the northeast Pacific is a 10 to 20 cm interannual cycle due to basin-scale phenomena such as the 1982/83 and 1991/92 El Niño events in the North Pacific. Tabata et al. (1991) have shown that non-tidal fluctuations in the longshore currents of around 25 to 50 cm/s over the shelf break of Vancouver Island are highly correlated (correlation coefficient, $r \approx 0.8$) with the sea level fluctuations of 10 to 20 cm at the adjacent coast.

The 1982-83 El Niño event led to minor flooding of the delta at the mouth of the Fraser River. The sequence of events leading up to the flooding are related here. El Niño itself is a surge of warm water eastward across the Pacific Ocean along the equator, ending at the coast of Equador and Peru. This warm water layer extends to about 100 m depth, and raises sea level at the Equador coast. This surge of warm water spreads poleward as a wave hugging the coasts of North and South America. In normal El Niño events, such a surge reaches northward to the California coast, wheras extreme El Niño events, such as encountered in 1982-3, 1957-58, and 1941-42, will push this surge all the way to the Vancouver Isand coast and into Queen Charlotte Sound. These waves penetrate to British Columbia during the winter, a time of year when sea level is already highest.

El Niño is the oceanic side of a global phenomenon called the Southern Oscillation, so-named for the change in air pressure differences across the south Pacific Ocean during an El Niño. Since the 1982-83 El Niño-Southern Oscillation event (scientists refer to these collectively as ENSO) it has been found that changes in air pressure in western Canada and Alaska are linked to ENSO. When El Niño occurs, almost always in the Northern Hemisphere winter, the centre of the Aleutian low often becomes even lower in pressure, while the high pressure zone near Edmonton becomes even higher. Between these two regions lies the west coast of British Columbia, where the increased air pressure gradients support stronger storms in winter. The stronger southeast winds of these storms drive poleward currents which raise sea levels along the coast, amplifying the high sea levels normally found there in winter.

In summary, these three effects are felt at all British Columbian shores.

1. The normal seasonal cycle of high air pressure and winds from the north in summer, low air pressures and winds from the south in winter, pushes coastal currents whose Coriolis adjustment associated with the earth's rotation raises sea levels in winter and drops them in summer;

2. The El Niño wave at Equador sometimes surges all the way to British Columbia along the North American Coast, raising sea levels;

3. The Southern Oscillation often strengthens the Aleutian low pressure system in winter, accompanied by stronger winds from the south, with stronger poleward currents and higher sea levels at shore.

In a given ENSO, either or both of events 2 and 3 may occur. During the 1982-83 ENSO, both hit the British Columbia coast, setting up a 20 cm surge that persisted for the entire winter at most British Columbia ports. The influence of this surge on sea level is evident in Figure 1.

Highest sea levels ever recorded in the Strait of Georgia at Point Atkinson hit on December 16, 1982. As noted above, the ENSO raised sea levels prior to this day. On December 15 a storm from the Pacific crossed the Washington State coast, pushing currents northward and sea levels upward. The next day as the storm crossed into the Strait of Georgia, the winds swung to the West, setting up waves which caused minor flooding in Boundary Bay near Crescent Beach. The recorded high tide at the nearest gauge at Point Atkinson was 5.61 m, or 0.89 m above the predicted level.

At present there is no evidence that global warming will lead to changes in the frequency or strength of ENSO events. Such a coupling is difficult to simulate in the present global models; therefore, such coupling might exist, it has just not yet been found. Nevertheless, any flooding due to the slow rise in sea levels accompanying global warming will most likely hit the coast during such El Niño winters as described above. The record of annual average sea level at most British Columbia ports in Fig. 1 reveals major peaks in 1941, 1958, 1983 and 1992, all of which are ENSO years.

As pointed out by Stewart et al. (1996), fluctuations in climate signals are going to be difficult to predict, in general, at least until the climate system is very much better understood. It will also be difficult to differentiate between climate fluctuations and climate change, for climate change is going to be much more complex than simply an increase in mean global temperature. For example, the dominant wave numbers, the phases and the amplitudes of large scale atmospheric waves must be expected to change, as will the ocean circulation and the ocean transport of heat and salt. Yet it is just such changes that must be responsible for the fluctuations in climate parameters already observed in the record, including those of sea level. The saving grace is the fact that sea level change caused by these atmospheric and oceanic variations are not likely to exceed a few tens of centimetres (i.e. an average annual rate of the order of ±1 mm/yr). Thus, if at any location a component of relative sea level change can be clearly attributed to long-term changes in sea level atmospheric pressure, prevailing winds, or prevailing currents, it could be anticipated with some confidence that this component of the rate of change would not continue, without change of sign, indefinitely.

Other factors

Human activity changes the amount of water stored on land. Filling of reservoirs and infiltration into aquifers increases the amount of water held on land, while mining of ground water decreases it. The two influences could about balance (Gornitz, 1993). The amounts involved seem to be rather less than equivalent to 1 mm/yr (Newman and Fairbridge, 1986), that is small compared to future sea level rise associated with global warming, but important relative to that observed during recent decades and inferred for the past several millennia (Aubrey and Emery, 1993).

Coastal erosion through sea level rise moves sediment from the shore face to the shallow nearshore shelf area, following what is termed Bruun's Rule (Bruun, 1962). Bruun's Rule states that with sea level rise there will be an equal volume transfer from the shore face to the adjacent shallow nearshore shelf, assuming no shore-parallel transport. The application of this principle has been successfully applied to understand coastal evolution on many of the retreating coastlines of the world, most particularly that of the eastern United States (Niedoroda et al., 1985).

FUTURE SEA LEVEL MEASUREMENTS

There are a number of ways to improve estimates of long-term global sea level change. One approach is to improve the distribution of tide gauge stations within the world oceans with special focus on the southern hemisphere and oceanic islands. A global network consisting of approximately 200 key sites, half of them on oceanic islands, has been proposed for future sea level studies (Pugh, 1987). We need to ensure that the basic system of long-term gauge stations is maintained in order to extend the duration of the time series. Since most records are dominated by large amplitude (10 cm) interannual fluctuations, such series have typical integral time scales of order 10 years. On this basis, a record of at least 100 years is needed for 10 degrees of freedom in any trend estimate. Finally, the absolute accuracy of tide gauge records must be improved. In his review article on space and terrestrial metrology, Bilham (1991) discusses the possible pathways to link sea level to a common vertical reference datum. This datum may be related to Very Long Baseline Interferometry (VLBI) sites, to Satellite Laser Ranging (SLR) sites or to a datum related to absolute gravity. Recently the Global Positioning System of satellites has been applied to measurements of vertical tectonic motion. Since all methods have vertical uncertainties of around 1 cm, it is probable that all these methods will be used in defining a future vertical datum. If we assume that there is a network of such sites where elevation is known vertically to within 1 cm, and that the sites are within 100 km of all tide gauge stations in the sea level network (an unlikely assumption), the various links in the network yield an optimistic uncertainty of 13 mm standard deviation per tide gauge (Table 2). For a network of 170 gauges the global uncertainty reduces to 1 mm. Unfortunately, some of the errors are systematic with the greatest error from the GPS link, an error that partly arises because GPS/tide gauge measurements are located where the horizontal water vapor gradients that affect GPS are likely to be severe. Further details on satellite positioning can be found in the excellent summary article by Bilham (1991.)

To the full extent possible, all causes of relative sea level change, not just those associated with global change, should be identified and quantified. Fortunately, there has been significant recent progress in this direction. Satellite-derived positions of geodetic control points using the Global Positioning System (GPS) are currently achieving an accuracy which permits monitoring of daily relative vertical positions (i.e. ellipsoidal heights) over

Table 2. Estimated uncertainties in relating a coastal sea level measurement to a global datum (from Bilham, 1991). Optimistic estimates are from theory; pessimistic estimates are based on field experience.

Step in the link: VLBI to tide gauge	Optimistic Estimate (mm)	Pessimistic Estimate (mm)
VLBI, SLR, absolute-g datum	6.0	15.0
Ground ties VLBI, SLR	0.5	1.0
Phase centre GPS antenna to ground	0.5	2.0
GPS/GPS link	10.0	30.0
Phase center GPS antenna to tidal datum	0.3	1.0
Tidal datum to zero point on sea level transducer	0.5	2.0
Local correction to annual mean sea level	5.0	10.0
TOTAL	22.8	61.0
Standard deviation if all uncertainties are random	12.7	35.1

distances of hundreds to thousands of kilometres with sub-centimetre resolution. Figure 7 shows the day-to-day variations in the relative vertical positions of two sites about 300 km apart in western Canada. The stability over 17 months of record is evident; regression estimates of a linear trend in these data have a formal 95% confidence interval of 1.8 mm/yr (Dragert and Hyndman, 1995). These two stations are located on the western margin of the North American (NA) plate near the active Cascadia Subduction Zone. As noted earlier, frictional coupling between the down-going Juan de Fuca oceanic plate and the overlying North American margin generates horizontal compression and both rising and sinking of the crust in coastal regions. Typical magnitudes for these local tectonic vertical motions are of the order of 1 to 2 mm/yr with extrema close to 5 mm/yr (Holdahl et al., 1989). These rates are expected to be present over time periods of hundreds of years during which time elastic strain accumulates, to be eventually released in a great (magnitude > 8) thrust earthquake.

Modern geodynamical measurement accuracies are approaching sub-centimetre levels in position, a few tenths of a milliarcsecond in angular orientation and several nanogals in gravity determination. In turn, the application of space-based techniques for the study of earthquake and tectonic displacement fields, glacial rebound and sea level changes and other geophysical phenomena of major social and economic importance requires satellite orbital accuracies of similar subcentimetre level referred to the irregularly rotating, deformable earth. There is now a global network of continuous GPS tracking stations operated as part of the International GPS Service for Geodynamics (IGS) under the auspices of the International Association of Geodesy. Data from this network allow the definition of the precise GPS satellite orbits and the precise global reference frame essential to the monitoring of positional changes at the level of a few millimetres.

To achieve the precise measurement goals requires theoretical understanding of the earth's dynamics, including the dynamics of its rotation, at a level of detail unimaginable a

Figure 7. The deviations of the daily solutions for the relative heights at ALBH (Victoria, British Columbia) with respect to DRAO (Penticton, British Columbia) which is assumed fixed. The heavy lines shows the fitted linear trend which has a slope of 0.6 $\pm$ 1.8 mm/yr. (From Stewart et al., 1996.)

decade ago. Except for the oceans and the atmosphere, the most difficult part of the planet to model in its contribution to earth's overall dynamics is the outer fluid core. In contrast to the oceans and the atmosphere, the fluid core is inaccessible to direct observation and its thickness is a substantial fraction of the earth's radius making it more difficult to observe and rendering its dynamical behavior theoretically more challenging. As a result, the incomplete understanding of the contribution of the outer fluid core to the earth's rotational dynamics is a major obstacle in reaching the measurement goals required for the full realization of the benefits of the potential accuracies of space-oriented techniques. Current models of the fluid core treat it as a nearly rigidly rotating body, and while these models have vastly reduced the level of residuals in VLBI nutation measurements and in surface-based gravity data, they are completely inadequate to future requirements. The Superconducting Gravimeter Installation has 11 stations worldwide which will provide gravity data of unprecedented accuracy and distribution for fundamental studies of Earth's dynamical behavior including the response of the fluid outer core, and will provide a data set of inestimable value in constraining models of glacial rebound and sea level rise in modeling global change.

For sea level measurements themselves, the Topex/Poseidon and the ERS-1 and ERS-2 satellites measure sea surface height directly using downward-looking radar. Once corrections are applied for sensor drift, the geoid, ocean tides, earth tides, water vapour and sea state, the globally averaged trends at the mm/year level may be measureable. A recent global analysis by Gruber (personal communication, 1996) reveals sea level changes of about 1 mm/year since 1992, although it would be difficult to verify confidence levels of 1 mm/year. Despite these drawbacks, the Topex/Poseidon series of satellites will continue to provide measurements well into the next century, and will become the standard for monitoring sea level changes, and also regional differences in such changes.

SUMMARY AND CONCLUSIONS

The basic message of this report is that expected sea level changes associated with regional effects are of comparable magnitude to those predicted to occur from global warming. We conclude that relative sea level is rising on the coasts of British Columbia and the Yukon, and will continue to rise at approximately the same rate over the next century. This could change if the major ice sheets in Greenland and Antarctica begin to melt more quickly due to possible global warming. Our analysis indicates that there are major differences in the rates of sea level rise at the southern and northern sectors of the British Columbia coast due to uplift along the southern coast caused by the frictionally-locked subducting plate under Vancouver Island. We also find major differences in the rates of sea level rise along the inner and outer coastal waters of British Columbia as a result of spatial differences in glacio-isostatic rebound. Expected sea level rise rates for British Columbia range from -1 to +2 mm/yr on the south coast to -1 to +6 mm/yr on the north coast.

For the Yukon, there is a large component of sea level rise from isostatic rebound. Predicted sea level rise rates for the Yukon coast vary from 3 to 9 mm/yr. Sea level rise from oceanic and coastal winds is poorly known but is probably pegged within a maximum range of $\pm$20 cm for the next few hundred years for both British Coumbia and the Yukon.

These slow changes are small compared to the expected sudden rise in relative sea level of 1 to 2 meters along the west coast of Vancouver Island that is expected to accompany the next megathrust earthquake along the Juan de Fuca trench. Historical evidence suggests such an earthquake last hit in winter in the year 1700, and that such earthquakes have return times of 300 to 900 years, with an average of 500 years. Fortunately, other regions of the British Columbia coast and the Yukon will be largely unaffected by this particular mechanism.

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Chapter 5

THE IMPACTS OF CLIMATE CHANGE ON RIVER AND STREAM FLOW IN BRITISH COLUMBIA AND SOUTHERN YUKON

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OVERVIEW

Changes in runoff amounts caused by changes in precipitation and temperature due to a doubling of the concentration of atmospheric carbon dioxide based on the Canadian Centre for Climate Modelling and Analysis general circulation model are estimated.

A water balance model based on a process known as the Thornthwaite procedure was used. The model estimates runoff (water excess) based on precipitation data (water input), temperature data (an index of water lost to evapotranspiration) and an estimate of soil moisture storage capacity. Data from 18 climate stations were extracted and monthly and annual runoff computed. In order to estimate how climate change might affect streamflow, historical temperature and precipitation data were then adjusted by the amounts predicted by the general circulation model.

Bearing in mind that the accuracy of the predicted changes in runoff depends largely on the accuracy of the general circulation model predictions for precipitation and temperature, the results indicate that significant changes in runoff are possible. An increase in annual runoff is indicated with this increase occurring in winter and spring, with the spring freshet runoff occurring up to one month earlier. Runoff during the summer low flow period would be lower in southern BC and slightly increased in northern BC and the southern Yukon. There is the potential for an increase in peak flows in coastal and southern BC.

HISTORICAL VARIABILITY OF CLIMATE AND STREAMFLOW

Long-term records of temperature, precipitation and streamflow in the Province of British Columbia are sparse. However a few stations have a continuous record extending back to early in the century. The data record from these stations has been investigated in order to identify long term variability or climatic shifts. The three figures below show fairly typical variation for BC stations.

Figure 1 shows the 120-month total precipitation for Fort St. James in the central interior of the Province. The plotted trace indicates for any date the total precipitation observed at the station for the previous 120 months. The trace reveals that the period 1960 to 1980 was generally wet with mean precipitation for this period about 10% greater than the long term mean. Since 1980 precipitation has decreased but as of 1996 it is again on the increase.

Figure 2 shows the mean flow for the Fraser River as monitored at Hope. This large watershed (217,000 km^2) drains the central interior of the Province. Natural flow has been computed for the period subsequent to 1952 when the Nechako Reservoir project modified flow on the Fraser River. The trace is similar to the trace of precipitation with the period 1960 to 1980 about 10% greater than the long-term mean and the flow returning to the long term mean at the present time.

Figure 3 shows mean temperature as observed at the Fort St. James station. Again the trace indicates the mean temperature for the previous 120 months. Temperatures for the period 1950 to 1980 were relatively constant and close to the long-term mean. However the full trace from 1910 to the present reveals a significant trend of increasing temperature especially in the period 1980 to the present. The current mean temperature of 3.8°C is 3° greater than that of 1910.

PROJECTING FUTURE STREAMFLOW

The 36-year period 1960 to 1995 was selected as the base period for this study. This period, as indicated by the above three graphs, shows marked variation in precipitation, temperature and runoff. However this could apply to any period this century. Considering the availability of data, the more recent period was chosen. Data from a number of stations across the Province and the southern Yukon were extracted on a monthly basis for this period. A modified Thornthwaite model (Gray, 1970) was used with observed monthly temperature and precipitation to compute monthly and annual runoff. The computed runoff was compared to observed runoff at a nearby streamflow station to ensure a significant relationship. The doubled CO_2 changes to temperature and precipitation as indicated by the Canadian Climate Centre for Climate Modelling and Analysis (Boer et al, 1992) general circulation model were then applied to the observed temperature and precipitation and the Thornthwaite model used to indicate changes to computed runoff. The results were then used to give a general indication of the impact of doubling the CO_2 content of the atmosphere on the hydrology of British Columbia and the southern Yukon.

RELATIONSHIPS OF TEMPERATURE, PRECIPITATION AND STREAMFLOW

Monthly total precipitation, monthly rainfall and monthly mean temperature were extracted from the Atmospheric Environment Service's climate database. Where necessary, missing values were estimated by comparison with nearby stations. For each station analyzed, monthly values for the period September 1959 to December 1995 were compiled.

The Thornthwaite model was modified to do a continuous accounting of rainfall, snowfall, snowpack, evapotranspiration and soil moisture on a monthly basis for the 436-month period. Soil moisture capacity for each station had been determined from a previous study (Coulson, 1996) which identified this value on a regional basis. The model output was assessed to ensure reasonable results for each month for the full period. The output provided computed monthly and annual runoff (water excess) at the station's particular location and elevation.

The computed runoff from the Thornthwaite model was compared to observed runoff an a nearby streamflow station using the same time period (1960 to 1995). This comparison was done on a monthly, seasonal and annual basis. In most cases, the comparison indicated that there was a significant correlation between computed and observed annual runoff. The monthly and

Figure 1. 120 month total precipitation for Fort St. James

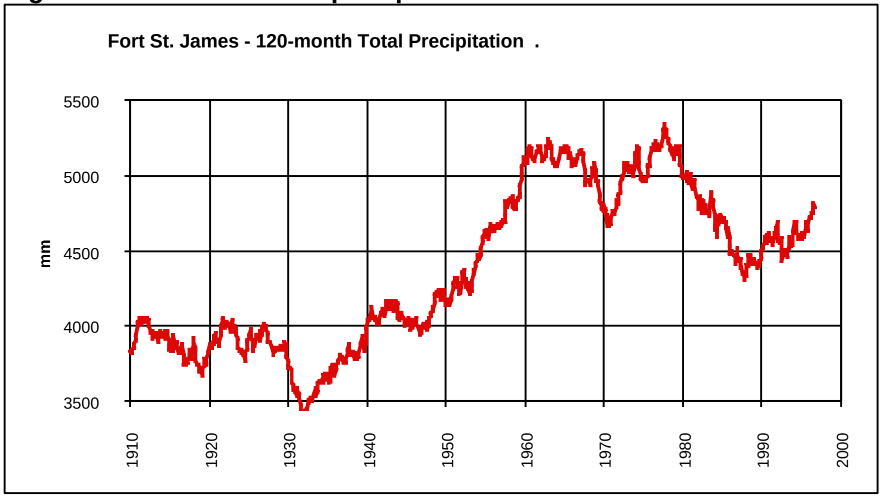


Figure 2. Mean flow for the Fraser River as monitored at Hope.

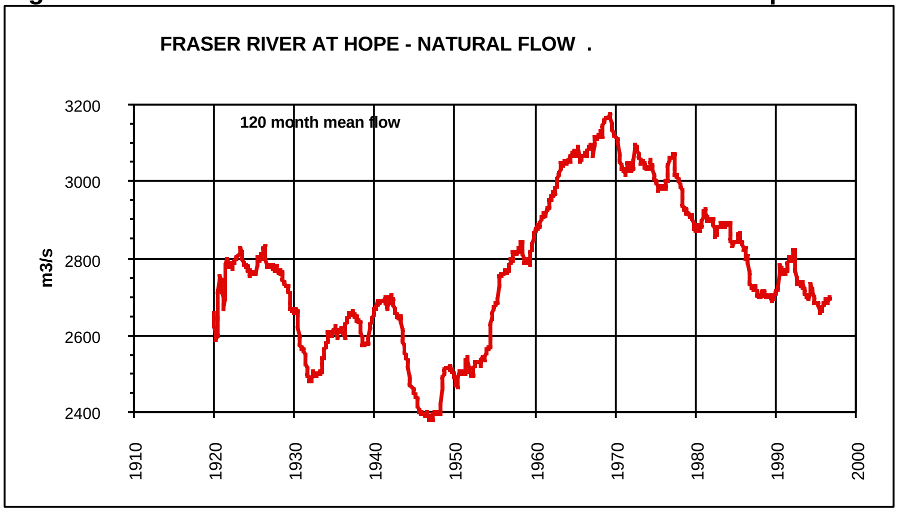
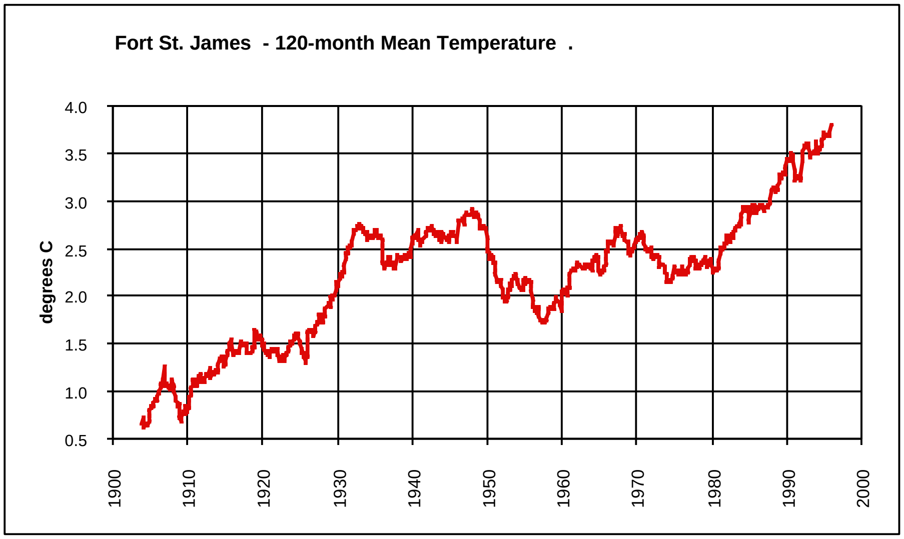


Figure 3. Mean temperature as observed over a 120 month period at the Fort St. James station.



seasonal correlations were not as successful although significant relationships were found in some cases. These comparisons were done for each year for:

- freshet period
- low flow period August to September
- maximum month

Although these latter comparisons were inconclusive, the significant relationships for annual runoff gave confidence that the Thornthwaite model was producing useable results at least on an annual basis. It must be pointed out that climate stations are situated at valley locations and do not always give a good indication of climatic conditions on an adjacent watershed.

The climate stations used with the Thornthwaite model studies are shown on the map (Figure 4) and are listed in Table 1 along with the streamflow station used for comparison. The degree of association of the Thornthwaite computed annual runoff with observed annual runoff is also shown in the table by the co-efficient of determination (r^2) expressed as a percent. Based on 36 years of previous data, a value of r^2 of 18% is significant at the 99% level of confidence.

POTENTIAL CLIMATE CHANGE

Monthly maps of predicted change of temperature and precipitation due to a doubling of the atmospheric content of CO_2. It is pointed out that the various general circulation models used to predict the magnitude and location of temperature and precipitation changes over British Columbia and the Yukon due to doubling of CO_2 rarely agree. These models produce only crude predictions at best and the results should be used with caution.

For each of the climate stations listed above, monthly changes in temperature and precipitation were extracted from the maps. The resulting changes in precipitation on an annual basis are summarized in the following table for each climate station (Table 2). The increases shown are similar in magnitude to the change in average precipitation from 1930 to 1960 as shown on Figure 1. The temperature changes for each station as predicted by the model on an annual basis are shown in Table 3

It is noted that the doubling of the CO_2 in the atmosphere gives an increase in mean annual precipitation and an increase in mean annual temperature for all stations tested in British Columbia and the southern Yukon. This increase in average temperature is greater in magnitude than that observed increase between 1910 and the present as shown on figure 3.

Table 1. Co-efficients of determination for climate and stream flow stations.

Climate Station	**Stream Flow Station**	**Co-efficient of determination (r^2) in percent**
Tofino A	Sarita River	55.7
Nanaimo A	Nanaimo River	74.3
Whistler	Harrison River	47.7
Mission WA	Alouette Lake	63.2
Princeton A	Similkameen R	69.2
McCulloch	Mission Creek	45.6
Vernon Coldstream	Coldstream Creek	37.3
Revelstoke	Illecillewaet River	39.5
Cranbrook A	St Mary River	21.9
Fernie	Elk River	43.4
Bella Coola	Bella Coola River	20.8
Sandspit A	Pallant River	45.5
Terrace A	Kitimat River	52.1
Fort St. James	Stuart River	53.2
Prince George A	Salmon River	55.0
Blue River	North Thompson River	35.2
Ft Nelson A	Ft Nelson River	2.1
Watson Lake YT	Liard R	36.8
Dease Lake	Dease River	28.5

Figure 4. Map of Climate Stations used in Study.

Table 2. Mean annual precipitation for the period between 1960 and 1995, estimated annual precipitation under doubled atmospheric $C0_2$ conditions and percent change for each climate station.

	Mean annual precip. (mm)	$2XCO_2$ precip (mm)	% change
Tofino A	3261	3814	+17
Nanaimo A	1132	1333	+18
Whistler	1309	1504	+15
Mission WA	1832	2087	+14
Princeton A	348	384	+10
McCulloch	699	787	+13
Vernon Coldstream	449	500	+11
Revelstoke	981	1136	+16
Cranbrook A	407	445	+ 9
Fernie	1178	1351	+15
Bella Coola	1657	1912	+15
Sandspit A	1346	1558	+16
Terrace A	1320	1535	+10
Fort St James	478	540	+13
Prince George A	611	664	+ 9
Blue River	1141	1308	+15
Ft Nelson A	447	482	+ 8
Watson Lake YT	414	498	+20
Dease Lake	421	515	+22

Table 3. Mean annual temperature for the 1960 to 1995 period, mean annual temperature given a doubling of CO_2 and the change in degrees.

	Mean annual temp. (mm)	$2XCO_2$ temp. (mm)	Change in °C
Tofino A	9.1	12.5	+3.4
Nanaimo A	9.7	13.2	+3.6
Whistler	6.3	10.0	+3.7
Mission WA	9.9	13.5	+3.7
Princeton A	6.1	10.1	+4.0
McCulloch	2.9	7.0	+4.1
Vernon Coldstream	7.5	11.6	+4.1
Revelstoke	7.0	11.2	+4.2
Cranbrook A	5.5	9.6	+4.4
Fernie	5.0	9.6	+4.7
Bella Coola	8.0	11.7	+3.7
Sandspit A	8.2	11.8	+3.6
Terrace A	6.3	10.2	+4.0
Fort St James	2.9	7.0	+4.1
Prince George A	3.8	7.9	+4.1
Blue River	4.4	8.5	+4.1
Ft Nelson A	-1.0	3.2	+4.2
Watson Lake YT	-2.9	1.5	+4.4
Dease Lake	-0.9	3.5	+4.5

POTENTIAL ANNUAL RUNOFF CHANGE

As described in an earlier section, the observed temperature and precipitation data were used to produce computed runoff for each climate station. The degree of association with observed runoff at a nearby streamflow station was also indicated. Monthly change in both temperature and precipitation due to doubling of the CO_2 content of the atmosphere was extracted as described in the previous section. These changes were applied to each month in the 436-month data series and the Thornthwaite model was used to compute monthly runoff with the changed temperature and precipitation. The results indicated an increase in annual runoff for each station tested (Table 4).

The magnitude of change as indicated by the Thornthwaite model should be used with caution, however some generalizations based on the numbers below can be made. An increase in average annual runoff should be expected throughout BC and the southern Yukon with a doubling of the atmospheric content of CO_2 . The increase will be relatively greater in areas of low precipitation and runoff such as the Okanagan and Similkameen. In comparison, Figure 2 shows an increase in average runoff from 1950 to 1970 of 24%.

POTENTIAL SEASONAL RUNOFF CHANGE

The computed runoff from the Thornthwaite model was reviewed on a seasonal basis to identify increases or decreases or shifts in the freshet runoff and low summer runoff due to doubling CO_2. The freshet season was considered to be the snowmelt period in the spring while August to September was used for the low flow. Due to the coarseness of the monthly model it was difficult to identify small time shifts in the timing of seasonal runoff.

The results did indicate that the freshet runoff volume increased and occurred up to one month earlier at most stations due to the climatic change. The following table (Table 5) provides the results for each station tested for change in the spring freshet.

Table 4. Computed runoff based on observed temperature and precipitation data, calculated runoff under doubled CO_2 temperature and precipitation conditions and the percent change for all climate stations.

	Computed runoff (mm)	2XCO_2 runoff (mm)	% change
Tofino A	2633	3105	+18
Nanaimo A	591	776	+31
Whistler	775	922	+19
Mission WA	1180	1362	+15
Princeton A	49	91	+86
McCulloch	299	362	+21
Vernon Coldstream	67	113	+69
Revelstoke	479	603	+26
Cranbrook A	53	90	+71
Fernie	743	845	+14
Bella Coola	1115	1315	+18
Sandspit A	754	892	+18
Terrace A	901	961	+ 7
Fort St James	117	148	+26
Prince George A	169	197	+16
Ft Nelson A	57	72	+28
Watson Lake YT	84	106	+26
Dease Lake	83	98	+19

Table 5. Expected changes in volume and timing of spring freshet runoff at climate stations.

	2XCO2 Change in volume	2XCO2 Change in timing
Tofino A	increase	no change
Nanaimo A	increase	no change
Whistler	increase	part month earlier
Mission WA	increase	part month earlier
Princeton A	increase	1 month earlier
McCulloch	increase	1 month earlier
Vernon Coldstream	increase	part month earlier
Revelstoke	increase	1 month earlier
Cranbrook A	increase	1 month earlier
Fernie	increase	1 month earlier
Bella Coola	increase	no change
Sandspit A	increase	no change
Terrace A	increase	part month earlier
Fort St James	increase	part month earlier
Prince George A	increase	1 month earlier
Blue River	increase	1 month earlier
Ft Nelson A	increase	part month earlier
Watson Lake YT	increase	no change
Dease Lake	no change	1 month earlier

Low monthly runoff from the model was inconclusive as computed runoff was zero in many cases. However it was observed that the evapotranspiration potential (ETp) increased due to increases in August and September temperatures while precipitation in these months decreased at most stations. This suggests that flows during the low summer season will decrease due to a doubling of the CO_2 atmospheric content. The results for each station follow (Table 6). The values show the increase in the evapotranspiration potential and the change in precipitation in mm for the August to September period.

Northern BC and southern Yukon differ from the stations in the southern portion of BC in that an increase in low flows is indicated.

POTENTIAL CHANGE IN PEAK FLOW

With the monthly model it was not possible to identify peak daily flow. However a comparison was made of the maximum monthly runoff in each year as computed by the Thornthwaite model. It was assumed that an increase in the maximum monthly runoff due to a doubling of the CO_2 content of the atmosphere would indicate a potential for an increase in peak daily flow.

The results are somewhat inconclusive but there does appear to be an increase in maximum monthly runoff along the coast and in the southern interior of BC (Table 7).

SUMMARY AND IMPLICATIONS

The above results do indicate significant climatic and hydrologic changes in BC and the southern Yukon if the forecast of changes due to doubling of the CO_2 content of the atmosphere by the CCC model are correct.

Runoff changes for local watersheds and the major watersheds in BC and southern Yukon clearly indicate an increase in annual runoff with this increase occurring in winter and spring. Summer runoff during the low flow period would be lower in southern BC and slightly increased in northern BC and southern Yukon. A potential increase in peak flows was identified for the coastal and southern BC.

These changes would have a significant impact on the water resource. Although annual water supply would increase, this increase would occur in the winter and spring which would necessitate storing larger volumes of water for use in the dry summer season when irrigation and domestic water use is greatest. Reservoirs would lose more water during the summer season due to increased evaporation which would also require greater storage of the winter and spring runoff. Areas without the benefit of storage reservoirs would find reduced water supply in rivers and streams during the low flow summer season.

Table 6. Potential changes in evapotranspiration and precipitation at climate stations given a doubling in atmospheric C02.

	Potential evapotransportation change (mm)	**Precipitation change (mm)**
Tofino A	+13	-33
Nanaimo A	+17	-10
Whistler	+14	-18
Mission WA	+17	-22
Princeton A	+20	- 4
McCulloch	+13	- 4
Vernon Coldstream	+22	- 4
Revelstoke	+21	- 7
Cranbrook A	+23	- 3
Fernie	+20	- 7
Bella Coola	+17	-35
Sandspit A	+14	- 8
Terrace A	+17	- 4
Fort St James	+15	- 7
Prince George A	+12	-15
Blue River	+17	- 8
Ft Nelson A	+14	+ 7
Watson Lake YT	+ 9	+18
Dease Lake	+ 7	+18

Table 7. Increase in maximum monthly runoff at each climate station computed by the Thornthwaite model for a doubling in atmospheric CO_2.

	Max Month change (mm)
Tofino A	+184
Nanaimo A	+88
Whistler	+ 6
Mission WA	+86
Princeton A	+22
McCulloch	- 4
Vernon Coldstream	+15
Revelstoke	-29
Cranbrook A	+19
Fernie	+30
Bella Coola	+81
Sandspit A	+41
Terrace A	+11
Fort St James	+ 9
Prince George A	+ 6
Blue River	+ 1
Ft Nelson A	+11
Watson Lake YT	+ 8
Dease Lake	+ 3

The impact on hydro power is similar but if reservoirs are sufficiently large the increase in annual runoff would allow an increase in hydro-power generation even allowing for the increased evaporation and lower inflows during the summer.

Increases in maximum monthly runoff which suggest increases in peak flows, have implications on the severity and frequency of flooding. Existing flood protection works may no longer be adequate and flood damage could be more severe and more frequent along the BC coast and across southern BC.

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RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

The use of the modified Thornthwaite model has provided straightforward computations of runoff before and after climate change. The above study has utilized the results to their limit to indicate change in hydrologic characteristics. Although additional stations could be investigated by this model, the results would not likely provide different conclusions. The next step is to utilize a daily hydrologic model to determine the potential impact of climatic change. Improvements in the CCC general circulation model would give greater confidence to the results.

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Chapter 6

GLACIER RELATED IMPACTS OF DOUBLING ATMOSPHERIC CARBON DIOXIDE CONCENTRATIONSON BRITISH COLUMBIA AND YUKON

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OVERVIEW

Climate change could result in the rapid retreat and demise of a number of glaciers in southern British Columbia in the early part of the next century. Paradoxically, in northwestern British Columbia and western Yukon, glacier advance that is now taking place is likely to continue unabated with climate change.

The projected retreat or advance of British Columbia and Yukon glaciers as a result of climate change will depend largely on their geographic location and their elevation. Changes in temperature and precipitation projected by atmospheric general circulation models suggest that the current retreat of most glaciers in southern British Columbia and the southern Rocky Mountains will continue and perhaps intensify as a result of a doubling of carbon dioxide concentrations in the atmosphere. The relatively low elevation of much of the surface area of these glaciers would be the cause of this projected retreat, since higher temperatures would cause both a higher fraction of annual precipitation to fall as rain as well as an acceleration of summer melting. A minority of glaciers in southern British Columbia have a large portion of their surface area at very high elevations. These glaciers will likely continue to receive adequate snow accumulation during winter and spring as the climate changes and would not undergo this rapid retreat.

In northwestern British Columbia and much of the Yukon, increased precipitation, even if a higher percentage of it is in the form of rain, will likely offset any increase in summer melt due to increased temperatures. Therefore, the present glacier advances in the northwest will likely continue as a result of climate change.

Many southern rivers and streams that are now fed by glacier runoff could be significantly impacted as a result of climate change. As glacier retreat accelerates, increased summer runoff could occur. However, when the glacier has largely melted, the present late summer and fall glacial input into streams and rivers will be lost, resulting in a significant reduction in flow in some cases. This reduction in stream discharge could occur within only a few years near the end of a glacier's life.

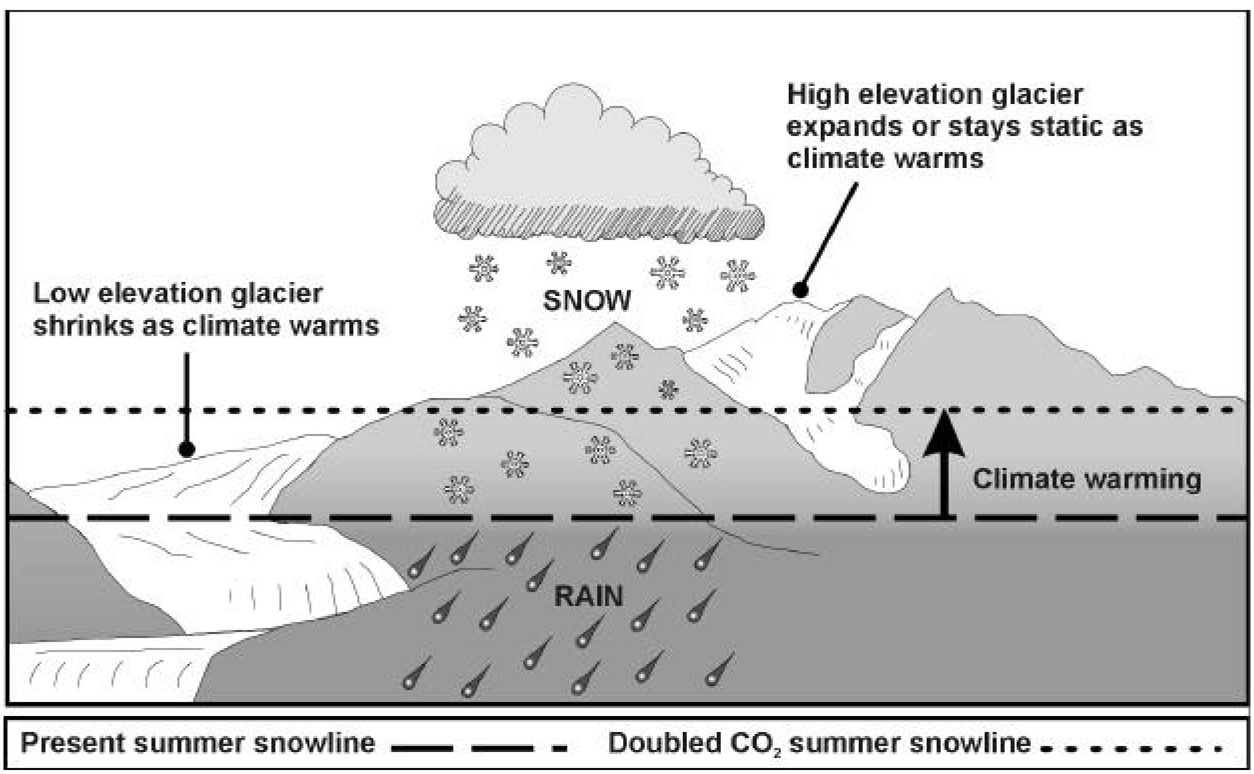
THE DEPENDENCE OF GLACIERS ON CLIMATE

Glaciers are composed mainly of snow and ice that accumulates, metamorphoses, and ablates in response to environmental change and inherent flow mechanics. Accumulation is the addition of snow and ice to a glacier by snowfall or, in some cases, the freezing of rain or meltwater. Metamorphoses is the conversion of snow to ice inside the glacier. Ablation is the loss of ice or snow due to melt, sublimation, erosion or calving.

In British Columbia and southern Yukon at all but the highest elevations, the glaciers are mainly "temperate-type", meaning that their internal temperatures are at the melting point throughout. In this region, the late summer snowline marks the elevation above which the glacier experiences net accumulation and below, net ablation. At very high locations and in the far north, glacier internal temperatures may remain below freezing during the summer, leading to internal accumulation. In this case, refrozen meltwater and summer rainfall can accumulate within the glacier below the observed snowline.

The distribution of glacier area with elevation determines whether a glacier will grow or shrink due to a change in temperature or precipitation. Glaciers comprised of large areas at a high elevation, where climatologically temperatures are very low and will remain so in a changed climate, may still receive adequate snow throughout the year. Even though there may be an increase in temperature due to a climate change, it is therefore possible that glacier growth could still occur at these high elevations. Conversely, a glacier with large areas at low elevation would probably shrink if temperatures rise, due to the decreasing fraction of precipitation falling as snow throughout the year, as well as increased summer ablation. The relationship is shown in Figure 1.

FIGURE 1. The importance of glacier area distribution with elevation on the state of health of a glacier. The high elevation glacier will remain static or will expand as climate changes. The low elevation glacier will shrink with climate change. The dashed line is the present summer snowline. The dotted line is the expected summer snowline as temperatures rise due to climate change. Not that precipitation is also expected to increase.



HISTORICAL GLACIER CHANGES

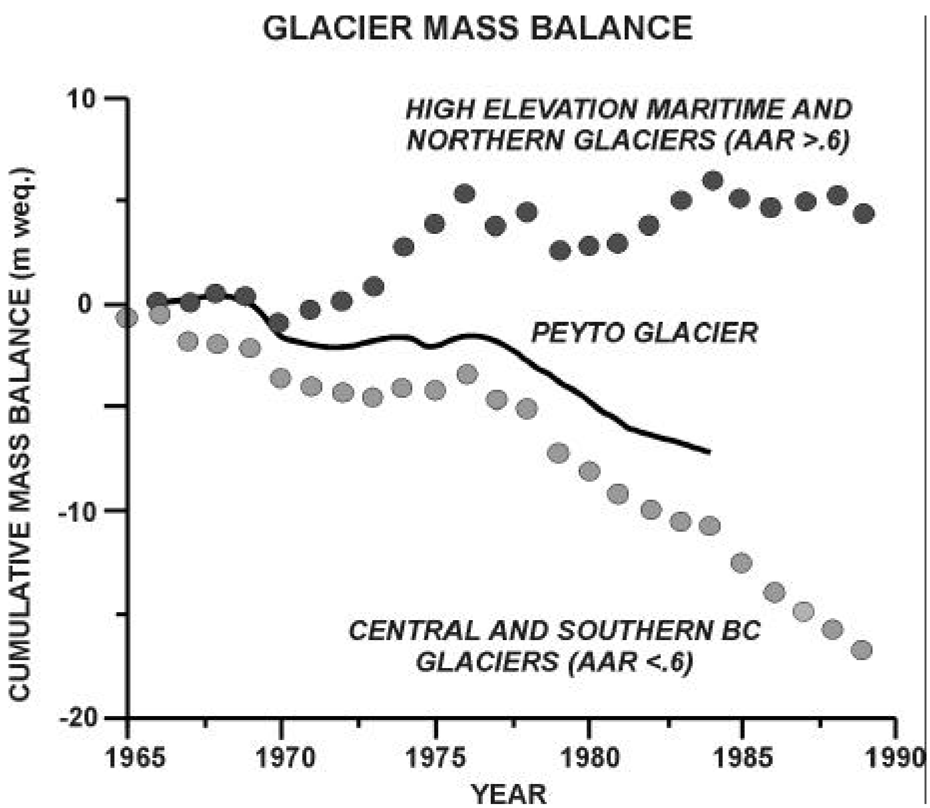
In previous millennia, warming similar to that projected by the general circulation models for a doubled carbon dioxide atmosphere led to the disappearance of most glaciers in British Columbia and nearby areas. More recently, from the seventeenth through nineteenth centuries, cooler temperatures and increasing precipitation led to dramatic glacier advance. Since the 1920s, as temperatures in British Columbia have increased, glacier extents have again dramatically reduced across most of southern British Columbia and the southern Rocky Mountains. In contrast, many glaciers in high snow accumulation regions such as southwestern Yukon and northwestern British Columbia have experienced glacier advance this century.

The state of glacier health may be estimated from the mass balance, defined as the annual difference between glacier mass gain and mass loss. If the glacier mass balance is positive then the glacier should grow in thickness and eventually the leading edge, or terminus, should advance. If the mass balance is negative, the terminus should retreat.

Measurements of glaciers in western North America show that the glacier mass balance has remained negative at the majority of monitoring sites since measurements began. The exceptions are glaciers that have very high snow accumulation and maritime locations, which have experienced positive balances. A major shift in glacier mass balance occurred in 1976 when negative mass balance for most glaciers became even more negative than it had been in previous decades.

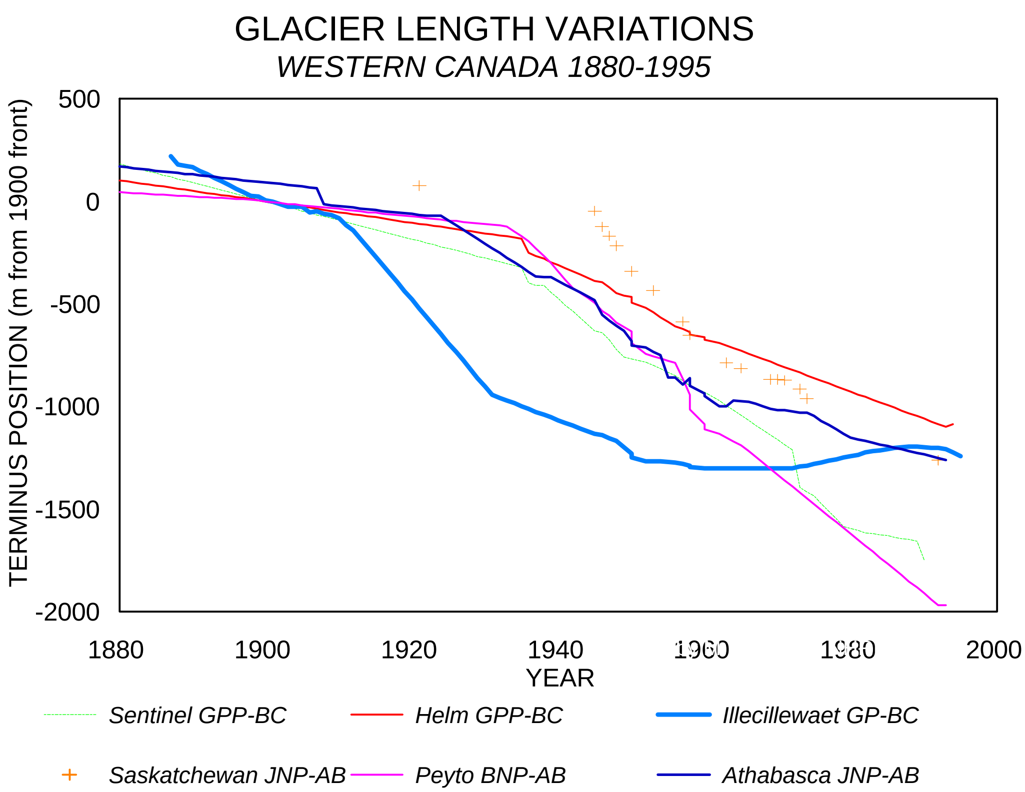
The cumulative mass balance is the summing of consecutive annual mass balances over a period of several years. Figure 2 shows the cumulative mass balance of the two categories of glaciers: retreating glaciers, which are in the majority, and advancing glaciers, confined largely to northwestern British Columbia and parts of Yukon. Records for glacier mass balance are only available in Canada since about 1965, but by drawing analogues to the North Cascades in Washington State the record for British Columbia glaciers may be brought back to about 1945.

FIGURE 2. Cumulative mass balance for benchmark glaciers in western North America.



Most glaciers in British Columbia have dramatically retreated throughout the last century (Brugman, 1991; Harper, 1993; Luckman et al., 1987; Wood, 1988). This corroborates the glacier mass balance calculations noted above. The glacier terminus positions for a number of glaciers is shown in Figure 3.

FIGURE 3. Glacier length variations in Western Canada 1880 to 1995.



GLACIER AUGMENTATION OF STREAM AND RIVER FLOW

A typical distribution of summer river flow in British Columbia and Yukon basins is dominated by high runoff during late July and August, when glacier melt is greatest. The peak in glacier runoff normally follows the peak in snowmelt by one to two months and in many cases the glacier runoff peak is larger.

The rate of glacier melt in a summer is dependent not only on the summer temperature and solar insulation, but also on the snowfall of the previous winter. If the winter is characterized by unusually low snow accumulation, large areas of dark glacier ice and crevasses will be exposed. The low albedo on the darkened glaciers will enhance adsorption of solar radiation causing increased summer melt and runoff. Conversely, if winter snowfall is high and the glacier remains covered with snow for most of the summer, then high reflectivity will lead to reduced summer melt and runoff.

POTENTIAL IMPACT OF DOUBLING CO2 CONCENTRATIONS ON GLACIERS

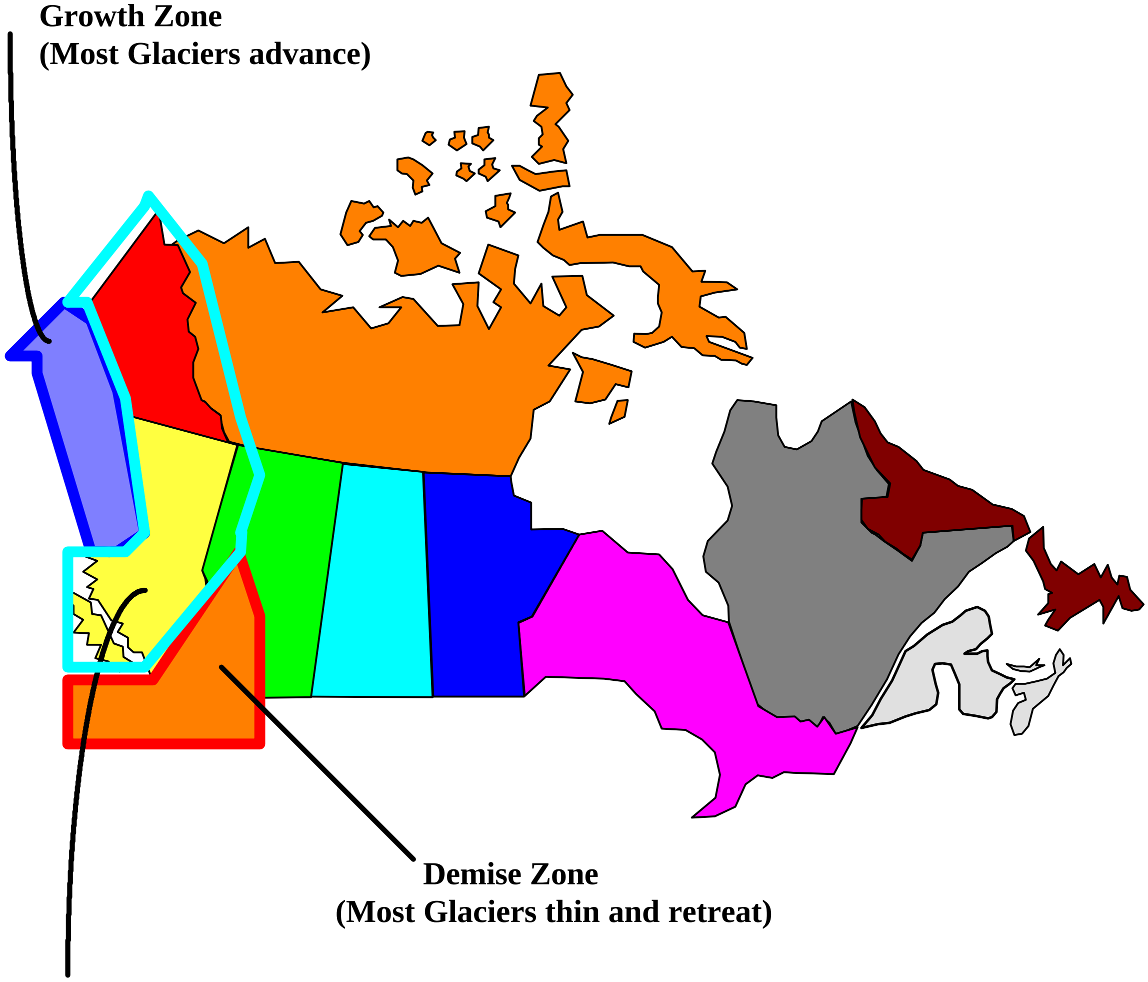
The general circulation models project that the winter precipitation may increase by 20% to 30% in glacierized areas from September through to May by the middle of the 21st century. During this period, the models also project a 1 to 5 degree increase in temperature (Taylor, 1997).

The impact of climate change should have the greatest negative effect on the lower-elevation glaciers of the Rocky Mountains and other areas of southern British Columbia. By contrast, in northwestern British Columbia and much of Yukon, glaciers will likely continue to advance. Figure 4 summarizes the projected impacts.

FIGURE 4. Map of Canada showing three characteristic regions where glaciers will be mainly advancing, retreating, or exhibit a combination of both projected for the latter half of the twenty-first century.

Glacier Response

Growth Zone
(Most Glaciers advance)



Demise Zone
(Most Glaciers thin and retreat)

Transitional Zone
(Glaciers with large, high accumulation areas advance, others retreat)

Potential Impacts On Glaciers In Southern British Columbia

The warmer temperatures in the spring and fall projected by the climate models would cause the glacier melt period to be extended by at least one month in much of southern British Columbia and the Rocky Mountains. This longer melt period could also result in a rise of the late summer snowline by between 60 to 300 metres, based on a vertical lapse rate of 0.6 degrees per 100 metres. It is estimated that this would mean that less than 30% of the glacier areas would be covered by snow by late summer, enhancing ice melt. This would cause the glacial mass balances to become increasingly negative. This would result in continued and perhaps accelerated glacial retreat and the eventual melting away of many of the glaciers in southern British Columbia and the Rocky Mountains. Glacier retreat will probably be catastrophic. For example, glaciers that are only 100 metres thick could disappear within 20 years.

The exception to this scenario would be the highest elevation glaciers of the Rocky Mountains and the southern interior of British Columbia such as the Illecillewaet glacier and the Columbia Icefields. These high elevations would continue to receive enough snow in winter to offset summer melt, and thus the glaciers at these elevations would likely not experience this rapid retreat.

Potential Impacts On Glaciers In Yukon And Northwestern British Columbia.

Climate change would impact glaciers differently in northern coastal regions of British Columbia, the Alaskan Panhandle and in much of Yukon. In the glaciated areas of these regions, increased snow would likely result in more than 70% of each glacier still being blanketed in snow by summer end, resulting in glacial mass balances being positive and glaciers continuing to advance. An example is the Taku, a large glacier near the coast in northwestern British Columbia, that is presently advancing and should continue to do so as the climate changes.

Potential Impacts On Glaciers In The Transition Zone Of British Columbia And Yukon.

Between the areas of probable continued glacier advance in northwestern British Columbia and Yukon and the areas of probable continued and accelerated glacier retreat in southern British Columbia and the Rocky Mountains lies a large transitional zone. Here the expected impacts of climate change on glaciers will likely be mixed, with some glaciers advancing and some retreating. The fate of these glaciers under a changed climate is uncertain and will depend largely on their elevation and proximity to the ocean.

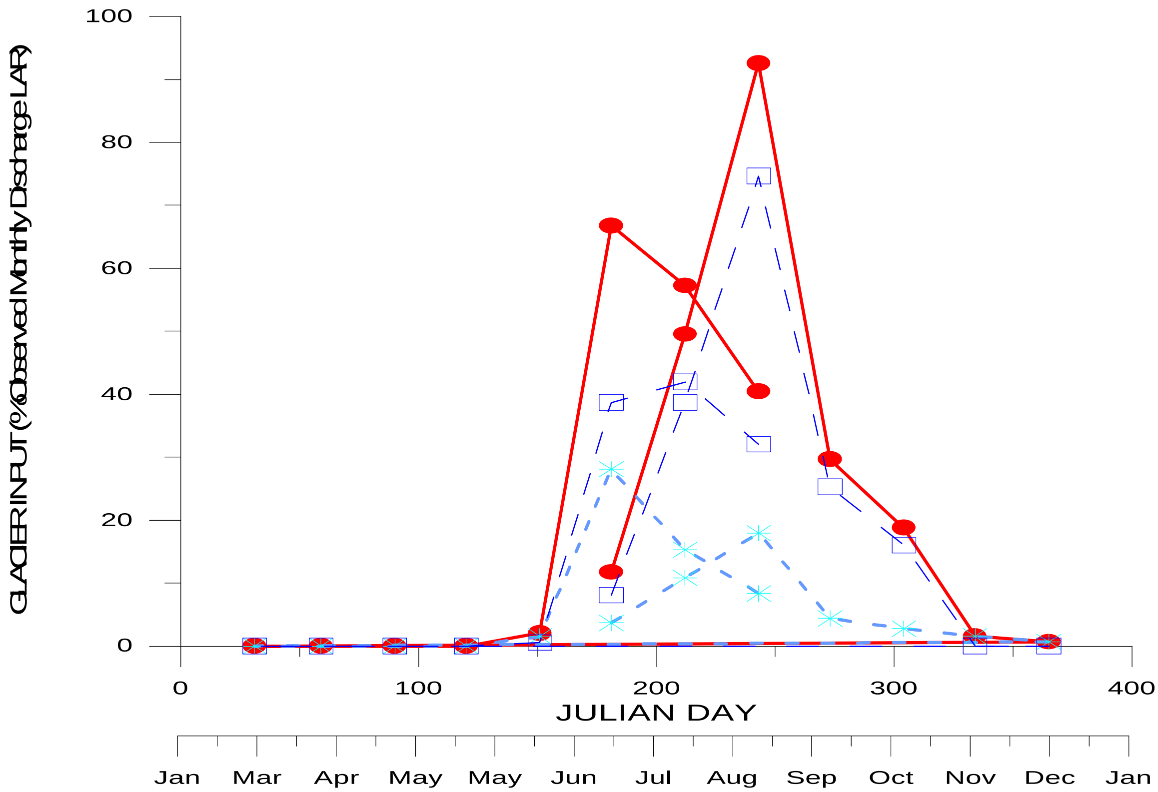
Potential Impacts On Glacial Runoff In Southern British Columbia.

There are two potential impacts of climate change for glacial runoff into streams and rivers in southern British Columbia and the Rocky Mountains.

Firstly, if glacier retreat continues and even accelerates in the early part of the 21st century, increasing glacier melt would swell the glacial runoff in late summer. This could augment stream and river flow, increasing the likelihood of more late summer and fall floods.

Secondly, when the glacial mass diminishes to the point that there is no longer a significant amount of ice to melt annually, the flows in glacier-fed rivers and streams could substantially diminish in late summer and fall. The Columbia River can be used as an example of the potential impacts of glacier disappearance as shown in Figure 5 (Brugman et al., 1996). The glacier water discharged into the Columbia River contributes about 10 to 30% of the annual total river flow. In the summer this figure can be as high as 90%. If the glaciers in the alpine regions of Columbia River basin, and their contributions to summer flow, disappear, then the monthly total discharge of the Columbia River from July through to October could fall by 20% to 90%. This could have a significant impact on river and lake levels, negatively effecting fisheries, hydroelectric energy generation, tourism and aquatic ecosystems.

FIGURE 5. Glacier water input to the Columbia River basin by month divided by the monthly total outflow at Lower Arrow Reservoir (LAR) which is man-controlled (Brugman and Pietroniro, 1996). The solid circles points are for total monthly runoff contribution from glaciers (snow + ice). The asterisk is for glacier snow and the open square is for glacier ice.



The concentration of suspended sediment in rivers and streams would also change as glaciers undergo these transformations. The high turbidity now experienced in late summer in many streams in southern British Columbia and the Rocky Mountains will be reduced when those glaciers that now provide water to these streams largely disappear.

ADAPTING TO GLACIER CHANGES RESULTING FROM CLIMATE CHANGE

Intelligent planning should prepare the residents, governments and industry of British Columbia and Yukon for the inevitable glacier-related changes that would accompany the projected temperature and precipitation increases. The potential impacts outlined above are large and diverse. Dramatic alterations of the hydrologic and hazard regime in British Columbia and the Yukon could result from glacier change.

The pattern of past change allows us to better understand future change. Past records of precipitation and temperature are limited in duration and extent, and can be unreliable. As a result, proxy data sets such as glacier fluctuation, ice cores and glacial stratigraphy are required.

Because of the uncertainties and the sensitivity of glaciers to minor climate fluctuations, we must exercise caution and prepare for both advance and retreat related impacts in central and southern regions and prepare for advance related impacts in northwestern British Columbia and the Yukon. Continued and perhaps accelerated glacier retreat appears to be inevitable in south and eastern British Columbia (and nearby Alberta and the U..S.A.) unless a dramatic shift from the predicted trend occurs.

SUMMARY

Temperature and precipitation projections obtained by the three atmospheric general circulation models suggest that the current retreat of most glaciers in southern British Columbia and the southern Rocky Mountains will continue and perhaps intensify as a result of a doubling of carbon dioxide concentrations in the atmosphere. The relatively low elevation of much of the surface area of these glaciers would be the cause of this retreat, since temperature increases would cause a higher percentage of precipitation to fall as rain as well as accelerating summer melt. A minority of glaciers that have a large portion of their surface area at very high elevations will likely continue to receive adequate snow accumulation during winter and spring and would not undergo this rapid retreat.

In contrast, in northwestern British Columbia and much of the Yukon, increased precipitation, even if a higher percentage of it is in the form of rain, will likely offset any increase in summer melt due to increased temperatures. Therefore, the present glacier advances will likely continue as a result of climate change.

A large transition area exists in the remainder of British Columbia and Yukon where climate change may cause some glaciers to advance and others to retreat.

Glacier runoff could be significantly impacted as a result of climate change. Where glacier retreat accelerates due to climate change, increased summer runoff could occur. When the glacier has melted, the present late summer and fall glacial input into streams and rivers will be lost, resulting in a significant reduction in flow in some cases. The stream discharge could suddenly decrease within only a few years.

FUTURE RESEARCH REQUIRED

Monitoring of glacier change is required to extend long term data sets enabling better significance testing of the meteorological and proxy data sets. This will also improve glacier mass balance and runoff modeling. New research methods must be explored and integrated into present monitoring of glaciers. Key data sets are glacier mass balance, ice extent, volume and flow, glacier runoff, terminus position, high elevation radiation and energy balance. Future research in glacier change should incorporate improved analysis of spatial variations with elevation and geographic location. Notable weak points in our present mass balance monitoring network includes northern coastal areas of British Columbia and the Yukon, and the northern and central interior of British Columbia.

Presently, glacier mass balance and monitoring programs are not consistently carried out in the major salmon spawning rivers (such as Columbia, Taku, Skeena, Stikine, Iskut, Fraser and Alsek), nor are they currently carried out in the major hydro electric producing basins (such as the Columbia, Peace, Yukon, Bridge River and Kootenay). Glacier terminus records at long term measurement sites should continue to be monitored in a manner consistent with methods used during the past century. The use of remote sensing in conjunction with traditional observation methods will allow scientists to develop consistent data sets that are less likely to contain observation errors. This will enable us to better track future climate variations and mitigate impacts.

ACKNOWLEDGMENTS

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Chapter 7

THE IMPACT OF CLIMATE CHANGE ON CATASTROPHIC GEOMORPHIC PROCESSES IN THE MOUNTAINS OF BRITISH COLUMBIA, YUKON AND ALBERTA

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OVERVIEW

Catastrophic geomorphic processes in mountain terrain are heavily influenced by climatic factors. As a result, the occurrence of these processes, which include landslides and outburst floods, is sensitive to climate change. In the Canadian Cordillera, the analysis of historical data and a limited number of case histories, suggest that under conditions of possible increased precipitation in future climatic change, the frequency of debris flows and other landslide types will increase. As in the past, these events should be expected to impact on settlements, infrastructural elements, resources and the environment, resulting in human and financial losses. Long term temperature change affects the volume of glacier ice in mountain regions. Glacier ice loss due to global warming has been identified as an important factor in the occurrence of a range of catastrophic processes, such as outburst floods and rock avalanches. With respect to predicted temperature increases, further glacier ice losses will result in continued debutressing of mountain slopes leading to slope deformation and, in some cases, catastrophic failure. The potential impact of rock avalanches should therefore be considered in the development of areas adjacent to and downstream of present-day glaciers. With continued warming, the frequency of outburst floods will reach a peak and subsequently decrease as the naturally-dammed reservoirs decrease in number and size. The nature of mountain permafrost in the Canadian Cordillera is not well known. This is an important knowledge gap in view of recent European work linking major rock avalanches and debris flows with the decay of mountain permafrost during recent warming. The further decay of permafrost in northern areas as a result of continued warming trends is likely to increase the occurrence of thaw-flow slides and other types of landslides. Locally, forest fires will amplify this effect.

INTRODUCTION

Catastrophic geomorphic processes are commonly driven by climate forcing. In the mountain environments of western Canada, probably the best known examples of this linkage are debris flows induced by heavy rains (Van Dine, 1985). These events have caused loss of life and frequently cause damage to the economic infrastructure, resources and environment of the region. Because of this linkage, the frequency of occurrence of these and other catastrophic processes can be related directly to climate change (e.g., Embleton, 1989; Eyebergen and Imeson, 1989) as a result of changes in rainfall and/or temperature regimes.

This paper describes some of the links between climate and catastrophic geomorphic processes and investigates how climatic change may affect the magnitude and frequency of their occurrence in the Canadian Cordillera[1]. The subject is of concern in other mountainous areas of the world as indicated by a large number of recent studies (e.g., Borgel, 1992; Zimmerman and Haeberli, 1992; O'Connor and Costa, 1993; Rapp, 1995).

CLIMATE CHANGE AND CATASTROPHIC GEOMORPHIC PROCESSES

The Intergovernmental Panel on Climate Change (IPCC) report on the *Impacts, adaptations and mitigation of climate change* (Watson et al., 1996) concludes that changes in precipitation regimes will affect the magnitude and/or the frequency of hazardous natural processes such as avalanches and debris flows. Such changes could result from a long term increase in mean annual precipitation, an increase in the frequency of intense landslide-producing storms, or an increase in the intensity of individual storms.

Climate warming since the last century has resulted in massive glacier ice loss in the glacierised regions of the world, as summarised by Watson et al. (1996). Drawing on work by Clague and Evans (1993, 1994) and Evans and Clague (1993, 1994), the Intergovernmental Panel (Watson et al., 1996) notes that large-scale glacier ice loss in mountainous regions has caused mountain slope instability in recently deglaciated valleys, debris flows from recently exposed moraine deposits, and catastrophic outburst floods due to sudden draining of moraine- and ice-dammed lakes.

Glacier ice loss is well documented in the Canadian Cordillera (e.g., Mathews, 1951; Ryder, 1987; Osborn and Luckman, 1988; Luckman, 1990) and is manifested in the retreat of glacier margins and the lowering of glacier surfaces due to thinning.

At Melbern Glacier, for example, Clague and Evans (1994) showed that Grand Pacific and Melbern glaciers, two of the largest valley glaciers in British Columbia, have decreased over 50% in volume in the last few hundred years (total ice loss = 250-300 km^3). Melbern Glacier has thinned 300-600 m and retreated 15 km during this period; about 7 km of this retreat occurred between the mid-1970s and 1987, accompanied by the formation of one of the largest presently existing, ice-dammed lakes on Earth (Fig.1). Grand Pacific Glacier, which terminates in Tarr Inlet at the British Columbia-Alaska boundary, retreated 24 km between 1879 and 1921.

Temperature increases may also lead to permafrost degradation and result in slope instability. Research in the Swiss Alps has indicated that the susceptibility of glacial or colluvial debris to being mobilised during heavy rainstorms may be increased by the degradation of mountain permafrost (Haeberli, 1992; Zimmerman and Haeberli, 1992). In addition, the degradation of mountain permafrost has been linked to recent large magnitude rock avalanches in the European Alps, at Val Pola, Italy, in 1987 (Dramis et al., 1995) and at Randa, Switzerland, in 1991 (Schindler et al., 1993). Permafrost degradation due to climate warming may also be implicated in some landslides in Quaternary sediments in high-latitude regions .

It is important to note that the recent pattern of climate change is part of a longer term recovery from the colder temperatures of the Little Ice Age which culminated in the 17th, 18th and 19th centuries (Luckman, 1986; Osborn and Luckman, 1988; Clague and Mathewes, 1996). During the Little Ice Age, which began with major advances about 700 years ago (Grove, 1987), glaciers not only reached their maximum extent since the Pleistocene but were also at their thickest since that time (Ryder and Thomson, 1986).

[1] See Slaymaker (1990) for an assessment of the impact of climate change on non-catastrophic processes in the Cordillera.

Figure 1. Aerial view of Lake Melbern formed between Konamoxt Glacier (distance) and Melbern Glacier (foreground) in northwestern British Columbia in 1991. As documented by Clague and Evans (1993), the lake began to form in 1979 as dead ice between the two glaciers began to float and break up. The lake was fully developed in 1987 covering an area of 12 km^2. In this photograph, the lake is just over 6 km long.

Temperature and precipitation variability has been a feature of the Holocene, and this epoch has included periods that were wetter and warmer than the present (Mathewes and Heusser, 1981).

LANDSLIDES

A variety of landslide types[2] may be triggered by heavy rains in the mountain environment. The most common types are small-magnitude debris flows, debris avalanches and rockfalls, which are commonly less than 50,000 m^3 in volume.

Rainfall-induced debris flows and debris avalanches are a major cause of natural disturbance in forest ecosystems (e.g. Schwab, 1983) and also adversely affect salmon spawning grounds, the quality of community water supplies from surface reservoirs (e.g., *Globe and Mail*, November 23, 1995), and the integrity of transportation corridors in the Cordillera (e.g., Evans and Lister, 1984; Evans and Clague, 1989).

Rockfalls caused by heavy rains are a major hazard along vital transportation corridors that cross the Cordillera (e.g., Peckover and Kerr, 1977).

Larger landslides may also be triggered by heavy rainstorms but more usually result from the culmination of a long term increase of precipitation over a period of years or decades. Heavy rains may cause a major temporary increase in water pressure on a sliding surface in a pre-existing landslide leading to an increase in slope movement (e.g., Patton, 1984).

Debris flows and debris avalanches

Although debris flows are usually associated with heavy rainfall (e.g., Broscoe and Thomson, 1969; Eisbacher and Clague, 1981; Septer and Schwab, 1995), the relationship between total storm rainfall or rainfall intensity, and debris flow occurrence is complex (Church and Miles, 1987). Factors that complicate the relationship include the role of snowmelt, antecedent moisture conditions, the availability of debris, and the fact that rain gauges are generally too widely spaced to detect localised high-intensity rainfall cells which may trigger debris flows.

In an investigation of debris flows and heavy rainfall events on the Queen Charlotte Islands, Hogan and Schwab (1991) found that on a temporal scale of years, a positive correlation existed between annual precipitation and reported slope failure frequency. Within a given year, only those months preceding the slope failure were important in conditioning the hillslope for failure. Daily antecedent conditions were also important in determining the landslide-initiation threshold for a given rainstorm. Debris flows are frequently the result of notable but not exceptional storms.

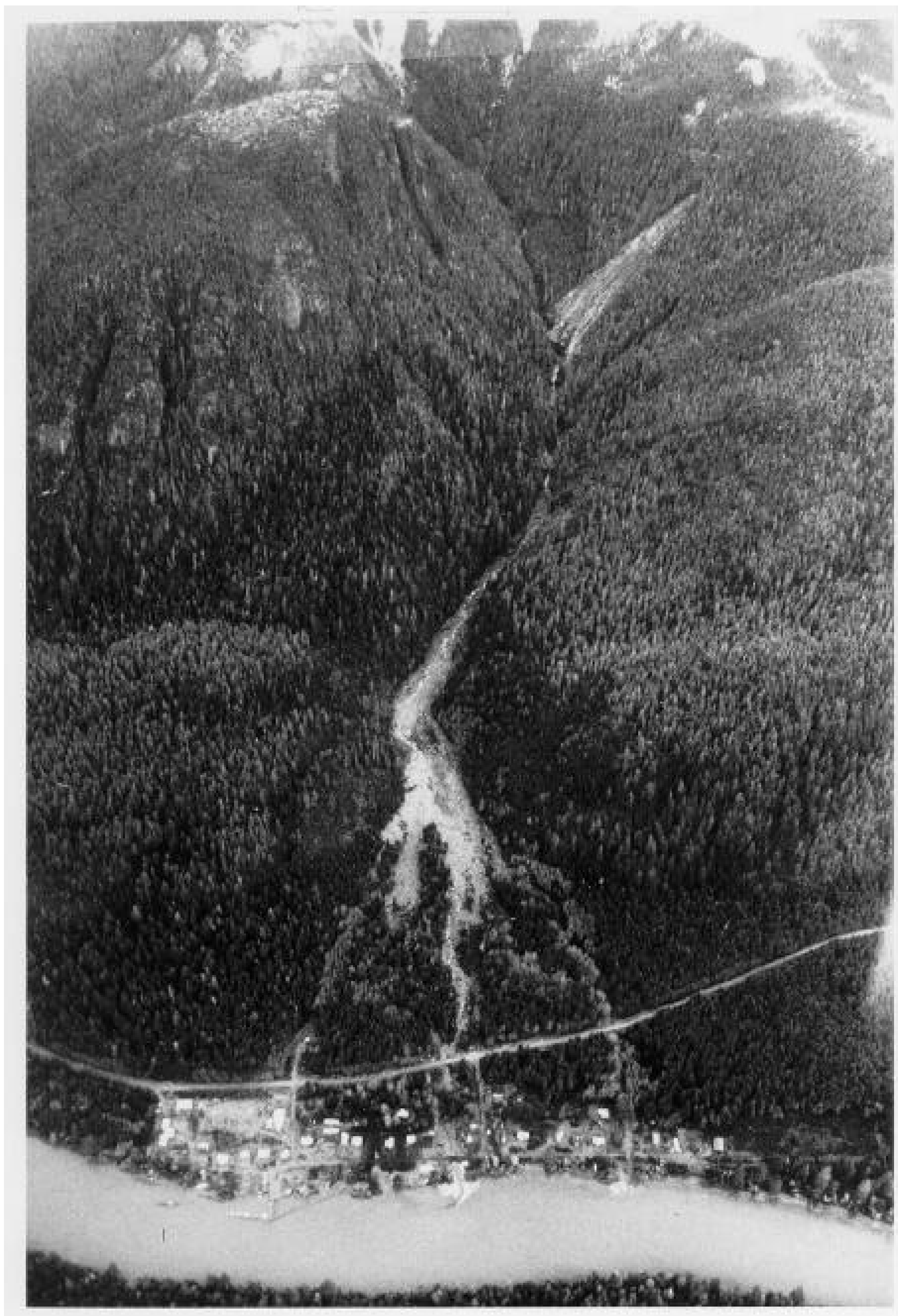
The impact of debris flows caused by heavy rains is shown by four heavy rainfall events that occurred in southern British Columbia between 1983 and 1995.

1. The July 1983 rainstorm in the Revelstoke area represented an event with a probable return period of 220 years. Landslides triggered by the storm were widespread ; the Revelstoke Forest District suffered damage estimated to be $2M, and both the Trans Canada Highway and the CP Rail mainline were blocked in several places by debris flows (Evans and Lister, 1984).
2. In November 1989 torrential rains occurred throughout British Columbia. Many debris flows occurred in the Rivers Inlet area including one which damaged the village of Oweekeno (Fig. 2). The local intensity of failures was as high as 7 events / km^2 (Septer and Schwab, 1995).
3. In June 1990 a heavy rain fell in the southern Interior of British Columbia. Many debris flows were triggered by the event, particularly in the vicinity of Enderby where a debris flow destroyed a B.C. Hydro transmission tower. Near Kelowna, a debris avalanche at Philpott Road caused the death of three people (Cass et al., 1992).
4. In November 1995, heavy rains in southwestern British Columbia triggered over 160 landslides in the Chilliwack valley alone, and major debris flows occurred near Hope.

Several factors, which themselves result from changes in the mountain ecosystem, may also affect the susceptibility of steep slopes to rainfall-induced landslides. Forest harvesting practices, for example, may increase the

[2] Recent reviews of landslide types and their classification may be found in Dikau et al. (1996) and Cruden and Varnes (1996).

Figure 2. Aerial view of debris flow which occurred in the watershed behind Oweekeno a First Nations village near Rivers Inlet, central Coast Mountains, British Columbia. The debris flow initiated as a debris avalanche on a steep forested hillslope and became transformed into a debris flow which ran out onto the debris fan in the lower part of the photograph. Some damage was done to the village located on the fan. The debris flow was one of many to have occurred in the Rivers Inlet area due to torrential rains in November 1989 (photograph courtesy of Dr. O. Hungr)



susceptibility of steep terrain to rainfall-induced landsliding (Schwab, 1983).

Some debris flows are also associated with recent glacier retreat. In the Swiss Alps, during the summer of 1987, numerous debris flows were triggered by intense rainfall of unusually long duration (Zimmerman and Haeberli, 1992). In a large number of cases, the source of the debris was Little Ice Age terminal moraine deposits exposed during recent retreat. Debris production may also have been related to the decay of ice cores within the moraines. Similar explanations have been offered to explain the occurrence of some recent debris flows in the southern Coast Mountains of British Columbia (Jordan 1987), and the Mount Stephen debris flow which occurred in the Rocky Mountains near Field, British Columbia in 1994 (Thurber Engineering, 1994).

Landslides in northern areas of permafrost

Areas of the northern Canadian Cordillera underlain by ice-rich sediments are subject to landsliding (McRoberts, 1978). Retrogressive thaw slides and active layer detachment slides are common on slopes in documented from the Mackenzie Valley and adjacent areas (Fig. 3) at the eastern margin of the Cordillera (McRoberts and Morgenstern, 1973; Aylsworth et al., 1992). In central Yukon, the Surprise Rapids earthflow complex developed in ice-rich sediments after a forest fire swept the site in the late 1800s. Development of the complex has been coincident with post Little Ice Age climatic amelioration (Ward et al., 1992).

In the St. Elias Mountains, debris flows caused by the melting of ice-rich sediments during periods of warm temperatures have been described by Harris and Gustafson (1988). Debris flows triggered by heavy rains also occur in this environment (Broscoe and Thomson, 1969; Evans and Clague, 1988).

The stability of permafrost terrain is adversely affected by forest fires. Fires modify surface albedo and result in an increase in active layer thickness. Harry and MacInnes (1988) have documented widespread landsliding which followed two forest fires in the Mackenzie Valley, N.W.T.

Mountain slope deformation and rock avalanches resulting from glacier ice loss

The debutressing of mountain rock slopes as a result of glacier ice loss has been identified as an important factor in slope instability in areas adjacent to present-day glaciers (e.g., Bovis, 1982, 1990; Evans and Clague, 1994). The magnitude and effects of glacier debutressing can be spectacular. At Melbern Glacier in northwest British Columbia, for example, a 400 to 600 m lowering of the glacier surface has debutressed adjacent mountain slopes, causing extensive, non-catastrophic slope deformation (Clague and Evans, 1993).

Of the 31 large - magnitude catastrophic rock avalanches known to have occurred in the Cordillera since 1855, 17 (55%) have occurred in slopes adjacent to glaciers which have experienced twentieth century downwasting (Fig. 4; Evans and Clague, 1988). Where catastrophic failure has not taken place, mountain slopes that have recently been debutressed frequently show signs of limited movement by the presence of bulging, cracking and anti-slope scarps formed by differential movement in the rock mass.

OUTBURSTS FROM MORAINE-DAMMED LAKES

Moraine-dammed lakes are found in high mountains close to existing glaciers (Clague and Evans, 1994). They formed when glaciers retreated from moraines built during the Little Ice Age and where the moraines dam glacial streams. Moraine dams are susceptible to failure because they are steep-sided, have relatively low width-to-height ratios, and consist of poorly sorted, loose sediment. In addition, these dams and the lakes behind them commonly occur immediately downslope from steep slopes that are prone to glacier avalanches and rockfalls. Moraine dams generally fail by overtopping and incision. The triggering event is most frequently an ice avalanche from the toe of the retreating glacier which generates waves that overtop the dam. Melting of ice cores and piping are other reported failure mechanisms (Evans, 1987; Clague and Evans, 1994).

Several moraine dam failures have produced large floods and debris flows in the Canadian Cordillera in recent years (Evans,

Figure 3. Earthflow in permafrost terrain, Dekale Creek, Mackenzie Mountains, N.W.T.

Figure 4. Aerial view of the 1986 rock avalanche from the peak of Mount Meager, Coast Mountains, British Columbia.

1987; Clague et al. 1985; Blown and Church, 1985; Clague and Evans, 1994). In the early 1970s, for example, the sudden failure of the moraine impounding Klattasine Lake in an unpopulated part of the British Columbia Coast Mountains released approximately 1.7 x 10^6 m^3 of water and triggered a massive debris flow (estimated volume 2-4 x 10^6 m^3) that traveled 8 km to block the Homathko River.

In the same region, ca. 6 x 10^6 m^3 of water was released from Nostetuko Lake when the moraine impounding the lake failed in 1983 (Fig. 5). The breach was initiated by waves generated by an ice avalanche into the lake. The waves overtoppped and incised the moraine, producing a flood that devastated the Nostetuko valley downstream and traveled more than 100 km to the sea.

JOKULHLAUPS

Jökulhlaup is an Icelandic word for a catastrophic outburst flood resulting from the sudden draining of a glacier-dammed lake or a body of water contained in or confined under the ice. Historic occurrences in the Cordillera are reviewed by Evans and Clague (1994) and Clague and Evans (1994)[3]. Some formerly stable, glacier-dammed lakes have gone through a cycle of jökulhlaup activity during this century as glaciers have retreated from maximum positions achieved during the Little Ice Age. An example is Summit Lake, dammed by the Salmon Glacier in the northern Coast Mountains of British Columbia (Fig. 6; Mathews, 1965, 1973; Mathews and Clague, 1993). This lake first drained catastrophically in 1961 after a lengthy period of stability, and has drained annually since 1970, with peak discharges of the largest floods in excess of 3000 m^3/sec.

In contrast, many lakes that formerly produced jökulhlaups have disappeared since the Little Ice Age due to glacier retreat. Lake Alsek, one of the largest Holocene glacier-dammed lakes in the world, formed behind Lowell Glacier in the Saint Elias Mountains, Yukon Territory, and periodically produced jökulhlaups with peak discharges larger than the mean flow of the Amazon River (Clague and Rampton, 1982; Clarke, 1989). Lake Alsek formed and emptied many times during the nineteenth and perhaps early twentieth centuries, but has not existed in recent years due to retreat of Lowell Glacier.

Jökulhlaup frequency is related to climate warming through glacier retreat (Evans and Clague, 1994; Clague and Evans, 1994). The initiation of a jökulhlaup cycle occurs when a threshold of retreat and thinning is reached. Jökulhlaups then take place with decreasing magnitude and frequency until the glacier dam ceases to exist.

Jökulhlaups may also generate debris flows (Jackson, 1979; Clague and Evans, 1994). A detailed analysis of the Cathedral Mountain debris flows near Field, British Columbia shows a clear relationship between twentieth century retreat and thinning of Cathedral Glacier, jökulhlaup frequency and debris flow occurrence (Jackson et al., 1989). Jökulhlaup-generated debris flows were responsible for major disruption of traffic on the main CP Rail line through the Rocky Mountains beginning in 1925. No jökulhlaup or significant debris flow activity has occurred since pumping of meltwater from the glacier was initiated in 1985.

RESPONSE TO FUTURE CLIMATE CHANGE

A number of General Circulation Models (GCMs) have been proposed to simulate future climate change with respect to changes in precipitation and temperature. under various greenhouse gas emission scenarios.

Changes in precipitation

Some GCMs predict a marked increase in precipitation in parts of the Cordillera, particularly in the late winter and fall. Since these periods correspond to the “debris flow seasons”, an increase in the frequency of this type of landslide can be expected. A similar conclusion can be reached with respect to rockfalls.

If the increase in precipitation is sustained over a period of years or decades, more larger deep-seated failures are likely to occur.

Changes in temperature

Increases in temperature are predicted by most GCMs. Of particular interest are the

[3] The most recent jökulhaup in the Cordillera, the 1994 outburst flood on Farrow Creek in the southern Coast Mountains, is documented by Clague and Evans (1997).

Figure 5. Aerial view of the breached moraine dam at Nostetuko Lake, Coast Mountains, British Columbia in 1987. As described by Blown and Church (1985), the breach and outburst flood took place in 1983 when a mass of ice broke off the tongue of Cumberland Glacier (left background) and entered Nostetuko Lake. This generated a wave which overtopped the moraine and initiated the breach. The moraine dam was formed by a terminal moraine complex which marks the Little Age extent of Cumberland Glacier. The lake was created during the twentieth century retreat of the glacier.

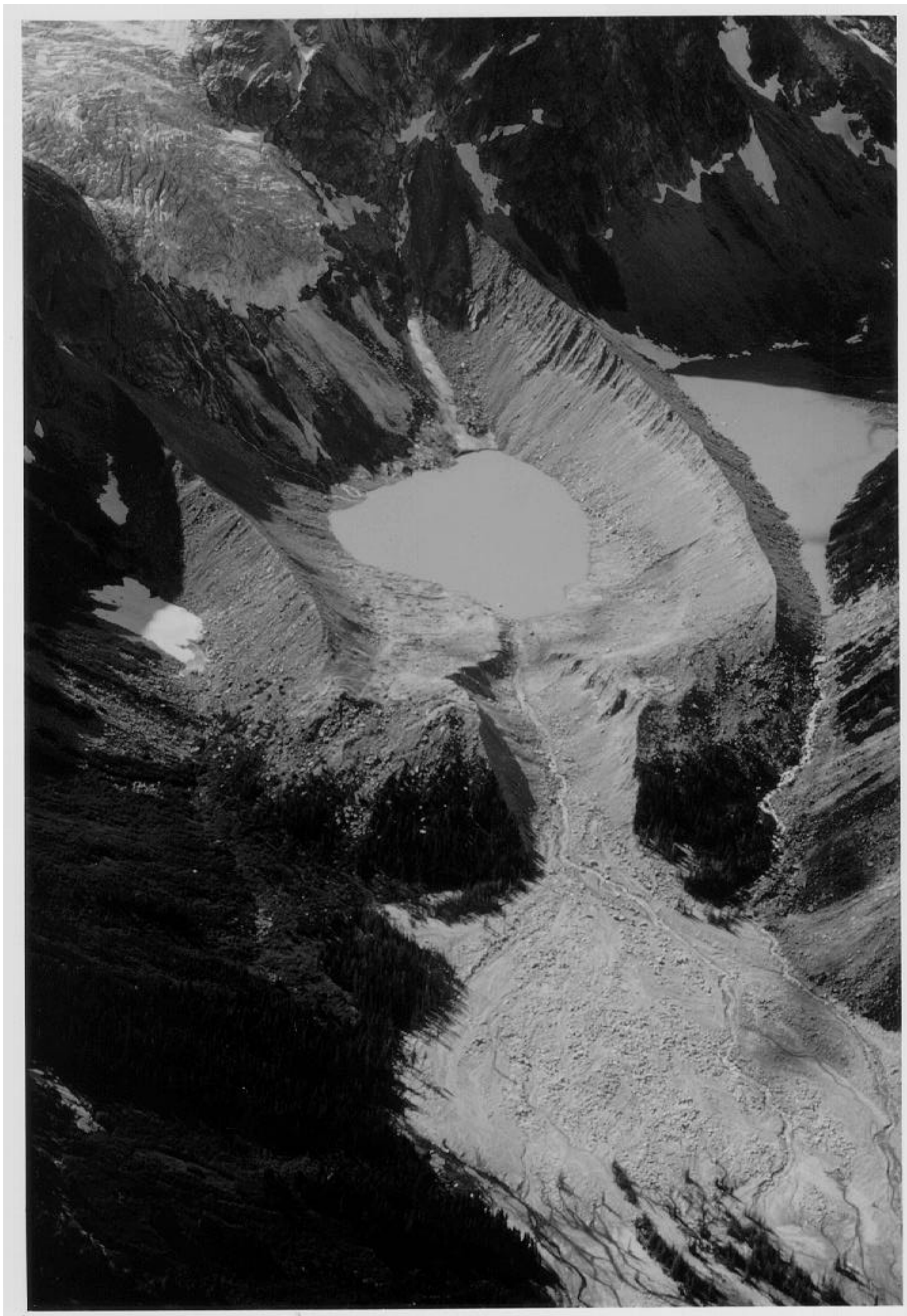


Figure 6. Aerial view, looking down valley, of Summit Lake and Salmon Glacier in the northern Coast Mountains, British Columbia. The lake is dammed by Salmon Glacier and has drained on numerous occasions since 1961 generating jökulhlaups in the Salmon River valley downstream.

predicted increases in summer temperatures which will result in further glacier ice loss.

The northern Cordillera may experience the greatest warming, resulting in significant degradation of permafrost and an attendant increase in the frequency of thaw-flow slides in the region. This instability will be exacerbated if an increase in forest fires accompanies the anticipated warming.

CONCLUSIONS

Catastrophic geomorphic processes in mountain terrain are heavily influenced by climatic factors. As a result, the occurrence of these processes, which include landslides and outburst floods, is sensitive to climate change.

Analysis of historical data and a limited number of case histories, suggest that under conditions of increased precipitation in future climatic change, the frequency of debris flows and other landslide types would increase. As in the past, these events should be expected to impact on settlements, infrastructural elements, resources and the environment resulting in human and financial losses. To further assess the impact of predicted precipitation increases, research is required on the landslide response to rainstorms and long term precipitation trends. The nature of the landslide response is complicated by such factors as forest harvesting and other land-use changes.

With respect to predicted temperature increases, further glacier ice losses will result in continued debutressing of mountain slopes leading to slope deformation and in some cases catastrophic failure. The potential impact of rock avalanches should therefore be considered in the development of areas adjacent to and downstream of present-day glaciers. Further research is required to explore the lag-time involved in this process. Under continued warming, the frequency of outburst floods will reach a peak and subsequently decrease as the naturally-dammed reservoirs decrease in number and size. Research is required to examine if this peak has already been reached.

The nature of mountain permafrost in the Canadian Cordillera is not well known. This is an important knowledge gap in view of recent European work linking major rock avalanches with the decay of mountain permafrost during recent warming.

In northern permafrost areas, the further decay of permafrost as a result of continued warming trends is likely to increase the occurrence of thaw-flow slides and other types of landslides. Locally, forest fires will amplify this effect.

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Part 4

POTENTIAL IMPACTS OF CLIMATE CHANGE ON NATURAL ECOSYSTEMS OF BRITISH COLUMBIA AND YUKON

Chapter 8

EFFECTS OF CLIMATE CHANGE ON COASTAL SYSTEMS IN BRITISH COLUMBIA AND YUKON

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OVERVIEW

A review of literature indicates the possible effects along the British Columbia and Yukon coasts of sea-level rise and increased frequency of extreme storm events expected to result from climate change. Three principal effects on coastal areas are likely to occur: erosion and/or sedimentation; coastal flooding; and permanent inundation or low gradient, intertidal areas. While region-specific data remains somewhat sparse, available information indicates the potential for significant erosion in British Columbia along eastern Vancouver Island and northern and eastern Graham Island and in Yukon along the entire coast. Available information also indicates the potential for wetland losses, changes in coastal species distributions and abundance, altered ecosystem structure along both coasts, and, in British Columbia, significant economic costs associated with protecting human settlements.

INTRODUCTION

Heralded as a nation stretching from sea to sea to sea, Canada is renowned for possessing the longest coastline, and the second largest Fisheries Management Zone (FMZ), of any nation in the world. Prior to the arrival of Europeans in Canada, First Nations made extensive use of the Pacific and Northern coasts and their resources. With the arrival of Europeans, coastal use, particularly in what was to become British Columbia, increased as cash-based economies developed that were tied to the sea. Much later, the discovery of petroleum resources in the Beaufort region increased development along the short Yukon coast. Today, much of Canada's wealth, both economic and intangible, is still derived from the sea: a significant percentage of the country's Gross Domestic Product is derived from the harvest of living marine resources in waters off British Columbia and from non-renewable resources extracted from the seabed of the Beaufort Sea. Native and non-native communities on the coast seek out the sea for relaxation, recreation, spiritual rejuvenation and cultural continuity. And, Canadians, even far inland, reap the benefits of a myriad of ecosystem services — from climatic regulation to the production of the very oxygen we breathe — provided by the sea.

Global Climate Models (GCMs) are now sufficiently robust to permit scientists to predict, with reasonable certainty, that enhanced greenhouse forcing[1] and the consequent rise in global temperature attributed to human actions (hereafter referred to simply as "climate change") will have two principal effects in the coastal zone: sea levels will rise and the hydrological cycle will intensify, leading to shorter return periods for extreme storm events and increased rainfall intensity. The continuing low resolution of existing GCMs, however, makes it difficult to predict the impact that these changes will have on specific coastal areas.

This paper represents an attempt to reduce some of these regional uncertainties. In it, the authors look at the effects sea-level rise and increased storm activity will have on the British Columbia and Yukon coasts. In particular, we attempt to identify those coastal landscapes that are most vulnerable to rising sea levels and increased storm activity and enumerate the possible impacts of these changes on the biological communities (including human settlements) associated with these regions.

This information, it is hoped, will enable decision-makers concerned with this region to pre-empt the most significant negative impacts (and take advantage of potential benefits) associated with anticipated climate change.

FIRST-ORDER IMPACTS OF CLIMATE CHANGE: SEA-LEVEL RISE AND INCREASED STORM ACTIVITY

Sea-level Rise

Global sea level has been rising over the last 100 years at a rate of 1.0-2.5 mm/yr (IPCC, 1995). This rise is believed to be one of several factors responsible for the recently-noted worldwide trend towards beach retreat (Bird, 1987). Recent predictive work by the Intergovernmental Panel on Climate Change (IPCC) indicates that the average global temperature is expected to rise by 1.0ºC to 3ºC by the year 2100 which will result in a sea-level rise of 15 to 95 cm by the year 2100 (IPCC, 1995). This rise is two to five times more rapid than the historical rate. The "best guess" predicted rise is thought to be roughly 5 mm/yr, a rate which would result in a rise in sea level of approximately 50 cm by the year 2100 (IPCC, 1995). Sea-level rise will not occur evenly over time due to lags associated with climate response, resulting in annual sea level changes that are less than the predicted amount in the first half of next century and greater than the predicted amount in the second half of the century (Reid and Trexler, 1996). As well, climate response lags will result in continued sea-level rise after the year 2100, even if

[1] The term "enhanced greenhouse forcing" is used to describe human-induced climate change. It is used to distinguish human-induced change from the natural greenhouse warming caused ("forced") by gases that existed in the atmosphere prior to the Industrial Revolution and were responsible for bringing the average global temperature to a habitable 15ºC. Without this natural greenhouse forcing, the average global surface temperature would be well below 0ºC -- a temperature hostile to most life on Earth.

Figure 1. Predicted sea-level rise along the British Columbia Coast (Thomson, 1997) coupled with schematic location of shorelines vulnerable to change (after Clague, 1989). (+) indicates sea-level rise; (-) indicates sea-level fall. Note that boundaries are indicators only: locations of sea-level rise or fall are not specific. Estimates of sea-level change are conservative. Vulnerable shorelines are generally sedimentary in origin.

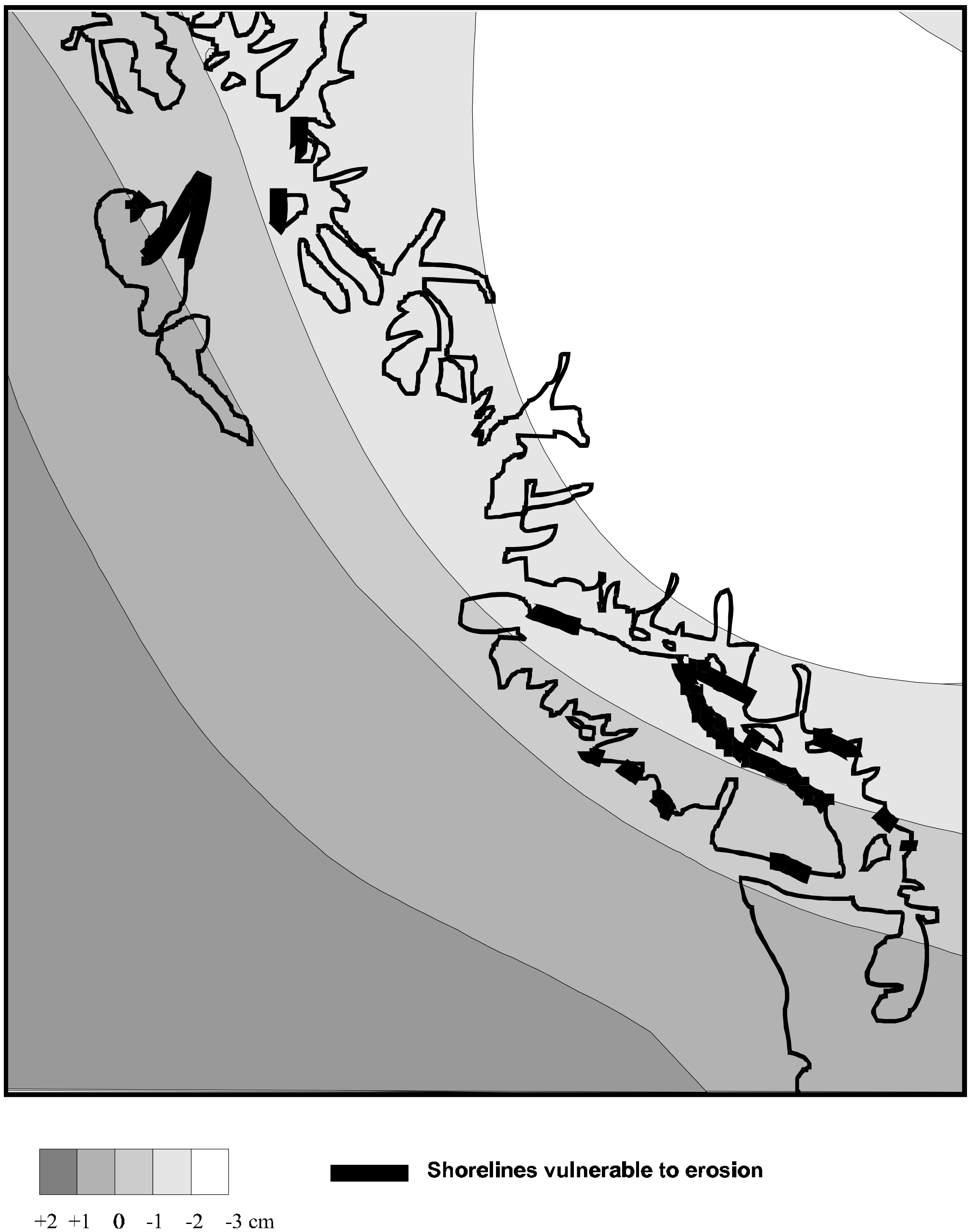


Table 1. Predicted sea-level rise for the coasts of British Columbia and Yukon over the next century (after Thomson, this volume)

	South BC outer coast	North BC outer coast	South BC inner coast	North BC inner coast	Yukon coast
Eustatic change	+10 to +20	+10 to +20	+10 to +20	+10 to + 20	+10 to +20
Steric Change	0 to +10	0 to +10	0 to +10	0 to +10	0 to +10
Oceanic wind effects	0 to +10	0 to +10	0 to +10	0 to +10	0 to +10
Coastal wind effects	0 to +10	0 to +10	0 to +10	0 to +10	0 to +10
Isostatic rebound	-10 to +10	-10 to +10	-20 to -30	-20 to -30	+20 to +40
Tectonic uplift	-10 to -40	0	0	0	0
Total Change	-10 to +20	0 to +60	-10 to +20	-10 to +20	+30 to +90

Note: Sea level rise is denoted by (+); sea level fall is denoted by (-). All figures in cm.

significant efforts to reduce greenhouse gas emissions are made (IPCC, 1995).

The overall IPCC prediction is based on an aggregate global estimate of eustatic[2] and steric[3] changes associated with increased global temperatures. As a result, it does not fully represent the net or "relative" sea-level rise likely to be experienced by specific coastal regions because it does not take into consideration regional tectonic activity. Recent work by Thomson and Crawford (1997) attempts to gain a better understanding of the "net" sea-level rise likely to be experienced along the British Columbia and Yukon coasts by merging IPCC data with regional tectonic information. Their results show: a rate of sea-level rise that is slightly lower than the IPCC estimate along the British Columbia Coast as a result of tectonic uplift; and, a rate of sea-level rise along the Yukon coast that is slightly larger than the IPCC estimate due to subsidence and the amplification of climate change effects at high latitudes (table 1; figure 1).

Storm Events

A great deal of uncertainty continues to surround the issue of changes in storm activity associated with climate change. According to the IPCC, data regarding frequency, magnitude and spatial distribution of cyclonic events are as yet inconclusive, as are data concerning changes in global storm tracks (IPCC, 1995). Recent models have shown a tendency towards increased frequency of events similar to the El Niño-Southern Oscillation (ENSO) in the Pacific Ocean, together with attending increases in temperature, precipitation and surge along the western coast of North America. Realistic simulations of ENSO-like events are not yet available to test this more rigorously, however.

Additionally, it has not yet been possible to adequately model increased climatic variability[4]. Several recent studies however, have shown that climate change is likely to increase the frequency of extreme events. GCMs, for instance, consistently predict a higher frequency of convective precipitation in mid- to high-latitudes (IPCC, 1992). Based on these data, a number of

[2] "Eustatic changes" in sea level are those caused by growth or melt of land-based ice sheets and glaciers (Thomson and Crawford, 1997).

[3] "Steric changes" in sea level are those caused by volumetric changes associated with heating or cooling of ocean waters (Thomson and Crawford, 1997).

[4] While global storm frequency changes cannot be predicted by current GCMs, it is speculated that storm frequency may increase along the Yukon coast as a result of increased land-sea temperature differentials. This is because storms in the Beaufort region ride along a frontal surface caused by summer air-sea temperature that is aligned parallel to the coast. Longer, warmer summers may thus result in increased summer storm activity (E. Taylor, personal communication).

authors (Gordon, *et al.*, 1992; Titus, *et al.*, 1987; Reid and Trexler, 1996; Vellinga and Leatherman, 1989) have predicted larger numbers of more intense rainfall events and a decreased return period for extreme events, both of which could lead to increased erosion, increased sedimentation, and increased areal coverage and frequency of flooding.

SHORELINE CHARACTERISTICS -- BRITISH COLUMBIA AND YUKON

British Columbia

Shoreline Types:

According to Clague and Bornhold (1980), the Pacific coast is dominated by moderate- to high-relief fjordal features and a coastline composed primarily of rock resistant to erosion. Exceptions to this general rule include:

- areas backed by cliffs or low gradient backshores of unconsolidated Pleistocene sediments, nonresistant bedrock, or a mix of sediment and bedrock ("Mixed" and "Beach" types);
- coastal and fjord-head areas where deltas are stable or forming ("Delta" types);
- estuaries, lagoons and intertidal mudflats ("Mudflats" types); and
- areas where human activities (e.g.: agriculture) or structures (e.g.: homes; businesses; and recreational facilities) have altered the shore character ("Man-modified" types).

These exceptions account for roughly 15% of the total British Columbia coastline (Dunn, 1988; Clague, 1989), as indicated in table 2, although regional differences are significant (tables 2, 3, 4 and 5; figures 1 & 2). The effects of climate change will be considered on these shoreline types.

Figure 2. Comparison of shoreline types for different regions of British Columbia.

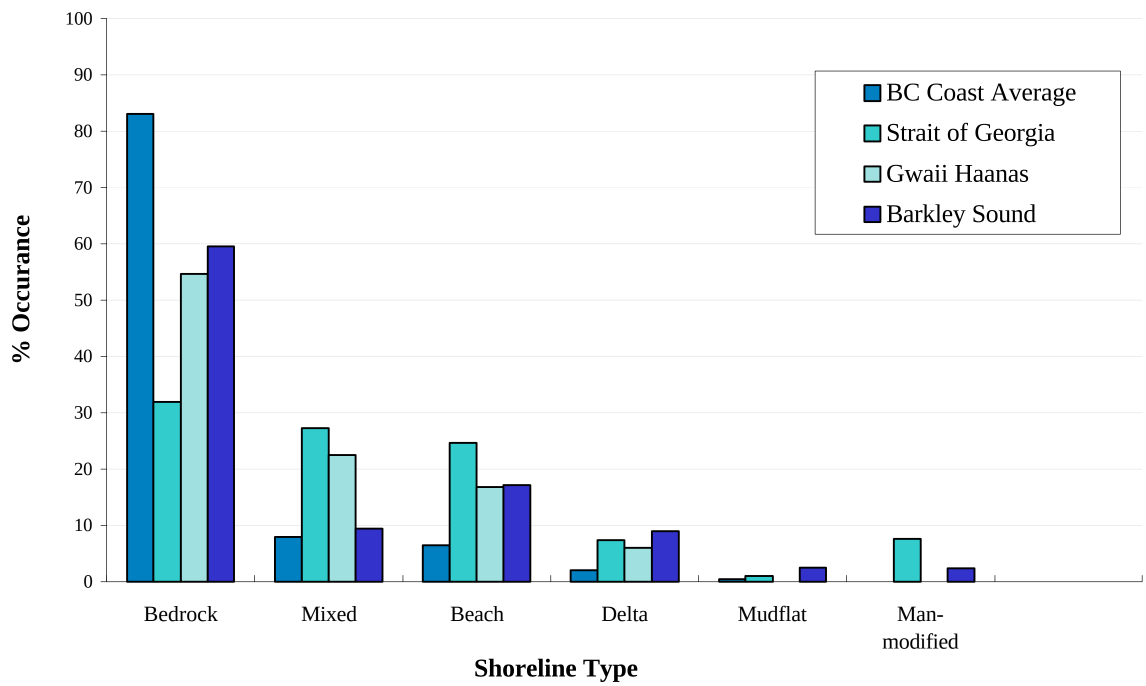


Table 2. British Columbia's overall coastal characteristics

Coastal Type	% Occurrence
Bedrock	83
Mixed (bedrock and sediment)	8
Beach	6.5
Delta (fjord and open coast types)	2
Mud Flat	.5
Man-modified	
Total	**100**

Source: Dunn, 1988. Note: Man-modified data not available

Table 3. Coastal character distribution for the Strait of Georgia

Coastal Type	Length (linear km)*	% Occurrence
Bedrock	1108.29	32
Mixed (bedrock and sediment)	947.35	27.3
Beach	860.51	24.7
Delta (fjord and open coast types)	256.26	7.4
Mud Flat	39.3	1
Man-modified	262.38	7.6
Total	**3474.09****	**100**

Data source: Luco, 1996. *Note: preliminary figures; **Note: approximately 330km still remain to be mapped, however, proportions are unlikely to change.

Table 4. Coastal character distribution for Barkley Sound

Coastal Type	Length (linear km)	% Occurrence
Bedrock	465.29	59.5
Mixed (bedrock and sediment)	74.48	9.5
Beach	133.78	17.1
Delta (fjord and open coast types)	70.2	9
Mud Flat	19.13	2.5
Man-modified	18.91	2.4
Total	**781.79**	**100**

Data source: Coastal and Ocean Resources Inc., !994

Table 5. Coastal character distribution for the Gwaii Haanas

Coastal Type	Length (linear km)	% Occurrence
Bedrock	913	54.7
Mixed (bedrock and sediment)	376	22.5
Beach	281	16.8
Delta (fjord and open coast types)	100	6
Mud Flat	0	0
Man-modified	0	0
Total	**1670**	**100**

Data source: Worbets, 1979

Distribution of Shoreline Types:

Differences in bedrock geology and differences in Pleistocene glacial impact have yielded a complex shoreline. A number of generalizations, however, can be made which reveal the regions which are likely to be most significantly affected by rising sea levels and increased storm activity.

The Coastal Trough (figures 3 and 4), a geological formation which includes the Queen Charlotte, Hecate, Nahwitti, Nanaimo, Georgia and Fraser lowlands, is underlain by unconsolidated sediments and poorly resistant rocks -- a fact which explains the predominance of beaches and related features in this region (Clague, 1980). Coastal areas in this region that are sensitive to the effects of sea level and storm activity include: the Masset-Rose Point-Tlell triangle on Graham Island, an area characterized by wide, sandy beaches lying below 200 m in elevation; sedimentary bluffs along Virago Sound on the north end of Graham Island; sedimentary bluffs and beaches on the west coast of Porcher Island; the open coast Skeena River delta; the majority of the sand and gravel beaches in the Nanaimo and Georgia lowlands; and, the Fraser lowland, including both the open coast Fraser River delta area and the Point Grey beach-cliff system (Clague, 1980; Clague, 1989).

Areas not included in the Coastal Trough, notably portions of the west coast of Vancouver Island, are also expected to be significantly affected by appreciable sea-level rise and increased storm activity. These include: wide sand beaches (many of the "pocket" variety, protected on either end by headlands resistant to erosion) found discontinuously along the Estevan Coastal Plain; cobble-boulder beaches on south-western Vancouver Island, and mud flats north of Tofino at Browning Passage and Grice Bay; and small open coast deltas (Clague, 1989).

Sea-level change and storm activity are also likely to affect deltas found at fjord-heads both on the mainland and on western Vancouver Island. Examples of affected coastal areas include Alberni Inlet, Quatsino and Nootka Sound on Vancouver Island and well as Squamish Harbour and Kitimat Harbour on the mainland (Clague, 1989).

Finally, approximately 80% of British Columbia's population lives within the coastal zone and are responsible for creating an additional shoreline type, referred here to as "man-modified". Climate change is likely to have a considerable impact on human-altered coastlines typical of human settlements, industrial structures, and agricultural lands located on the coast. These include housing, road infrastructure, agricultural land, port facilities and flood protection installations (Clague,1989), the majority of which are located along the Lower Mainland coast and along the south end of Vancouver Island. A number of human activities occurring in the coastal zone can also be expected to be affected and will be discussed later.

Yukon

Shoreline Types and Distribution:

According to Lewis (1974), the short Yukon coastal zone has been shaped by erosion and redistribution of unconsolidated Yukon coastal plain sediments. Three generalized coastal forms may now be found:

- steep cliffs fronted by narrow beaches;
- sand and gravel beaches; and
- tundra.

The relative abundance of these types along the Yukon coast is indicated in table 6.

Cliffs extend from the Alaska-Yukon border to the mouth of the Backhouse River; around Herschel Island; intermittently from Whale Bay to the Mouth of the Sprint River; westward from Kay Point to Sabine Point, and intermittently again to the Yukon-Northwest Territories border (Worbets, 1979).

Table 6. Yukon coast characteristics

Coastal Type	Length (linear km)	% Occurrence
Cliff	114	33.3
Gravel	101	29.5
Man-modified	0	0
Sand	4	1.2
Tundra	123	36
Total	**342**	**100**

Figure 3 Major coastal environments of the Hecate Depression and Northern Coast Mountains (after Clague and Bornhold, 1980).

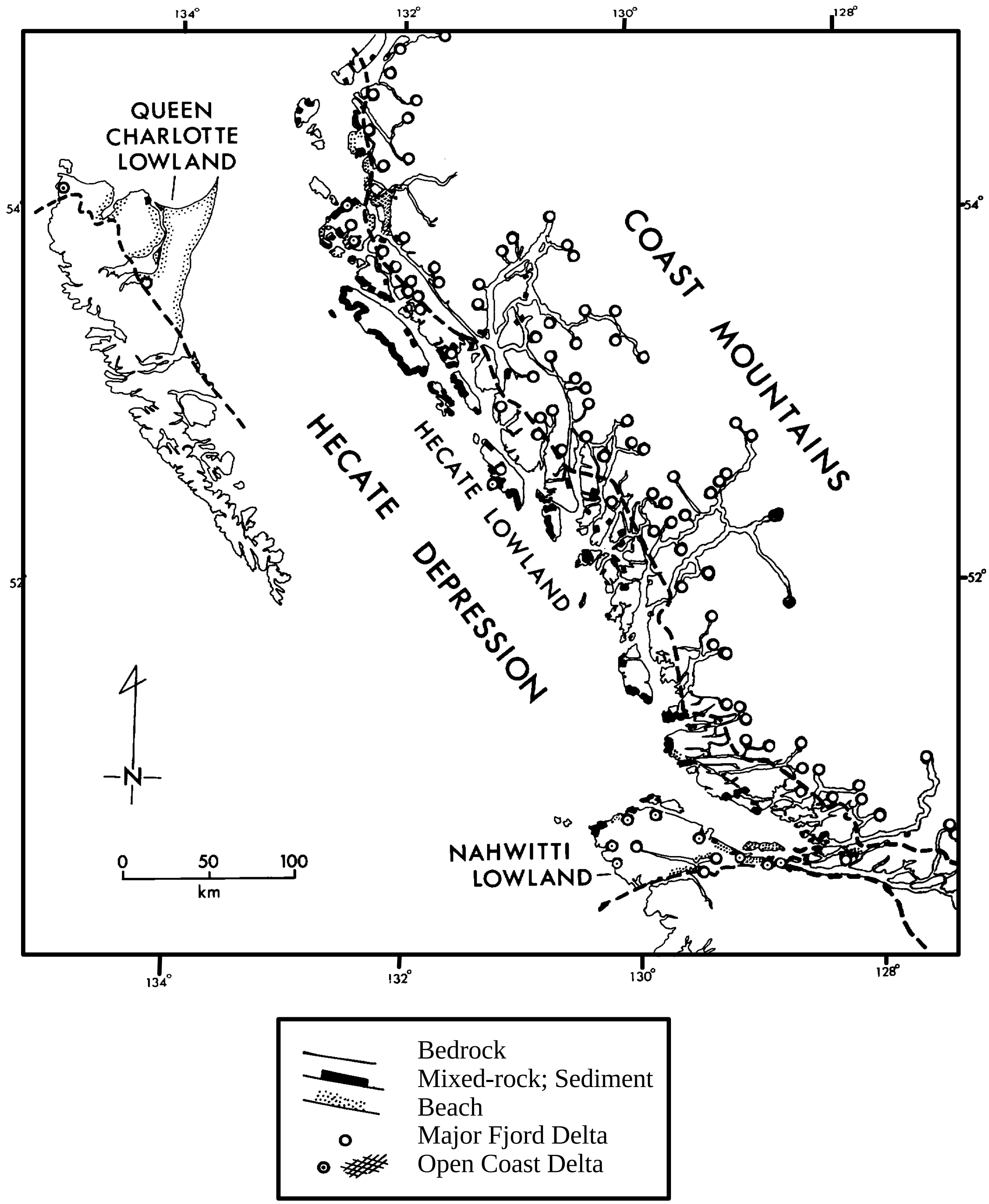
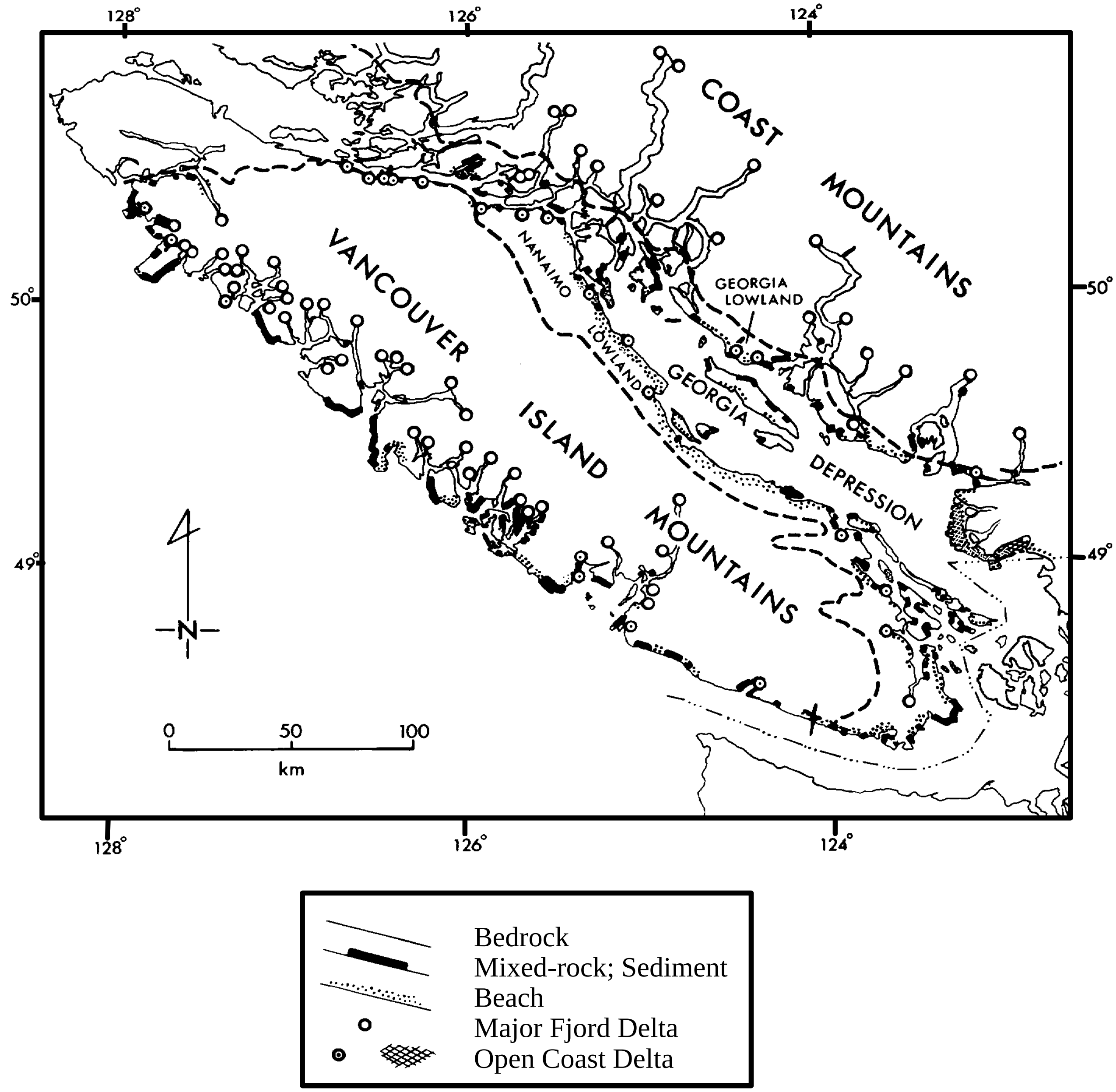


Figure 4 Major coastal environments of the southern Insular and Coast Mountains and the Georgia Depression (after Clague and Bornhold, 1980).



Beaches run the entire length of the Nunaluk Spit (which serves as a barrier to the tundra coastline behind it); along the Avadlek Spit which extends south from the west corner of Herschel Island; along Pauline Cove on Herschel Island; and intermittently from the tip of Kay Point to the Yukon-Northwest Territories border (Worbets, 1979).

Tundra lines the shore at the seaward limit of the wide Malcolm and Firth river deltas, Workboat Passage and Ptarmigan Bay (the region currently protected by Nunaluk Spit and Herschel Island), from Niakolik Point to Kay Point (a region encompassing the Babbage River delta), and around the mouths of most smaller river systems (Worbets, 1979).

Critical to an understanding of the way in which the Yukon shoreline will perform under enhanced greenhouse conditions is an understanding that the coast and many offshore areas are characterized by continuous permafrost (Lewellen, 1970). Permafrost, or ice-bonded sediments, are defined as any “naturally occurring earth material whose temperature is below 0ºC for several years regardless of the state of any moisture that may be present” (Lachenbruch, 1968). This permanently frozen layer is expected to thaw, in part or in whole, as a result of climate change (Lewis, 1974), making it less resistant to erosion and weathering. Thus, all shoreline features along the Yukon coast are vulnerable to the effects of sea-level rise.

No permanent human settlements are located along the Yukon coast. Industry, however, is heavily dependent upon the coastal zone, as are native communities.

EFFECTS OF SEA-LEVEL RISE AND STORM ACTIVITY ON COASTS AND COASTAL ECOSYSTEMS

Shoreline Effects

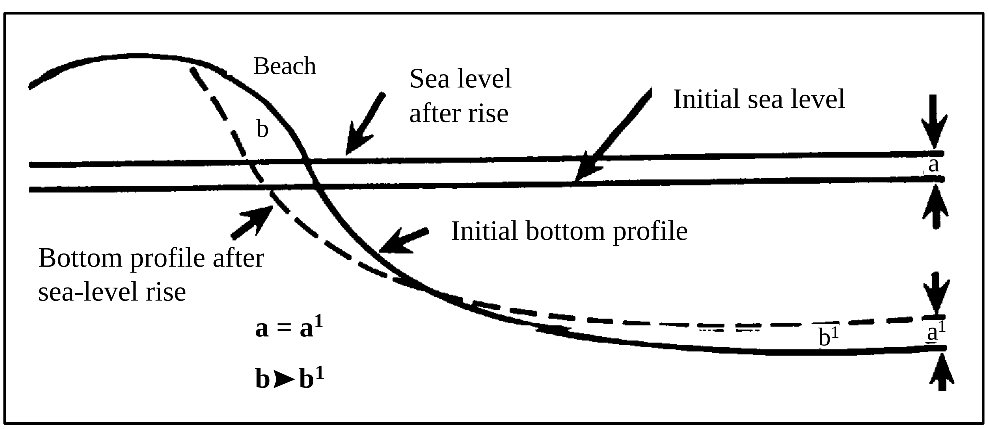
As mentioned in Dunn (1988), climate change will have three principal effects on coastal areas: erosion and/or sedimentation; coastal flooding; and, permanent inundation of low gradient, intertidal areas. What follows is a discussion of the effects these changes will have on the various British Columbia and Yukon shoreline types.

British Columbia: Sedimentary Coasts and Beaches

According to Bird (1987), a higher sea level and increased storm intensity can be expected to cause beach accretion to slow and beach erosion to increase. Several mechanisms will be responsible for these changes.

First, higher waterlines will necessitate a change in beach profile. According to what is now referred to as the “Bruun rule” (figure 5), for each rise in sea level, the offshore bottom will rise an equivalent amount to prevent the beach profile from over-steepening (Bardach, 1989).

Figure 5. The Bruun Rule indicates that sea level rise will cause beach erosion: if sea level rises by one foot, on-shore sediments will be eroded and displaced to the offshore bottom which will also rise by one foot to prevent beach over-steepening (graph after Bardach, 1989).



On the basis of the Bruun rule, Titus (1987) has predicted that, though actual amounts will depend heavily on individual beach profiles and wave regimes, a 30 cm rise in sea level is likely to cause an average of approximately 30 metres of erosion along most U.S. beaches. As this 30 cm simulation is well within the range predicted for portions of the British Columbia coast, it is reasonable to assume that beaches in British Columbia will experience similar beach erosion.

As well, landward beach migration will be exacerbated by wave action and log debris, as higher water levels and larger seasonal sea level variations allow them to attack backshore areas more frequently and with greater intensity (Dunn, 1988). Backshore cliffs will retreat as a result and the integrity of coastal structures may also be affected.

British Columbia: Deltas, Estuaries, and Estuarine Wetlands

Deltas are highly dynamic systems and represent the achievement of equilibrium between the accumulation of upland sediments at river mouths and the removal of those sediments by wave, tide and current action. As a result, deltas are likely to be strongly affected by sea-level rise and increased precipitation. Recent reports from the IPCC (1995) indicate that rising sea levels will have two major effects on low-lying deltas and unvegetated tidal flats: increased submergence, especially where sedimentation cannot keep pace; and, more extensive and more rapid erosion.

Increased winter precipitation causing increased upland erosion (Environment Canada, 1991), increased upland flooding associated with more frequent winter storm and surge events, and increased river flow due to glacial melt may result in sufficient sedimentation to offset coastal erosion and submergence.

GCM modeling work done on the Wilson Creek basin in Manitoba has shown a range of potential run-off effects associated with climate change: the basin can expect anywhere from a 83% increase to a 11% *de*crease in mean annual run-off (Zaltsberg, 1990). No similar studies have occurred for watersheds in British Columbia. Insufficient data are thus currently available to allow a conclusive statement to be made regarding the net effect of climate change on most portions of the British Columbia and Yukon coasts. Given that most rivers on Vancouver Island are currently stable (i.e. not actively prograding) and do not receive glacial inputs, it is however, probable that deltas associated with these particular rivers will not keep pace with expected sea-level rise. Should sedimentation increase, biological communities at river mouths can be expected to be affected (see discussion below on ecological effects).

Similar uncertainty, due to a paucity of data, surrounds the effect of climate change on deltaic geomorphology. According to the IPCC, some authors feel that active delta channels will widen and deepen, enhancing their role as a sediment sinks and increasing erosion in adjacent coastal areas. Field work in Britain has revealed sediment distribution leading to wider and shallower channels (Pethick; 1993). Work in Australia shows channel widening, increased sedimentation, and steady vertical accumulation, changes which would allow deltas to keep pace with sea-level rise but which might endanger backwater swamps (Chappell and Woodroffe, 1994).

In all cases, authors agree, however, that geomorphological changes are not likely to prevent saline water from penetrating further upstream with concomitant changes in community structure. An increased potential for groundwater contamination also exists (IPCC, 1992).

A great deal more information exists regarding the effects of sea-level rise and storms on coastal wetlands, given the high levels of species diversity associated with them. Much of the work, however, has been done on wetlands in warm-temperate regions[5], limiting the applicability of data to the British Columbia coast. Nevertheless, several conclusions may be drawn. Recent work on wetlands has shown that salt marshes can adapt to sea-level rise provided that a number of conditions are met: sedimentation and internal biomass production must keep up; and, the entire marsh must have the potential to move to higher ground or farther inland.

While predictions regarding sedimentation rates cannot be made with any accuracy, as indicated above, a study (Pethick, 1993) along the southeast coast of England where, due to subsidence, sea level is already rising at a rate of 4-5 mm/yr, has shown that salt marshes are capable of migrating inland but that their continued progress is impeded by man-

[5] British Columbia is considered to be a "cool temperate" region.

made flood embankments. This process, in which seaward wetland edges are lost and compensating landward growth is hindered, is referred to as "coastal squeeze" (IPCC, 1992). Unless barriers to wetland migration are removed, significant shrinkage and eventual disappearance of wetlands along Squamish, Nanaimo, and Fraser Rivers (each of which has an extensive dyking system) is highly likely.

Even if significant barriers to wetland migration are removed, Reid and Trexler (1996) indicate that little wetland formation is likely to take place at rates of sea-level rise greater than 10 mm/yr, a rate only slightly above the predicted rate for portions of the BC and Yukon coasts.

The ultimate fate of coastal wetlands will also be affected by the presence or absence of large interior marsh ponds[6]. Vellinga and Leatherman (1989) predict that sea-level rise will cause these shallow ponds to form, enlarge, and/or coalesce within wetlands themselves, to the detriment of marsh vegetation.

An increase in the return rate of extreme storm events is also expected to have a significant impact on wetlands. According to Vellinga and Leatherman (1989), a 50 cm rise in sea level would "make a storm with a frequency-magnitude of 75 years have the flooding effect of a 100-year event in terms of surge level and landward penetration" (p. 182). An increase in extreme event frequency would thus replace the cyclical expansion and contraction of the seaward boundaries of wetlands (IPCC, 1992) with progressive erosion (IPCC, 1992), exacerbating the impact of simple sea-level rise.

Vellinga and Leatherman (1989) have concluded that a 1 m rise in sea level (slightly above the high-end predictions for portions of the BC coast) could result in a loss of 50-80 percent of U.S. wetlands, a figure they believe to be generally indicative of global losses. Work by Trexler and Reid (1996) yields a somewhat more conservative estimate: "over the range of plausible estimates for sea-level rise by the year 2100 (0.5 to 2 m), some 15 to 70 percent of the remaining coastal wetlands on the East and Gulf Coasts of the United States could be eliminated" (p. 27).

Yukon Coast

Sea-level rise and a shortened return period of extreme events along the Yukon coast are likely to cause erosion, flooding and inundation through the mechanisms mentioned above. Several additional factors associated with climate change may also affect the Yukon coast.

Notably, warming trends will be greater than the predicted global average in higher latitudes (Bardach, 1989) with winter increases being larger than those in summer. Climate models have predicted temperature rises along the Yukon coast of 2ºC to 4ºC during the summer and 2ºC to 12ºC temperature rise during the winter (Environment Canada, 1991). This warming will have numerous ice effects in the Beaufort Sea region and coastal permafrost can be expected to thaw (Bardach, 1989).

Specifically, a 35% decrease in winter ice thickness (currently averaging 2.5 metres) is predicted, along with significant northward retreat of the southern limit of sea-ice and complete absence of summer sea ice among the Arctic Islands (Maxwell and Barrie, 1989). In places where seasonal ice remains, earlier thaw and later freeze-up are predicted: climate work in Hudson Bay (Etkin, 1991) has shown that a 1ºC rise in temperature advances winter ice breakup by 4 to 14 days and similar results are likely for the Beaufort Sea.

Decreased period and extent of sea-ice cover will result in larger ocean fetches and greater wave attack on the coastal zone (Lewis, 1974), with attendant erosion. Recent modeling work has suggested that, based on projected increases in fetch alone, wave energy during the open water season may increase wave heights by 16% to 40% (McGillivray, et al, 1992).

More frequent summer storms may exacerbate the above effects (see footnote 4). Winter storms, however, may actually reduce erosion by driving pack ice on shore where it can cushion the coast from wave attack (Lewellen, 1970).

Rates of thermal erosion[7] can also be expected to increase with increased air temperatures. The Alaska and Yukon coasts already experience significant erosion during the

[6] "Interior marsh ponds" are areas of open water that form behind the seaward marsh-grass limit.

[7] "Thermal erosion" is the erosion of permafrost resulting from increased air and water temperatures.

Figure 6. Yukon/Beaufort Sea coast showing possible erosional patterns associated with sea-level rise.

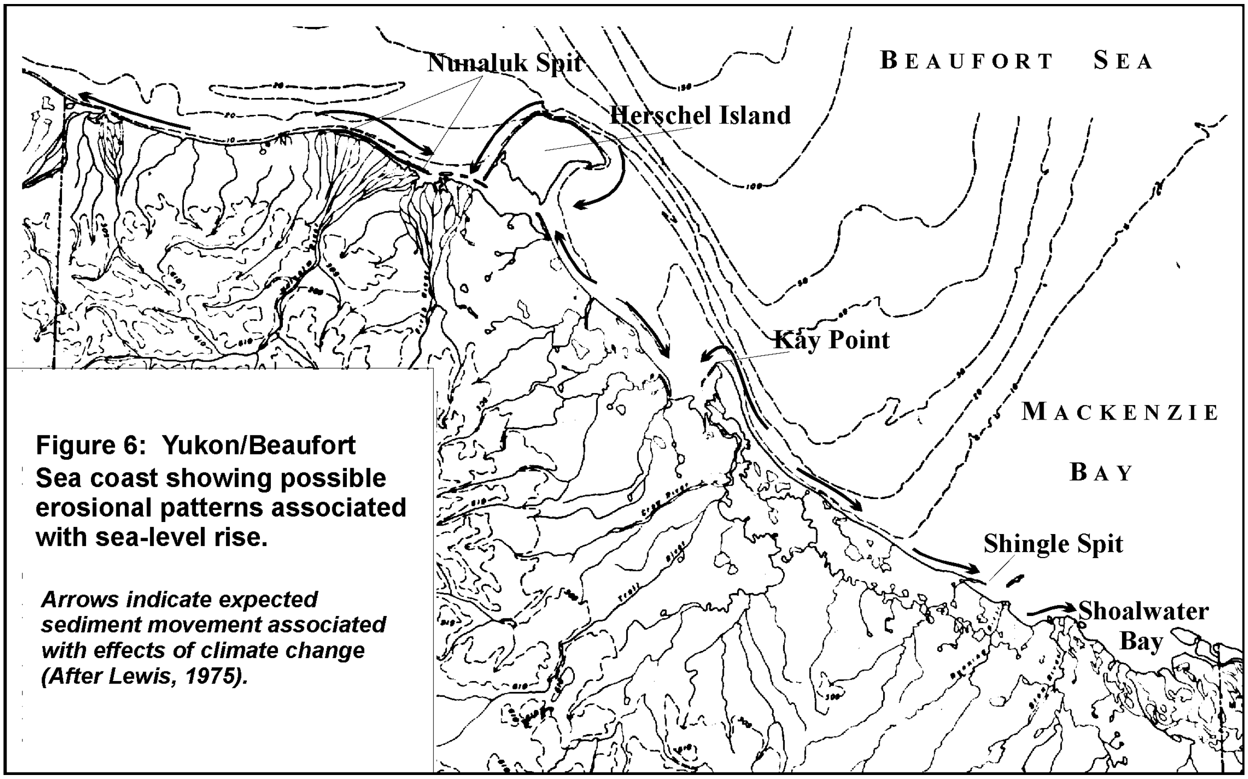


Figure 6: Yukon/Beaufort Sea coast showing possible erosional patterns associated with sea-level rise.

Arrows indicate expected sediment movement associated with effects of climate change (After Lewis, 1975).

annual thaw. According to Lewellen (1970), erosion rates in the mid-1960s and early-1970 ranged from "a few decimetres" to as much as 10 metres per year. Maximum erosion occurred in those areas where permafrost contained considerable pore, wedge or massive ice (Lewis, 1974) or where the permafrost shoreline was exposed to the sea (Lewellen, 1970). Warming is also expected to deepen the "active layer"[8] inland which may cause increased slope movement due to ice wedge and pingo melt, soil creep, soil relaxation, mud flows, and slumping (Maxwell and Barrie, 1989).

Additional precipitation in high latitudes associated with climate change may increase spring runoff and flooding (Maxwell and Barrie, 1989). Whether permafrost melts inland, coupled with this increased runoff, will lead to sufficient additional sedimentation to offset the expected coastal erosion is not known. Importantly, however, this increased runoff may offset the loss of sea-ice associated with warming. Mysak and Power (1992) have shown that years of high run-off correlate positively (following a lag of at least one year) with ice extent on the Beaufort Sea shelf due to reduced regional salinity.

Although, as noted above, sedimentation may increase, the final resting place of newly-eroded sediment cannot be determined with any great accuracy. General predictions may be made by extrapolating from work (figure 6) done by Lewis (1974). Sediments eroded from the seaward side of Herschel Island may be redistributed to the landward end of the island, causing tombolos[9] and/or a shallow lagoon; sediment transport eastward along the Malcolm and Firth River deltas may enhance spit and tombolo formation, providing some coastal protection against further erosion. A similar process may be expected to occur near Kay Point and may be responsible for the formation of a lagoon at the mouth of the Crow River in what

[8] The active layer is the seasonally thawed layer sitting on top of the permanently frozen ground.

[9] "Tombolos" are accretional landforms connecting islands to the mainland.

is now Phillips Bay. Alternatively, erosion along the back of Kay Point may eventually cut through the Point, redirecting the outflow of the Crow River. Shingle Point may elongate substantially and Shoalwater Bay may receive additional sediment loadings.

Ecological Effects

Given the uncertainties associated with net changes in sea-level rise and storm activity along the Pacific and Arctic coasts and the effect that these changes may have on coastal processes and morphology, it is very difficult to predict with any degree of certainty the exact effects of climate change on species and biological processes along the BC and Yukon coasts. A number of authors, however, have begun to explore this murky area. Preliminary findings and predictions appropriate to the Pacific and Yukon region are listed below.

General Effects: Biodiversity

In general, the ecology of coastal systems is considered to be poorly understood. A number of statistics, however, attest to the important contribution these systems makes to global biodiversity. Ray (1991), estimates that 60% of global macroscopic phyla are marine and of these, roughly 80% occur in coastal regions -- regions which occupy just 8% of the Earth's surface. Based on these figures, Ray argues that the coastal zone is *the* most biologically diverse region on Earth (Ray, 1991 -- emphasis added). The Georgia Depression ecoprovince, which includes the Fraser River delta, supports the highest diversity of birds found anywhere in British Columbia: 90% of all species known to occur in the province -- 163 passerine and 239 non-passerine species -- are found within the Georgia depression; fully 60% of the species known to breed in British Columbia breed in this region (Campbell, *et al.*, 1990). A significant proportion of these birds (non-passerines in particular) are associated with nearshore and/or coastal ecosystems.
Figure 6.

Reid and Miller (1989) have argued that sea-level rise and increased storm event frequency could have significant effects on this coastal richness. These effects include changes in population sizes, species distribution, species composition, and in geographical extent of habitats and ecosystems, all of which could increase the rate of species extinction.

In their study on the effects of climate change on U.S. wetlands, Reid and Trexler (1996) concur with this assessment, arguing that regional shoreline changes can be expected to increase rates of species extirpation[10] and extinction. They base these conclusions on numbers of imperiled coastal species in the United States found within 1.5 to 3 metres of sea level (table 7[11]).

Given the amplification of warming effects in winter in the Arctic, a number of studies have recently been undertaken which explore the specific impacts of ice-regime changes on Arctic biodiversity. Increased snow depth associated with increased precipitation "may pose problems for current foraging and nesting patterns, with resultant alterations in the locations of traditional wildlife habitats" (Maxwell and Barrie, 1989, p. 47).

Specific Effects: Plant Species/Plant Communities

In areas where wetland retreat cannot keep pace with sea-level rise, periodic flooding and/or permanent inundation is expected to cause water logging and soil chemical change in coastal wetlands. Resultant changes in wetland flora include: altered spatial distribution of marsh plant species, an increase in salt tolerant species and concomitant decrease in freshwater species; and, a net decrease in plant species diversity at the leading edge of many wetlands (Latham, *et al.*, 1991).

As mentioned above, higher sea levels can also be expected to cause pooling to occur within wetlands which will drown marsh vegetation and thus contribute to wetland loss.

Seagrass beds, which play an important role in delta stabilization and which serve as spawning, nursery, and refuge areas for a number of fish and shellfish species, are also expected to be affected by climate change.

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10 "Extirpation" refers to loss of a species from a portion of its current range.

11 In table 7, the figures for the Oregon coast are likely to be most representative of the British Columbia coast. Comparable figures for Arctic regions are not available.

Table 7. Coastal species in the United States classified federally as "threatened" or "endangered", or classified by states as "rare" (after Reid and Trexler, 1996).

Region	Birds	Mammals	Reptiles/ Amphibians	Fish	Plants	Total
I. Federally Listed Species Found within 10 feet of Sea Level						
Oregon	**4 (2)**	**0**	**0**	**0**	**(2)**	**4 (4)**
Massachusetts	0	0	0	0	0	0
Maryland	2	1^{1}	0	0	1 (12)	4 (12)
North Carolina	1	0	1	0	(7)	2(7)
Florida	8^{2} (52)	8^{7} (9^{7})	9 (9^{3})	1 (2^{1})	12^{1} (83^{14})	38 (108)
II. Rare Species Restricted to within 5 feet of Sea Level						
Oregon	**0**	**0**	**0**	**0**	**0**	**0**
Massachusetts	11	0	0	0	9^{1}	20
Maryland	11	0	0	0	38	49
North Carolina	0	0	1	0	10	11
Florida	19^{3}	11^{9}	11^{4}	2^{1}	27^{4}	70
III. Rare Species Found within 10 feet of Sea Level						
Oregon	**7^{1}**	**0**	**1**	**0**	**8**	**16**
Massachusetts	17	1	1	1	22^{1}	42
Maryland	16	1^{1}	2	1	102^{2}	122
North Carolina	1	0	1	0	19	21
Florida	35^{8}	19^{15}	30^{14}	9^{1}	167^{18}	258

Notes to table: In sections II and II, total numbers refer to species determined by The U.S. Nature Conservancy to be "critically imperiled", "imperiled", or "rare or uncommon". Species may be listed in a given state but be abundant in other U.S. states. Parentheses indicate candidate species. Superscripts indicate the number of subspecies or varieties included in the total. Figures in bold are thought to be most representative of the BC situation.

While temperate eelgrasses (*Zostera spp.*) tolerate a wide range of temperatures and salinities (Phillips, 1984), there is evidence that increased water turbidity, associated with extreme event wave action, increased precipitation, and increased meltwater runoff, will have negative effects on eelgrasses. Specifically, increased sedimentation can bury plants and can reduce water clarity. The latter effect has been shown to reduce eelgrass plant densities which may have the feedback effect of reducing sediment trapping, increasing erosion of bottom sediments, and producing further turbidity (Phillips, 1984).

Zostera spp. have shown the ability to migrate landward, with light-limited losses in deeper water associated with sea-level rise being offset by expansion in shallower water. In particular, *Zostera japonica*, a species believed to have been introduced to the west coast of North America with oysters prior to 1950, has shown a strong ability to colonize formerly unvegetated tidal flats from Oregon to the southern Strait of Georgia (Baldwin and Lovvorn, 1994a). As will be indicated below, this has benefited a number of migratory bird species. Nevertheless, the benefit has occurred at the expense of unvegetated tidal flats which are valuable to a number of other bird species. This loss of tidal flats may be exacerbated by climate change: work in the United Kingdom indicates that "a sea-level rise of 0.8m could lead to the loss of the present upper marsh by reversion to lower marsh and a reduction of at least 20% in the area of mud flats..." (Rose and Hurst, 1992). Given the phenomenon of coastal squeeze, tidal flat losses may be even greater in vulnerable areas of British Columbia.

Detailed work on the effects of climate change on entire plant communities is sketchy. Reid and Trexler (1996) have noted, however, that as might be expected, a range of possibilities exists. Presently robust plant communities (those relatively undisturbed by human activities) which have few rare or threatened species restricted to within 3 metres of sea level are expected to fare better in the face of rising sea levels than are those areas that have been compromised by human activity and/or have numerous rare species restricted to within 3 metres of sea level.

Work on marine algal species in the Arctic indicates that ice algae, sometimes referred to as "inverted benthos" (Rose and Hurst, 1992) plays an important role in sustaining the marine food web prior to the formation of significant open water algal blooms in spring. These algae, which are fed upon by a number of amphipod species, are thought to derive inorganic nutrients from sea water within the ice and may experience increased productivity as a result of light funneled to them through the ice (Rose and Hurst, 1992). It is thought that the loss of sea ice associated with climate change would reduce the early nutrient availability represented by sea-ice which, in turn, would delay the onset of the Arctic's biological spring.

Specific Effects: Sessile animal species

Relatively little work is available which explores the effects of sea-level rise and increased storm activity on sessile marine species. While one study (Scarlato, 1977) has shown that bivalves in the northwest Pacific are capable of spawning across a wide range of temperatures, suggesting an ability to respond well to climate change, few other studies are available. Despite the paucity of data, it is reasonably safe to postulate that species in intertidal and subtidal regions will respond differently to changes in water depth, length of inundation, salinity, temperature, presence of predator species and other limiting factors. This may lead to significant restructuring of communities in the various intertidal habitats or zones as the ranges and abundance of species change.

Specific Effects: Motile, non-commercial[12] animal species

A great deal of research has been done on the effects of sea-level rise and storm activity on commercial species, the results of which can generally be applied to non-commercial fish species. Two effects are of particular relevance: first, increases in precipitation will wash increased amounts of organic material through watersheds and into estuarine areas. Oxygen depletion caused by the decomposition of this material may cause large-scale fish die-offs (Reid and Trexler, 1996) and/or may affect survival rates of anadromous species (Environment Canada, 1991). Secondly, the loss of habitat critical to certain fish and shellfish life-cycle stages may reduce estuarine productivity. Anecdotal evidence from Australia reveals an 80%

[12] Another paper in this series looks specifically at the impact of climate change on significant commercial species in British Columbia.

decrease in a whiting fishery following loss of seagrass beds in a nearby bay (Reid and Trexler, 1996).

Changes in fish, shellfish and crustacean populations can also be expected to have a profound effect on predator species, especially marine mammals (cetaceans and pinnipeds), along both the Yukon and the British Columbia coasts.

In the Arctic, later freeze-up and earlier melt could also have significant negative effects on numerous marine species, including marine mammals. Key species like arctic cod which depend on ice-algae and amphipod communities (Rose and Hurst, 1992) may decrease in numbers, affecting their predator species. Several seal species live, breed, and whelp almost exclusively at the ice edge, walrus and polar bear rely heavily on ice as a means of transportation and polar bear rely on ice floes as a platform for hunting (Rose and Hurst, 1992). Life-cycle stages dependent on the presence of sea- and land-fast ice may be significantly disrupted.

Specific Effects: Sea- and Shore-birds

The effects of climate change on sea level can be expected to have an number of effects on bird species using the British Columbia's coastal zone. In the period since its introduction, the leaves, rhizomes, and seeds of *Zostera japonica* have become an important, sometimes preferred, food source for many migratory waterfowl species (Baldwin and Lovvorn, 1994a). The expected expansion of introduced eelgrass into the unvegetated upper intertidal zone in response to sea level rise is likely to benefit those species that feed on eelgrass or on animals associated with eelgrass beds (e.g.: brant, *Branta bernicla*; great blue heron, *Ardea herodias*); eelgrass expansion is expected to have a negative impact on species that depend on infaunal and epifaunal invertebrates found in the unvegetated intertidal zone (e.g.: western sandpiper, *Calidris mauri*) (B. Elner, personal communication).

Sea level rise itself may also affect waterfowl foraging strategies. For instance, dabbling ducks have been shown to be able to reach sediments at a maximum water depth of 20 cm; grazers have been shown to reach floating leaves at depths of up to 0.5m (Baldwin and Lovvorn, 1994b). Higher water levels associated with increased frequency of extreme events and in the lag period between absolute sea-level rise and upper tidal zone colonization by *Zostera japonica* will increase the need for waterfowl to find alternate foraging areas. This is not necessarily a problem in itself: a number of waterfowl species are opportunistic feeders, demonstrating a strong ability to adapt to new food sources as they become available. In particular, farmland in the Puget Sound and Fraser River delta regions now provides a significant, and sometimes critical, alternate food source for migratory species, even when ample food is available in the intertidal region (Lovvorn and Baldwin, 1996; Boyd, 1995). What is not clear at this point, is whether or not the low-lying agricultural areas will continue to be productive as sea level increases, particularly in light of the potential for salt water intrusion into these areas.

Food sources for sea birds may also be affected: increased water turbidity may both reduce fish stocks and make it more difficult for species like terns, mergansers and cormorants to catch the remaining fish (Rose and Hurst, 1992).

Several studies have also indicated that sea-level rise can be expected to have an effect on bird reproduction along both the British Columbia and Yukon coasts. Waders, terns and waterfowl nest in areas susceptible to flooding on high spring tides. With more frequent extreme events, these species can expect significant increases in nest loss (Rose and Hurst, 1992).

Temperature changes associated with climate change may also affect bird reproduction. In the Arctic, abnormally cool and exceptionally warm springs have been correlated with significant reproductive failures in black-legged kittiwakes. The suspected cause is the relative date of ice break-up and the availability of prey species (Rose and Hurst, 1992). Climate change, and the resulting change to onset of spring, may thus leading to more frequent reproductive failures among migratory species along the Yukon coast.

Permafrost melt and subsequent land slumps may also "cause serious harm to shorebirds and geese, at least in the short term, because the first areas affected [will be] the wet meadows that are their most important feeding sites" (Rose and Hurst, 1992, p. 31).

Specific Effects: Human Activities and the Built Environment

As noted earlier in this paper, 80% of British Columbia's population lives on or near the coast, with the majority living in just two centres: the Capital Regional District and the Greater Vancouver Regional District. Sea-level rise and increased storm activity will have a number of effects on both the built environment and on activities currently taking place in the coastal zone.

According to Clague (1989), a sea-level rise of “a few tens of centimetres” will result in flooding of some waterfront homes and port facilities during severe storms, especially in winter. Upgrading existing dykes and building new ones to protect residents of Richmond (elevation: <4 m) can be expected to cost hundreds of millions of dollars and encroach on habitat, in those places where upgrading remains possible[13]. Furthermore, sea-level rise will raise groundwater levels in low-lying areas, forcing additional expenditures on pumping. Much of Langley Township and the rest of the Fraser Valley east to Hope, as well as many areas outside of major population centres, rely on ground- and well-water: these regions may face salt-water intrusion and salinization of drinking water. Finally, increased salinization due to groundwater contamination associated with sea-level rise may be expected to reduce the productivity of agricultural lands in low-lying areas. Potential groundwater contamination may also place stress on surface drinking-water supplies.

Increased precipitation causing increased runoff is also likely to put greater stress on water and sewage systems. Present systems are likely not designed to handle increased precipitation. This will require treatment facilities to be by-passed more frequently, leading to more numerous releases of raw sewage to the marine environment, greater stress on the marine environment, and increased danger to human health.

A number of recreational activities reliant on the coastal zone are also likely to be affected. Wetland losses in the 24 year period between 1954 and 1974 have been estimated to have cost the United States fishing industry US$208 million annually. Coastal recreation in a warmer world can be expected to increase at the same time as total beach area decreases. This will result either in significant unrealized gains and realized losses to the tourism industry or in significant expenditures on beach nourishment. While foregone profits (“unrealized gains”) have not yet been quantified, Dutch estimates indicate that maintaining the existing shoreline along 100 km of sandy beaches in response to a 1 m sea-level rise (again, above the high-end predictions for British Columbia and the Yukon) would require 160 to 330 million m^3 of sand at a total cost of US$0.7 to 1.3 billion (Vellinga and Leatherman, 1989). Beaches in the city of Vancouver and along the west coast of Vancouver Island will be of particular concern.

Construction costs associated with sea-level rise are also expected to increase. A study on recreational properties in the Great Lakes showed that breakwater construction and/or maintenance and dock repair costs associated with high-water events ranged from $100 to $100,000 over a one to ten year period; floating dock construction costs ranged from $3,000 to $200,000 (Bergmann-Baker*, et al.,*1995). Given the strength of increased storm events on the Pacific and Arctic coasts, these costs are likely to reflect minimum costs associated with rising sea level in these regions.

Traditional subsistence hunting and fishing in the Yukon region may be adversely affected as access to coastal regions over thawing permafrost is made more difficult and as certain target species composition and distribution changes. Furthermore, Inuit use of land-fast ice as a winter transportation corridor and hunting area can be expected to be adversely affected.

The shipping industry, however, can be expected to benefit from sea-level rise. In the Arctic, a longer ice-free season is likely to make the Northwest Passage a viable economic alternative for ships transiting from northern Europe to Japan (Bardach, 1989). This, however, will increase the risk of cargo losses and commodity spills (including oil spills) in the Beaufort Sea region and elsewhere.

Petroleum exploration and exploitation, particularly in the Beaufort Sea, is likely to be facilitated given a longer ice-free season and sea-bed permafrost melt[14].

[13] In some cases, dykes are already at their maximum size and weight for the carrying capacity of the surrounding terrain (B. Shattock, personal communication).

[14] This, ironically, would open the door to further fossil fuel use and further climate change.

OTHER EFFECTS OF CLIMATE CHANGE ON COASTAL SYSTEMS

In addition to sea-level rise and increased frequency of severe storm effects, a number of other climate change effects have been postulated as outlined below.

Increased water temperature

According to the IPCC (1992), a doubling of carbon dioxide from pre-industrial levels will result in a change in sea surface temperature of 1.5ºC to 4.5ºC. As with air temperature changes, changes to sea temperature will be more pronounced in higher latitudes, reducing the temperature differential between polar and equatorial regions. Preliminary studies along the coast of British Columbia using 80 year data sets for sea-surface temperature indicate a warming trend, the cause of which has not been conclusively determined (Freeland, 1990). An increase in sea temperature is expected to have the following effects:

- a poleward shift of sub-equatorial water masses and their resident biota. As a result, temperate and sub-arctic marine communities will face increased competition from migrating subtropical species (Fields, *et al*., 1993; Clark, 1993). This is likely to cause the range of northern estuarine species to contract (figure 7). During the 1982-83 ENSO event which raised sea temperatures by 2ºC, "13 subtropical motile species were found significantly farther north than their previously recorded range and 18 species of invertebrates and 38 species of vertebrates were reported to have increased in abundance in the northern parts of their range during this time" (Fields,*et al*., 1993, p. 363).

- lower viscosity. Viscosity affects numerous biological processes, determining everything from the energy bivalves expend while filter-feeding to the efficiency of predatory activities. The effects of a change in dynamic viscosity on these processes is presently unknown (Clark, 1993).

- decreased oxygen solubility. This is likely to place stress on species with low erythrocyte counts adapted for cold water regimes (Clark, 1993).

- increased carbonate solubility (Clarke, 1993). Using the same energy output, increased carbonate solubility may allow bivalves to develop thicker, better calcified shells with unknown effects on predator species.

- changes to marine species' physiology. Although precise effects are not yet known, Clark (1993) notes the importance that temperature plays in determining ionization, protein structure, diffusion, and reaction rates. In ectothermic[15] species, a change in water temperature could have significant impacts on these physiological processes.

- changes in species abundance and biomass*.* Longer growing seasons, lower natural mortality and faster growth rates can be expected to increase species biomass (IPCC, 1992). These benefits may be offset by changes to migratory patterns, reproductive cues and patterns, and ecosystem relationships (IPCC, 1992). The IPCC notes, in particular, that "rapid changes due to physical forcing will usually favour production of smaller, low-priced, opportunistic species

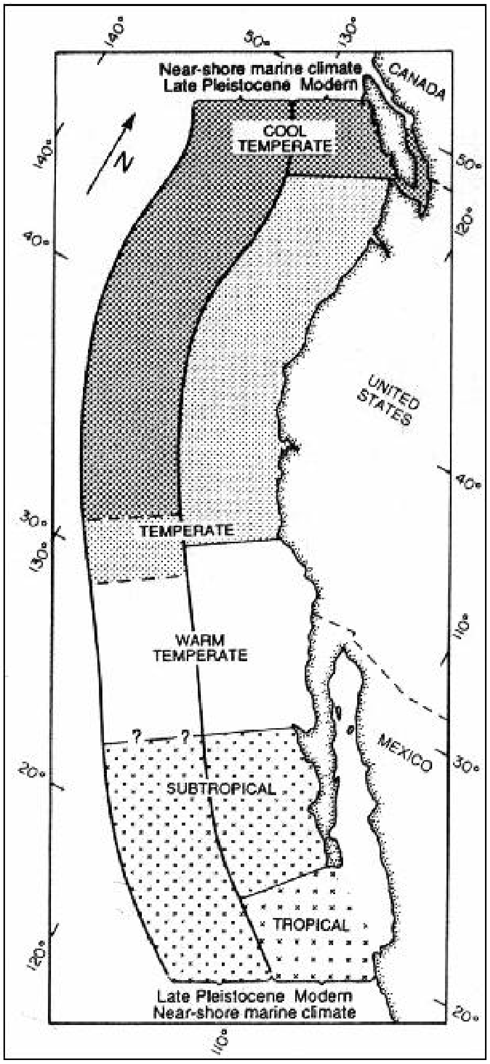
- that discharge large numbers of eggs over long periods.

- decreased economic value, at least during the period when ecosystems are adapting to new equilibrium temperatures (IPCC, 1992).

As can be seen from the brief discussion above, changes in water temperature associated with climate change may have an overall greater impact on marine ecosystems.

[15] "Ectothermic" or "cold-blooded" species are those that have little ability to regulate their own internal temperature and thus have internal temperatures close to that of surrounding waters.

Figure 7. Position of biogeographic provinces on the west coast of North America currently and during the upper Pleistocene (a period in which global temperatures were 2 to 4 degrees cooler than present). From Fields, et al., 1993.



CHANGES IN OCEAN CIRCULATION PATTERNS

Changes to upwelling patterns

Some controversy surrounds the effects of climate change on upwelling patterns and hence on biological productivity in the coastal zone.[16] Based on glacial and inter-glacial records, Fields, *et al.* (1993), suggest that the decrease in the latitudinal temperature gradient will reduce wind stress which, in turn, will diminish upwelling. Other authors (e.g.: Bakun, 1990), however, have argued that increased longshore winds associated with more frequent and intense storm activity will increase coastal upwelling, resulting in increased biological productivity.

As noted earlier, increased frequency of events similar to the El Niño/Southern Oscillation (ENSO) event could also reduce upwelling and biological productivity along the west coast of North America. According to Fields, *et al*. (1993), the 1982-83 ENSO event reduced nutrient availability, causing a significant decline in primary productivity. Zooplankton biomass "was lower in 1982-83 than during any previous recorded year off California; reduced zooplankton stocks were also recorded as far north as British Columbia (Fields, *et al.*, 1993, p. 363).

Enhanced seasonal sea level differentials

British Columbia presently experiences predictable seasonal variation in beach profiles: a summer accretion phase is followed by a winter erosion phase (Harper, 1980). This trend is most pronounced for high energy beaches like those found on the west coast of Vancouver Island, and is least consistent for low energy beaches like those found on the south eastern coast of Vancouver Island. Thomson and Crawford (1997) suggest that changes to the Aleutian Low and the North Pacific High are likely to enhance this inter-seasonal variation along both the Yukon and British Columbia coasts: winter sea levels are likely to be up to 20 cm higher and summer sea-levels are likely to be up to 20 cm lower.

With a larger increase in winter sea-level, shoreline erosion is likely to increase. It is not clear whether sediments will be replaced by longshore transport of larger sediment volumes associated with increased winter precipitation and spring run-off and/or by larger summer decreases in sea level.

16 "Upwelling" is the process by which deep, cold, nutrient-laden water is pulled to the sea-surface, usually by diverging currents or by coastal currents that draw water away from the coast. The nutrients (organic and inorganic compounds, usually containing phosphorus and nitrogen) are used by phytoplankton in primary production.

Increased Concentrations of Atmospheric Carbon Dioxide (CO_2)

It is estimated that atmospheric CO_2 levels will double over pre-industrial levels by the middle of the next century, a change which is likely to enhance plant growth. Not all plants will respond equally, however. In particular, plants relying on a "C_3" photosynthetic pathway are expected to have a competitive advantage over plants relying on a "C_4" pathway, an advantage which is likely to alter the species composition of coastal wetland communities (Reid and Trexler, 1996).

Tectonic activity

Recent discoveries indicate that, contrary to earlier assumptions, the British Columbia coastal zone is tectonically active. As indicated in Thomson and Crawford (1997), evidence suggests that in the Pacific, that the Juan de Fuca Plate, rather than subducting, locks against the North American Plate. It is believed that the tension built up between these two plates is released in infrequent[17] "mega-thrust" earthquakes of magnitude 8 or greater. The last such quake occurred 300 years ago. The next is expected to cause coastal subsidence of 1 to 2 metres and the formation of a tsunami 1 to 10 metres in height. The extensive flooding and significant permanent inundation associated with a tectonic event of this nature would have obvious impacts on the coastal zone of British Columbia. These impacts would exacerbate, and overshadow, the expected impacts of climate change.

While the Yukon region is less tectonically active, earthquakes of magnitude 5 occur occasionally in the northern Ogilvie mountains (GSC, 1996); similar quakes could cause minor land slumps and slides along the coast and along the banks of inland rivers.

Population pressure and disease

A recent study by Myers (1993) has estimated that by 2050, 150 million ±50 million people in developing countries will be forced from their homes as a result of inundation, flooding, and drought associated with climate change. This dislocation potential will have significant social impacts British Columbia and, to a lesser extent because of the climate, in Yukon. In British Columbia, increased heat stress will also drive people to beaches in greater numbers, putting additional stress on these systems. Warmer waters will lead to northward migration of sub-tropical species, including algal species responsible for red tides[18] that are toxic to humans as well as to marine species. Attendant economic and health effects have not yet been estimated.

SEA-LEVEL RISE AND INCREASED FREQUENCY OF EXTREME EVENTS: IMPLICATIONS FOR COASTAL MANAGEMENT IN BRITISH COLUMBIA AND YUKON

Clearly, the very best response to climate change would be to limit greenhouse gas emissions, thus reducing the overall potential for sea-level rise and major weather pattern disjunctures. In the absence or limited implementation of this abatement strategy, management efforts in the coastal zone must be directed at dealing with the effects of sea-level rise and increased frequency of severe storm events.[19] These management responses range from complete shoreline defense to full retreat from rising sea levels.

"The pure retreat option would, in theory, best protect coastal ecosystems because those ecosystems would be free to migrate landward without human impediment. The economic and political [as well as social] costs of abandoning current and future coastal developments, however, make the pure retreat option untenable"

[17] Current data indicate an average return period of 500 years.

[18] "Red tide" is the common name for blooms of several species of pigmented single-cell algae. These algae produce endotoxins which, in significant concentrations, can kill finfish, shellfish, and marine mammals, and can cause serious illness in humans. Red tides are currently found on both the Atlantic and Pacific coasts of North and South America, usually at lower latitudes.

[19] Note that this is somewhat oversimplified. Even if greenhouse gas emissions were severely curtailed, some warming, and consequently some amount of sea-level rise, is now expected.

(Reid and Trexler, 1996, p. 34) suggesting the need for a mix of the two.

Along the British Columbia and Yukon coasts, this will mean conducting additional research to clarify some of the unknowns enumerated in this article regarding the site-specific impacts of climate change as well as to determine the best means of mitigating them. It will also mean taking "proactive" or "precautionary" measures, since early action is expected to reduce long-run economic, social, and environmental costs (figure 8).

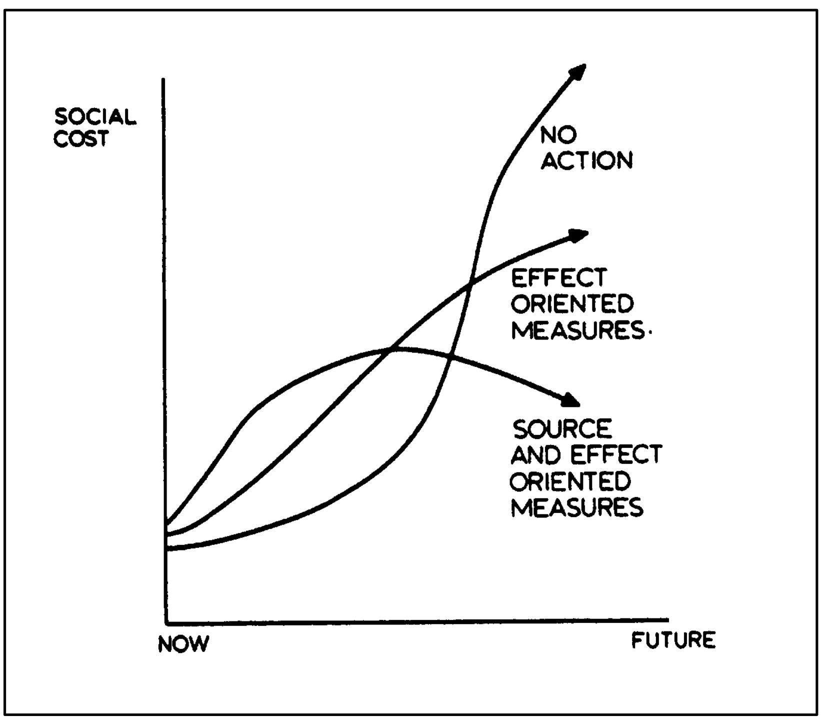
Research needs include:

- Inventory work: Data concerning vulnerable sites must be refined on both the British Columbia and Yukon coasts. Inventories of vulnerable species and ecosystems associated with these sites must be developed. Some work, using permanent stakes placed at the leading edge of marsh and eelgrass zones to detect progradation or retreat is already underway but studies of this nature need to be expanded.

- Sediment transport studies: work must be initiated to determine the extent to which additional precipitation causing additional runoff and sediment transport will offset sea-level rise in deltaic regions. Work necessary to determine net change over the long term could be easily conducted across the intertidal zone. Work will also need to be undertaken to determine specific geomorphic changes within estuaries under various sea-level rise scenarios. Site-specific work to determine changes in alongshore sediment movement is also required.

- Biological impacts studies: Modeling work specific to the British Columbia and Yukon coasts must be undertaken to determine the impact of various sea-level rise scenarios on vulnerable ecosystems. Specific attention should be paid to effects

Figure 8. Tentative cost scenarios. No action today to prevent climate change or mitigate its effects is least costly in the near term but has the largest social costs in the future; taking actions to mitigate its effects in the present is more costly today but reduces the long-run social costs. Taking action in the present to mitigate effects and reduce the causes of sea-level rise (greenhouse gas emissions) is most effective at reducing social cost overall but is most expensive in the near term (Vellinga and Leatherman, 1989)



of sea-level rise on the deltaic and estuarine systems of British Columbia and Yukon, for which relatively little data currently exists. Studies must also be conducted to determine the extent of additional organic loading and sediment scouring in rivers and streams to determine the impact of increased sedimentation and turbidity on nearshore ecosystems such as bivalve beds.

- Studies on other impacts of climate change: Much effort to date has focused on the effects of rising sea level. Water temperature changes, regional and seasonal ocean circulation pattern changes, and the effects of increased concentrations of CO_2 will also have significant effects on the coastal zone. Studies in these areas will need to be conducted to gain a clearer view of the total impact of climate change on the British Columbia and Yukon coastal zones.

- Coastal Zone Management studies: A large body of literature on coastal zone management already exists. Efforts must be taken to incorporate responses to climate change. In particular, efforts must be taken to explore new patterns of coastal ownership that will meet the needs of private land-holders and the need to allow the coastal zone to retreat.[20]

- Gaming exercises: These exercises should include both natural and social scientists. The purpose of such exercises should be to model a variety of regional responses to climate change in order to determine the one most socially acceptable.

Precautionary measures include:

- Conserving existing wetlands, estuaries, and deltas: Wetlands are the cheapest and most resilient "sea-walls" in existence. Appropriate conservation tools ranging from public and private purchase of lands to co-operative multiple-use management should be experimented with to minimize both economic and ecological costs associated with wetland loss.

- Creating "setback"[21] mechanisms which prohibit shoreline development in order to allow for landward migration of vulnerable ecosystems: In some instances this will require purchase of areas currently landward of vulnerable ecosystems as a buffer against human development that will foreclose migration options while in other areas it will require municipal action to prevent shoreline development. Given the large (and growing) population in a number of vulnerable areas (the Fraser River estuary, for example), pilot projects should be undertaken. Such projects may stave off the incremental approach to dealing with sea-level rise which focuses on technical solutions (usually dyking and damming) on an "as-needed" basis -- an approach which is likely to cause the greatest loss of vulnerable coastal ecosystems.

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[20] One interesting study in the United States, for instance, has suggested the development of a sea-level rise "insurance policy" which would be associated with coastal properties and would be paid out to property owners at such time as the property would need to be abandoned due to encroaching seas (Reid and Trexler, 1996).

[21] "Setbacks" are regulatory tools used to ensure that development is "set back" from the shoreline.

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Chapter 9

ECOSYSTEM RESPONSE TO CLIMATE CHANGE IN BRITISH COLUMBIA AND YUKON: THREATS AND OPPORTUNITIES FOR BIODIVERSITY

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OVERVIEW

Organisms vary in their ability to respond or adapt to climate change. Rare and endangered bryophytes, marine benthic macroinvertebrates, lichens, macrofungi, and vertebrates are discussed in relation to their response to climate change. In addition, comments are given on responses of protozoan parasites and vascular plant communities. Some species are likely to gain habitats as their range expands north or upslope, except those with nowhere to go, such as species living along the Beaufort Sea coast, or in specialized habitats that can not move. Species at the southern limit of their ranges may retract out of British Columbia, but expand in Yukon. Alpine tundra species, especially those in southern British Columbia, are likely to lose habitat. The ability of species to occupy potentially new range distributions created by new climate regime will be influenced by land use practices that favour some species and not others. Land uses that leave disturbed soil and lack of climax vegetation will favour early colonizing species in forests and grasslands. Vigorous fire suppression may preserve forests, but at the expense of grazing land and associated plant and wildlife communities. Timber harvest methods that leave some canopy intact and retain an interconnected network of climax plant communities, will facilitate dispersal of many organisms to new habitats. Wetlands will be especially difficult to protect, and managers (including private landowners) will have to be vigilant about livestock use and water withdrawals to protect species such as marsh-nesting birds.

INTRODUCTION

The purpose of this chapter is to put names and faces on the rare and endangered species whose conservation status is likely to change as a result of global warming. There will be winners and losers. Probable ecosystem adaptations have been described elsewhere in this volume (see chapters by Beckman et al, Hebda, Krannitz and Kesting). Species whose range expands - those at the lower elevations that can move up slope, and those at the northern limit of their ranges that can disperse northward - will gain habitat. Conversely, those species at the southern periphery of their distribution, at higher elevations, and occupying specialized habitat, will lose. Many of these species, such as micro-organisms, non-vascular plants, most marine and terrestrial invertebrates, are not included in official conservation listing schemes such as the BC Red and Blue lists (provincial lists of, respectively, endangered and threatened wildlife species in British Columbia), or COSEWIC (Committee of the Status of Endangered Wildlife In Canada) lists; hence, while they may be listed as rare by specialists, their conservation status has not been fully assessed. Moreover, half or more of the species that may live in British Columbia, and doubtless a like proportion in Yukon - mainly terrestrial invertebrates, fungi, lichens and some other poorly studied groups - have not even been described and named, let alone assessed as to their conservation status (Harding, in press). This listing of known rare species whose conservation status is unknown is therefore a first step in developing a strategy to conserve biodiversity in the face of a changing climate.

WINNERS AND LOSERS

Following are accounts of likely habitat gains and losses by taxonomic group from data provided by specialists in British Columbia and Yukon.

Mosses and Liverworts

This section was compiled from notes contributed by Dr. W.B. Schofield, University of British Columbia.

Rare bryophytes (mosses and liverworts, or "hepatics") in British Columbia have been analysed as to how their habitats may be altered by climate change. In this analysis, climate change is interpreted as a warming trend with lower precipitation in summer. Many of the species listed here are endemic to North America; however, some also occur elsewhere. Those that also occur elsewhere are listed here by their northern and southern range limits in North America.

Rare bryophytes at the northern limit of their range in British Columbia are categorized in Table 1 as those whose habitat is:

- coastal forest. These could increase their range if climate near the coast becomes drier; they might replace species of oceanic shoreline environments which are adapted to a moister climate.
- alpine tundra. A rise in temperature could eliminate alpine species.
- steppe-grassland. These species could increase their range northward.

Rare bryophytes at the southern limit of their distribution in British Columbia (Table 2) could be eliminated there as their range retracts or expands northward into Yukon. Finally, oceanic species requiring high precipitation and humidity (Table 3) could be eliminated through seasonal drying associated with climate warming. Most do not have common English names.

Terrestrial and Freshwater Invertebrates

This section was compiled from notes contributed by Dr. Geoff Scudder, University of British Columbia

The Okanagan Basin, whose grassland-steppe habitats are likely to expand in response to climate change, is home to 258 species of invertebrates (animals without backbones) that occur nowhere else in the province, of which 23 (9%) are endemic, i.e., they occur nowhere else in the world (Scudder, 1993a).

Prediction of invertebrates' response to climate change is complicated by the fact that some species feed only on specific plants or animals, whose range adaptation will be determined by that of their forage or prey species; while others are general feeders not tied to any host species and will be more directly affected by climate change.

Table 1 . Bryophyte species at or near their northern limit in British Columbia.

Coastal Forest			
Mosses			**Hepatics**
Alsia californica	Grimmia pulvinata	Pseudobraunia californica	Cephaloziella turneri
Amphidium californicum	Hedwigia stellata	Pterogonium gracile	Diplophyllum obtusifolium
Anacolia menziesii	Homalothecium arenarium	Ptychomitrium gardneri	Fossombronia longiseta
Andreaea schofieldiana	H. nuttallii	Racomitrium obesum	Frullania bolanderi
Bartramia stricta	H. pinnatifidum	R. pacificum	Porella roellii
Bryolawtonia vancouveriensis	Isothecium cristatum	R. varium	Riccia beyrichiana
Claopodium whippleanum	Orthotrichum diaphanum	Scleropodium tourettei	Sphaerocarpus texanus
Crumia latifolia	O. rivulare	Tortula amplexa	Targionia hypophylla
Dendroalsia abietina	Physcomitrium pyriforme	T. bolanderi	
Ditrichum ambiguum	Pleuridium subulatum	T. latifolia	
D. montanum	Pohlia longibracteata	T. muralis	
D. schimperi	P. ludwigii	T. subulata	
Entosthodon fascicularis	Porotrichum bigelovii	T. laevigata	
Alpine Tundra		**Steppe-grassland**	
Mosses		**Mosses**	
Bryum calobryoides		Bryoerythrophyllum columbianum	
Dichodontium olympicum		Coscinodon calyptratus	
Pohlia cardotii		Crossidium aberrans	
Pohlia erecta		Entosthadon rubiginosus	
Racomitrium pygmaeum		Phascum vlassovii	
Trematodon boasii		Plerigoneurum kozlovii	
		Pottia bryoides	
		P. nevadensis	
		P. wilsonii	
		Schistidium heterophyllum	
		Tortula brevipes	
		T. caninervis	

Table 2. Species of Yukon, Alaska and Northwest Territories that reach their southern range limit in British Columbia

Boreal Forest (mainly)		
Mosses		**Hepatics**
Aulacomnium acuminatum	Racomitrium panschii	Anastrophyllum assimile
A. turgidum	Sanionia orthotheciodes	A. saxicola
Cinclidium arcticum	Splachnum luteum	Arnellia fennica
Didymodon asperifolius	S. rubrum	Bazzania trilobata
D. nigrescens	S. sphaericum	Cephalozia macounii
Hygrohypnum polare	Tetraplodon pallidus	Gymnomitrion apiculatum
Hypnum bambergeri	Tomentypnum falcifolium	G. coalliodes
H. procerrimum	Trichostomum arcticum	Marsupella revoluta
H. recurvatum	Ulota curvifolia	Odontoschisma macounii
Loeskypuum badium	Warnstorfia trichophylla	Radula prolifera
Psilopilum cavifolium	Sphagnum lenense	Scapania simmonsii
		S. spitzbergensis
Alpine (mainly)		
Mosses		
Andreaeobryum macrosporum		

Table 3. Species confined to very oceanic coastal climates with high precipitation and humidity.

Mosses	Hepatics
Bryhnia hultenii (also, southern range in British Columbia)	Anastrepta orcadensis
Campylopus japonicus	Anastrophyllum donianum
C. schwarzii	Apotreubia nana
Ctenidium schofieldii	Bazzania tricrenata
Daltonia splachnoides	B. pearsonii
Dicranodontium subporodictyon	Calycularia crispula
D. uncinatum	Dentrobazannia griffithiana
Geheebia gigantea	Gymnomitrion pacificum
Gollania turgens	Herbertus sendtneri
Herzogiella adscendens	Lepidozia filamentosa
Hypopterygium fauriei	L. sandvicensis
Loeskypnum wickesiae	Marsupella boeckii
Paraleptodontium recurvifolium	M. commutata
Pleuroziopsis ruthenica	Mastigophora woodsii
Pseudoleskea julacea	Metzgeria leptoneura
Rhabdoweisia crispata	Odontischisma denudatum
Seligeria acutifolia	Plagiochila schofieldiana
S. careyana	Pleurozia purpurea
Wijkia carolottae	Scapania ornithopodioides
Zygodon gracilis	Sphenolohopsis pearsonii
Z. reinwardtii	
Sphagnum junghuhnianum	
S. subobesum	
S. wilfii	

As well, some ectotherms ("cold-blooded" species, which includes all invertebrates) may undergo basic physiological changes that may allow them to occupy new habitats, in addition to the changes in the geographic ranges; however, climate will change too rapidly for by far the majority of species to evolve the necessary adaptations. These "...species will have to move with the temperatures, or they will become isolated and perish." (Scudder, 1993a).

As noted previously (Scudder, 1993a), the ability of a species to shift its range and distribution will depend on its mechanisms of dispersal, and the barriers involved. For most invertebrates and some vertebrates, their limited means of dispersal will hinder their ability to move. Soil organisms and many plants certainly will need continuity of habitat to move. Only plants with spores or "dust" seed may match the rate needed to keep up with climate change. Because different species have differing dispersal ability, and respond individually to climate, communities will tend to fragment as species shift their ranges in different directions. Moreover, the interaction between habitat destruction and climate change is synergistic: the combination of the two processes could threaten more species than the sum of their individual effects.

In the dry interior of the Okanagan, some examples can be given of likely response to climate change by species whose distribution is known accurately, are at the northern limit of their ranges in British Columbia, and are not tied to any host plant. Examples are the seed bug, *Sisamnes claviger* and the burrowing bug, *Dallasiellus discrepans* (Scudder, 1993b). For these species, climate is thought to currently limit their distribution (Figures 1 and 2), and their future distribution will likely follow the new temperature and precipitation isotherms described by Taylor (1997). Species with these characteristics may be among the first to change their distribution in response to climate change. Other species with these characteristics not currently occurring in British Columbia, including pests, would probably spread northward into Canada from the United States.

Figure 1. Known distribution of the seed bug, *Sisamnes claviger* (Uhler) (*Hemiptera: Lygaeidea*) in Canada: occurs only in British Columbia.

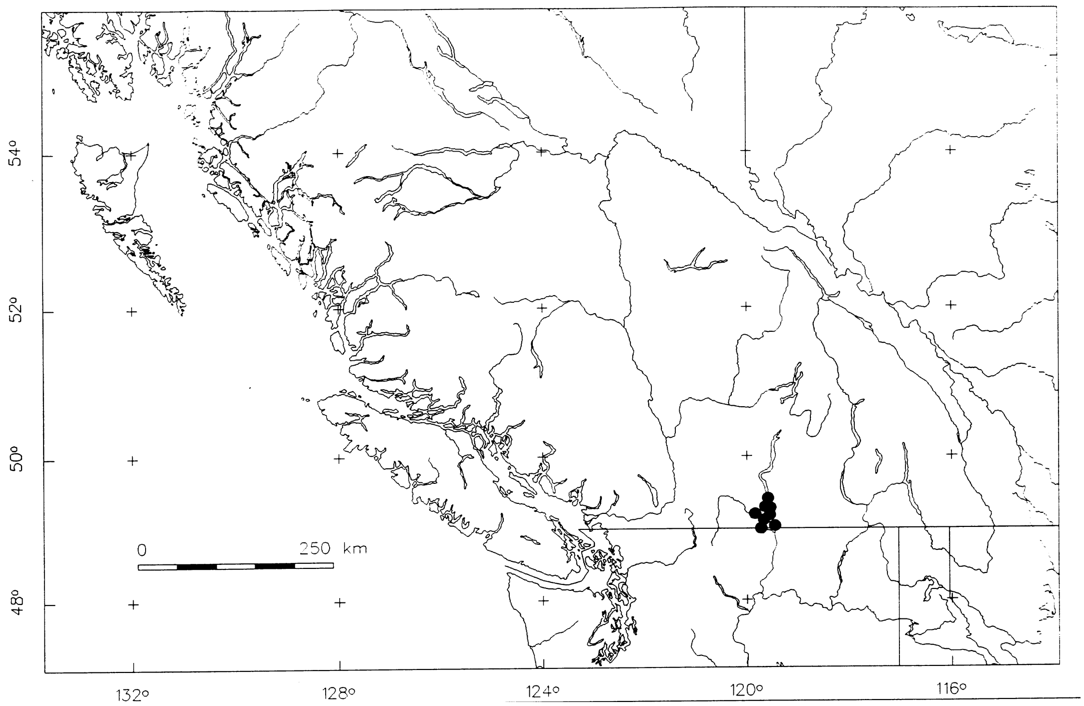
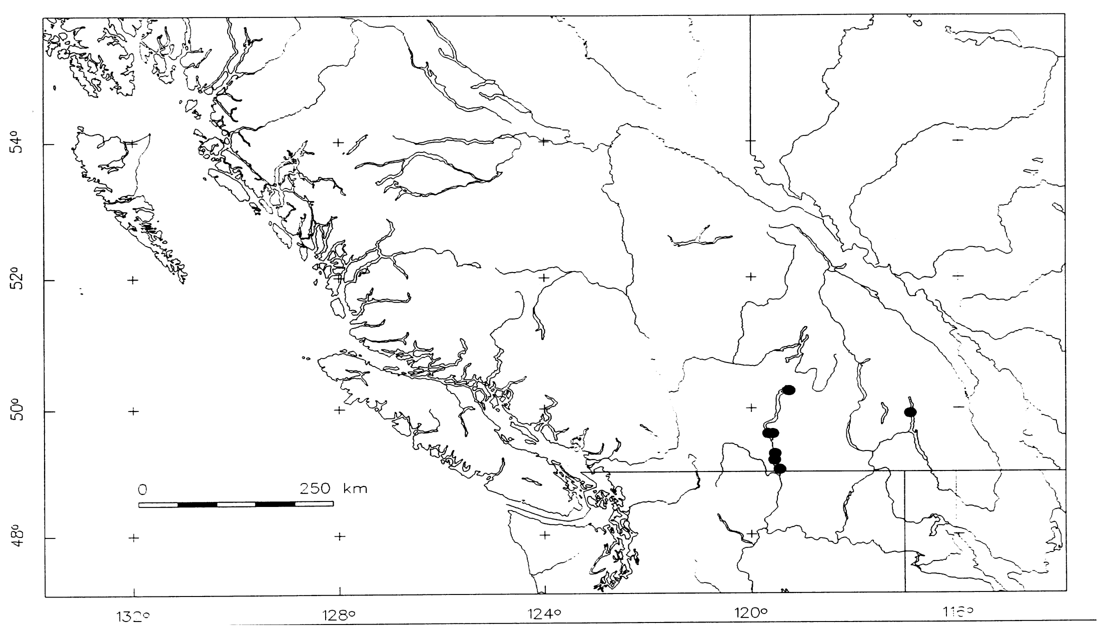


Figure 2. Known distribution of the burrowing bug, *Dallasiellus discrepans* (*Hemiptera: Cynidae*) in Canada: occurs only in British Columbia.



Protozoan Parasites

This section was compiled from notes contributed by Martin Adamson, University of British Columbia.

It is very difficult to predict how parasites would benefit from or react to climate changes, but there will probably be two mechanisms of change: species here now may become more effective, and new species may immigrate from more southerly climes. First, warm, humid climate is likely to aid parasitic transmission. Many diseases thought to be tropical actually occur here at very low levels, e.g., *Entamoeba hystolytica*, commonly known as Montezuma's Revenge, and *Giardia sp*., which causes the malady commonly known as beaver fever, would both thrive in a warmer climate. Secondly, qualitative changes in infestation/infection rates would occur if pests that now are killed by winter freeze are able to survive and continue reproducing over the winter. Loss of winter freeze that kills is a threshold point for new epidemiological scenarios. For example, fleas and mites that are now killed by the cold for at least two weeks every winter would, instead, continue to multiply if the environment were warmer by a couple of degrees.

The second scenario is immigration. I could see movement up from the south, for example, of *Bursaphelenchus sp*. a nematode that causes pine wilt. It kills rapidly by reproducing in the tree's vascular system and choking off its water supply, but operates only in a well-defined temperature range with a certain number of degree-days. South of Canada where this species now occurs, its host trees are of a resistant genetic strain. Climate change and the movement of the parasite will likely outstrip the trees' ability to adapt. For all of the parasite species with ability to migrate northward or upward in elevation faster than their host species can either move or adapt, infestation/infection rates will increase.

Marine Benthic Macroinvertebrates

This section was compiled from notes contributed by Bill Austin, Khoyatan Marine Laboratory/Marine Ecology Station, Duncan, B.C.

Beckmann et al. (1997) reviewed predictions of climate change impacts on the marine environment, including temperature (warmer by 1.0 - 4.5°C) and changes in current and upwelling patterns. The latter will derive from both open ocean circulation changes, and changes in river runoff, which drives estuarine circulation and influences nutrients and dissolved oxygen, as well as temperature. The temperature of the marine environment is relatively constant, compared to terrestrial ecosystems, many marine organisms are quite sensitive to even small temperature changes. The following lists are qualitative, indicating an assumed northward shift, but without implying how much, or what water temperatures it would take to effect these changes. Tables 4 and 5 are from a partial, preliminary list of rare and endangered benthic macroinvertebrates species whose only known occurrence is in British Columbia's marine environment. In some cases, sampling elsewhere (Washington and Alaska) could confirm whether these are endemic to British Columbia. The list is being prepared for the BC. Conservation Data Centre. Table 4 list those species which may lose habitat; table 5 give examples of some that may expand northward into newly created habitat.

Marine Macroalgae (seaweeds)

This section was compiled from notes contributed by Dr. Michael Hawkes, University of British Columbia

Table 6 lists 18 species of seaweed that could be considered rare. Most are at the northern or southern limits of their ranges (Hawkes, 1994; Hawkes and Scagel, 1986; Hawkes et al., 1979; Scagel et al., 1993). Also, if global warming causes an increase in sea temperatures, most kelp (Macrocystis and Nereocystis) would be affected and may even be eliminated from certain sites, as they require cool water.

Lichens

This section was compiled from notes contributed by Irwin M. Brodo, Macoun Nature Centre for Yukon; and by Trevor Goward for British Columbia.

Hebda (1997), expects the Coastal Douglas-fir zone to expand into the Coastal Western Hemlock zone, giving more habitat to 10-12 rare CDF zone lichen species and less to

17-18 rare CWH species (Table 7, from Goward, 1995). The Bunchgrass Zone is

Table 4. Benthic macroinvertebrates at the southern limit of their ranges, or with specific habitats that may change and little mobility to seek new habitats.

Species	BC Distribution	Notes	Global warming
Grantia sp. (aff: compressa), flattened sac sponge	Only found in Execution Rock Cave, Barkley Sound	dubious record from California	possibly the southern extent of population
Halichondria sp. (aff: fibrosa)	Elbow Point and Saanich Inlet	no other records in the world; sampled by PICES submersible	change in estuarine circulation and oxygen renewal could affect distribution
Tubularia sp., raspberry hydroid	several records w. coast Vanc. Isl.	no other records in the world	specific habitat: low silt water with high current
Synhalcurias sp., tall deep sea anemone	Saanich Inlet, McCurdy Pt.	no other records in the world	change in estuarine circulation and oxygen renewal could affect distribution
Corallimorphus sp., large knobbed tentable anemone	Fitz Hugh Channel and Potland Canal	no other records in the world	limited to cold northern BC waters
Thyonidium drummondii	two localities near Alert Bay	may be an undescribed species	
Echinarachnius parma, regular sand dollar	Vancouver Island		may already have retracted its range northward
Arctomelon stearnsi, Alaskan volute snail	off Queen Charlotte Isl.	prized by shell collectors	northern species extending just into BC
Spinther alaskensis, grublike sponge worm	1 record in Sidney Inlet	lives in atrial cavity of a sponge	northern species extending just into BC

Table 5. Benthic macroinvertebrates at the northern limit of their ranges, which may expand northward.

Species	BC Distribution	Notes	Global warming
Plocamilla igzo, a sponge	Houston-Steward Channel, Anthond Isl. Queen Charlotte Isl.	no records between BC and California	may increase range
Ophiopteris papillosa, chocolate brown spiny brittle star	a few localities, n. coast and w. coast Vancouver Island	no records between BC and California	may increase range
Ophioplocus esmarki, husky tan serpent star	Quatsino Sound	no records between BC and California; live bearer with no pelagic stage, hence limited mobility	may increase range
Emerita analoga, sand (mole) crab	Long Beach	periodic invader in large numbers; last record 1961	occurrence probably related to warm water influxes
Rhamphidonta retifera, walking clam	1 record on Nootka Isl.	no records between BC and California	may increase range

Table 6. Rare seaweeds of British Columbia

Seaweeds at the southern limits of their ranges	**Endemics**
Tokidaea chilkatensis	Kitkatla, Dolphin I.
Tokidadendron kurilensis	Langara I.; Triple I.; Prince Rupert & Kitkatla, Dolphin I.
Thuretellopsis peggiana	Dixon I., Barkley Sound & Juan de Fuca auto court, Vancouver I.
Phycodrys riggii	Rennell Sound, Haida Gwaii and Prince Rupert area
Laminaria longipes	Bunsby Islands area, Vancouver I.
Codium ritteri	Campania I.: Kitkatla, Dolphin I. Reported from Botanical Beach
Desmarestia tortuosa	Barkley Sound and Orr Island, Holberg Inlet. A B.C. endemic
Seaweeds at their northern limits	
Dictyoneuropsis reticulata	Hope I.; Cape Scott; Goose I.; Quatsino; Sombrio
Dictyoneurum californicum	SW coast of Vancouver I. from Botanical Beach to Sombrio River and along the west coast trail
Laminaria farlowii	Comox; Gabriola I.; Arab Cove, Vancouver I.
Laminaria sinclairii	Hope I.; Nasparti Inlet, Vancouver I.; Grassy I.; Commerell Pt., Lippy Pt., Long Beach, Darling R., & Sombrio R., Vancouver I.
Antithamnion kylinii	Seymour Narrows; Tribune Bay, Hornby I.; Ladysmith Harbour; Bamfield
Arthrocardia silvae	Cape Beale, Vancouver I.
Cumathamnion sympodophyllum	Botanical Beach, Vancouver I.
Hollenbergia nigricans	Hedley I. And Botanical Beach
Tayloriella abyssalis	Gil Island; Campania I.; Kelp Head, Queen Charlotte Sound
Tayloriella divaricata	BC Distribution: Princess Royal I. & Broken Is., Barkley Sound
Whidbeyella cartilaginea	BC Distribution: Chatchannel Pt., Union I. and Wizard Islet, Barkley Sound

likely to expand, *potentially* favouring eight rare lichens there, although land use damage to lichen habitat will severely limit the ability of lichens to occupy this new habitat, and will at the same time create microhabitat conditions (soil disturbance and increasing moisture deficit) suitable for invasion of exotic vascular plants, further limiting the ground available for lichen expansion (see Harding et al., 1994). Hebda (1997) feels that if drying occurs in the ICH Zone it will be invaded by Douglas-fir, and undergo complex floristic changes not yet predictable. Therefore, the future of six rare lichen species in this zone is uncertain, but predictions can not be optimistic.

The following lichens are at the northern edge of their range in British Columbia, and if soil conditions are suitable, may be expected to expand their range in the Province: *Erioderma sorediatum, Flavopunctelia flaventior, Heppia lutosa, Leiderma soredatium, Parmotrema chinense, Psuedocyphellaria raineriensis, Hypogymnia heterophylla, Koerbia sonomensis, Leptogium furfuraceum, Massalongia cf. microphylliza, Nephroma occultum, Poarmotrema crinitum, Phaeophyscia nigricans, Physcia callosa,* and *P. dimidiata*. Conversely, the following species are at the southern limit of their range and may be expected to retract from B.C. or expand northward into Yukon*: Agrestia hispida, Alectoria imshaugii, A. vancouverensis, Niebla cephalota, Ramalina subleptocarpha,* and *Usnea cf. Florida*.

Table 8 lists 18 species of rare lichens in Yukon. Their habitat requirements are too poorly known to predict how or if they will be affected by climate change. In general, those whose habitat is forests may expand their range, if they are able to disperse, while those of alpine and arctic tundra (2 of the 18 species listed below) may lose habitat. There are no common English names for most of these.

Macrofungi: mushrooms, toadstools and their relations

This section was compiled from notes contributed by Scott Redhead, Agriculture Canada, Ottawa.

Table 7. Lichenologically critical Biogeoclimatic Zones and Ecoregions

Coastal Douglas-fir Zone (Eastern Vancouver Island Ecoregion)	Coastal Western Hemlock Zone (Western Vancouver Island Ecoregion)	Bunchgrass Zone (Thompson-Okanagan Plateay Ecoregion)	Interior Cedar-Hemlock Zone (Columbia Mountains Ecoregion)
Collema auriforme C. fecundum C. nigrescens, Flavopunctelia flaventior Hypogymnia heterophylla Koerberia sonomensis Leptogium furfuraceum L. platynum L. Polycarpon Physconia detersa Punctelia subrudecta Waynea californica	Cetraria californica Collema fecundum C. flaccidum C. nigrescens Erioderma sorediatum Heterodermia leucomelos H. sitchensis Leptogium brebissonii L. polycarbon Nephroma silvae-veteris Pannaria ahlneri P. laceratula P. rubiginosa, Parmotrema chinense P. crinitum Phaeophyscia ciliata P. semipinnata Psuedocryphellaria rainierensis	Collema sp., Flavopunctelia flaventior Heppia lutosa, Leptogium schraderi Massalongia c.f. microphylliza Phaeophysica hirsuta Physcia callosa P. dimidiata	Leptogium cyanescens Lobaria retigera Nephroma silvae-veteris Pannaria ahlneri Phaeophyscia adiastola Stricta wrightii

Table 8. Rare lichens of the Yukon Territory

Species	Current Distribution
Arctomia delicatula	on Yukon-NWT border
A. interfixa	on Yukon-NWT border
Baeomyces placophyllus	uncommon, circumboreal species growing on soil
Cetraria kamczatica	amphi-Beringian; 1 record in Yukon is easternmost in N. America
Cladonia bacilliformis	widespread but uncommon in Alaska and NWT, only 1 record in Yukon; a boreal forest species.
C. kanewskii	amphi-Beringian to w. Yukon, s. to Queen Charlotte Islands
C. metacorallifera	Beringian, but also known from S. America
Collema crispum	temperate species, grows on calcareous soils
C. undulatum	uncommon arctic-alpine lichen with scattered, circumboreal distribution; grows on calcareous soil and rock
C. luteoalba	a crustose lichens of alpine tundra; 1 record in Yukon along Haines Highway
Melanelia olivaceoides	rare foliose lichen, few localities in N. America clustered on Alaska-Yukon border, and a single Rocky Mt. Locality; grows on rock and bark.
Ramalina almquistii	uncommon amphi-Beringia fruticose lichen on tundra soil or rock, mainly along the coast of the Beaufort Sea
Solorina octospora	soil lichen, widely scattered in Arctic (1 Yukon record in SW corner) and a few Rocky Mt. localities.
Umbilicaria polyrrhiza	rare, temperate with a few scattered Arctic localities. Single Yukon record on NWT border is northernmost in N. America.
U. caroliniana	a few Beringian localities, those on the NWT-Yukon border being easternmost - the other N. American records are in the Appalacian Mts.
U. cinereorufescens	NW North America and European disjunct populations, and 1 record from Arizona
U. havaasii	uncommon Arctic, circumboreal species throughout Arctic and west coast.
Vestergrenopsis isidiata	in NWT, but close to Yukon border, and in Alaska; a cyanobacteria-containing crustose lichen that grows on wet rock

Redhead (1994) reviewed the conservation status of macrofungi in British Columbia. That province has about 1,250 known species of macrofungi, and this is only a fraction of the species that live there, as many more remain to be discovered. Some species are aggressive plant pathogens (disease agents) or agents of destruction. Most, however, are critical to the health of the plant communities in which they occur, and many are important to human consumers. Nearly all timber trees and ornamentals depend on ectomycorrhizal fungi (those living in close association with roots) to provide nutrients, water and protection from root pathogens. Fungi benefit higher organisms, by providing food and habitat (tree cavities for nesting, rotting logs). Their role in decomposing dead wood and other plant matter is vital to forest health. The main threat to macrofungi is habitat destruction, and harvest of climax forest communities is a serious threat because these communities are not replaced by the short rotations of the industrial forest.

Our knowledge of fungi and their requirements is so limited that it is very difficult to say which if any would be negatively affected by climate change. With global warming we would expect southern species to enter into British Columbia. Where glaciers retreat (some on the coast would probably expand, owing to greater precipitation), there may be more habitat for some alpine species at higher elevation, although they may also lose habitat at lower elevations from encroaching treelines. However, if glaciers melt entirely in the western cordillera, we could expect to lose species from pioneering communities. In forests, where tree and shrub species are affected (such as by replacement of climax forests with young forests through short-rotation timber harvest), their associated mycological communities might well be affected also.

Vascular Plants

Chapters by Hebda and Krannitz (this volume) outlined the likely changes in plant communities. However, what potential changes are actually realised will be influenced by land uses, including timber harvest and reforestation, insect pest management, fire suppression, and grazing.

Insect Pest Management

Forest ecologists such as Pollard (1991b), Bergvinson (1988), Borden (1991) and Franklin et al. (1991) predict that, with global warming, forest pests may increase. The large outbreaks of forest insect pests during the 1980s offer an example of combined effects of global and local changes on forest ecosystem diversity. Hot, dry weather in the Interior has encouraged the Douglas-fir Tussock Moth (*Orgyia psuedotsugata*; Shepherd et al., 1988). Throughout large areas of the Interior, the absence of severe cold spells during the late 1970s/early 1980s permitted overwintering broods of some defoliator and bark beetle species to survive and spread over a much larger area, resulting in massive bark beetle (*Dendroctonus ponderosae*) infestations in lodgepole pine (Van Sickle, 1995), and consequent salvage logging on a large scale. Milder winter temperatures may have permitted northward range extensions of some insect pests, such as the Spruce Bud Moth (*Choristoneura fumiferana*), which was recorded for the first time north of Mackenzie in 1989 (Van Sickle, 1995). Likewise, the infestations of white pine weevil (*Pissodes strobi*) are so temperature-related that infestation hazard ratings based on weather records have been developed for the Prince George and Prince Rupert Forest Regions (Ebata, 1992a). The recent trend towards milder weather in the Southern Interior and the Prince George area (Harding and Taylor, 1994) doubtless played a role in these insect outbreaks. Because insect infestations are salvage-logged, insect irruptions encouraged by the mild weather of the 1980s influenced the rate and locations of forest conversion by timber harvest. This is a clear link between climate variability and land management.

Timber Harvest

Besides the obvious alteration in forest structure by elimination of old growth and associated species, commercial forestry destabilises other disturbance regimes, particularly the pest infestation rates noted above. MacLauchlan (1992) felt that selective harvesting of ponderosa pine in the drier portions the Interior Douglas-fir zone, and effective fire suppression (see below), encouraged outbreaks of the western spruce budworm (*Choristoneura* *occidentalis*). The extensively logged and reforested areas in interior and northern forests are more susceptible than natural forests to defoliators, such as the two-year cycle budworm (*Choristoneura biennis*) and the western balsam bark beetle (*Dryocetes confusus*) of northern and high elevation spruce and fir forests (Ebata, 1992b). To facilitate forest ecosystem adaptation to climate change in a way that will protect both economic (e.g., forestry) and environmental (e.g., ecosystem stability) values, we should manage forest to make them *less* susceptible to insect pests, not more. Possible strategies might include a more aggressive move to selection logging to encourage uneven-aged stands, reforestation with multiple species, and retention of climax stands among cutblocks are needed.

Fire Management

Fire suppression affects forest ecosystems directly, by altering ground cover and species assemblages; and indirectly, by affecting insect infestation rates, an example of a positive feedback mechanism for response of ecosystems to climate change. Flannigan and Van Wagner (1991) noted that since 1970 a drying trend and increase in available fuel has increased more than 50% nationally, and more increases are likely with greenhouse warming. In British Columbia, the recent combination of extremely dry weather and fire suppression has led to a paradox: Even though fire frequency has been increasing (more fires are started in hot, dry weather), the area burned has been decreasing (the fires are put out efficiently) (Harding, 1994). Fire suppression is encouraging encroachment of forest trees, mainly Douglas-fir, into both the Bunchgrass and Ponderosa Pine Biogeoclimatic Zones (see review by Harding, 1994). In western Montana pine-larch forests, there is also evidence that mountain pine beetle (*Dendroctonus poderosae*) and western spruce budworm (*Choristoneura occidentalis*) infestations have been encouraged by growth of young pine and Douglas-fir associated with modern fire suppression (Perry and Borchers, 1990). These forests are adjacent, and ecologically similar, to those in the southeast corner of British Columbia.

Wildlife and livestock grazing managers have a long history of using fire as a range and wildlife habitat improvement technique, and forest managers in B.C. have been experimenting with fire in forest management. Spittlehouse (1997) has recommended increased efforts at fire prevention and fire suppression to cope with climate change; however, with projected expansion of grassland-steppe plant communities, fire protection in much of the Ponderosa Pine and Interior Douglas-fir zones may be counter-productive, in terms of facilitating ecosystem adaptation to climate change. There has always been some tension between livestock and timber interests in interior forest lands (Dodd et al., 1971; Wikeem et al., 1993). Perhaps, given the increasing world food shortages and projected rise in all agricultural product prices, especially beef (WorldWatch Institute, 1996), it is time to encourage ascendancy of British Columbia's beef industry as a natural and economically beneficial consequence of climate change.

Grazing

In 1993 8.3 million hectares of Crown forest land was leased for livestock grazing, accounting for 60% of the province's total pasture forage requirements; the other 40% is produced on 1.5 million hectares of private rangeland and irrigated pasture (Ministry of Forests, 1994). Harper et al. (1991) list the following threats to biodiversity in the South Okanagan: urban and agricultural development; livestock grazing and trampling of riparian vegetation; range improvement by seeding alien, agronomic grass species; herbicide and insecticide applications; lake rehabilitation with poison; flood control; river channelling; and introduction of non-native species. Pitt and Tracy (1994) and others have shown that only a fraction of the Bunchgrass biogeoclimatic zone remains ecologically intact. Although direct losses of habitat to farms, orchards, roads, towns, and other forms of development account for only a small fraction of the total grassland area, they were doubtless at least a contributing factor in the declines of a number of species that require riparian (related to or on the bank of a watercourse) habitats, in and around which urban and agricultural development are concentrated. Urban and rural development and fragmentation are also centres for dispersal of alien weeds, such as knapweeds (*Centaurea spp.*), that have invaded large areas of the grassland ecosystems. Knapweed is implicated in the loss of endangered Burrowing Owl (*Athene cunicularia*) habitat, as well as reducing productivity of native perennial grasses for wildlife and livestock grazing. These effects will alter the ability of grassland and steppe ecosystems to occupy potential new distributions. To facilitate grassland ecosystem to climate change it may be necessary to expand networks of protected areas (a difficult task, since so much is private) where natural processes such as fire can be re-introduced and grazing eliminated, and expand private land stewardship programs.

Vertebrates

Birds

This section was compiled from notes provided by Pam Sinclair, Canadian Wildlife Service, Whitehorse and Richard Cannings, Cannings Holm Consulting (formerly of University of British Columbia)

There is no official “Red List” of Yukon birds at risk. However, 58 species (not including those listed by COSWEIC, unless the Yukon population is small) have small or geographically restricted breeding populations in the Yukon, and may therefore be at risk (Table 9). All are migratory. Of these, 40 are at the northern limit of their range, and most of these could expand their range in Yukon with global warming and the consequent ecological changes. A few, however, are alpine species that will lose habitat in Yukon, although they are secure elsewhere in their range. The Beaufort Sea Coast has 16 species with small or geographically restricted populations. They obviously have nowhere to go if their coastal plain habitat becomes unsuitable, and Hebda’s (1997) predictions that Arctic tundra will largely convert to forest or steppe communities portends ill for these species. Finally, there are two special cases. The Surfbird’s small breeding population, Canada’s only one, is limited to alpine tundra in west central and northern Yukon. There is also a small, disjunct population of Siberian Tit in the interior of northern Yukon.

Most birds obviously move easily to new habitats; but colonial-nesting birds, less so. It is also obvious that specialized wetland nesting habitats can not simply follow changing isotherms northward, or up slope, as can terrestrial plant communities. Red listed species of British Columbia are grouped in Table 10 by habitat type. Birds of the dry Interior: Bunchgrass, Ponderosa Pine and Interior Douglas-fir zones will gain habitat, if land use changes do not prevent their occupation of it. Those species breeding in specialized marshland habitats are in competition with licensed water withdrawals for urban, domestic and agricultural uses, and livestock watering that may intensify with diminished snowmelt runoff and summer or autumn precipitation. These changes would be exacerbated by livestock trampling of marshy shorelines. Birds that breed on islands offshore will not likely be affected by climate change, if marine ecosystems remain productive; however, commercial fishing will have to adapt to any fluctuations in marine productivity that may be associated with climate change, if collapse of marine ecosystems is to be avoided. Birds that breed east of the Rockies may gain habitat in the northeast corner of the province.

Table 9. Rare birds of Yukon

Marine Mammals

This section was compiled from notes provided by Graham Ellis, DFO (BC) and Doug Larsen, Yukon Department of Renewable Resources (Yukon)

Zooplankton and herring are the main prey of humpback (“threatened” on COSEWIC list) and right whales, while larger fish (especially salmon) are the main prey of resident killer whales. Gray whales feed on benthic invertebrates. Transient killer whales prey on marine mammals (seals and sea lions). Climate change will cause change in whale prey distribution, and it is difficult to know if whales will change their migration and feeding habitats to follow new prey distributions. Some whales exhibit feeding site fidelity, which may retard their adaptation to changing prey distributions.

Sea otters are more dependent on local habitats (kelp beds among rocky islets along exposed coast with wave surge), and are more likely to stay in one place and become food-limited, rather than change colony locations to seek better prey densities. They may switch food sources, as there is some evidence that the maternal parent teaches food preference to her offspring.

In Yukon, the Bowhead Whale is listed by COSEWIC as endangered. Reduced ice cover may allow greater exploitation of habitats, but range expansion is unlikely.

Species at the northern limit of their range	
Evening Grosbeak	*Short-billed Dowitcher
*White-throated Sparrow	Greater Yellowlegs
Swamp Sparrow	*Killdeer
Le Conte’s Sparrow	*American Coot
*Brewer’s Sparrow	*Osprey
Rose-breasted Grosbeak	*Ruddy Duck
*Western Tanager	*Redhead
Canada Warbnler	*Gadwall
*MacGillivray’s Warbler	*Blue-winged Teal
Mourning Warbler	
Ovenbird	**Birds of specialized habitats, small ranges**
Pied-billed Grebe	*Surfbird
*Black and White Warbler	Siberian Tit
*Bay-breasted Warbler	
Townsend’s Warbler	**Birds of the Beaufort Sea Coast**
Cape May Warbler	*Brant
*Magnolia Warbler	*Common Eider
Red-eyed Vireo	*Sandhill Crane
Philadelphia Vireo	*Whimbrel
Solitary Vireo	*Ruddy Turnstone
*Cedar Waxwing	*Semipalmated
Winter Wren	*Pectoral Sandpiper
*Mountain Chickadee	*Stilt Sandpiper
Northern Rough-winged Swallow	*Peregrine Falcon (tundrius)
Eastern Phoebe	*Yellow Wagtail
Dusky Flycatcher	Bluethroat
Yellow-bellied Flycatcher	*Black Guillemot
Pileated Woodpecker	*Parasitic Jaeger
*Black-backed Woodpecker	*Red Phalarope
*Black Tern	*Long-billed Dowitcher
*Wilson’s Phalarope	*Buff-breasted Sandpiper

*nesting confirmed

Table 10. Red listed birds of British Columbia.

Species	Breeding Habitat
Birds of the dry Interior: Bunchgrass, Ponderosa Pine and Interior Douglas-fir zones	
Ferruginous Hawk	has bred (rarely) in PP/IDF near Ashcroft
Prairie Falcon	large cliffs in BG/PP/IDF, Okanagan to Chilcotin
Sage Grouse	extirpated from south Okanagan
Burrowing Owl	once bred in Thompson/Okanagan
Williamson's Sapsucker (nataliae ssp.)	IDF near Cranbrook
White-headed Woodpecker	mature ponderosa pine in PP south of Kelowna
Sage Thrasher	large sagebrush in BG, s. Okanagan/similkameen
Sprague's Pipit	has bred (very rarely) in IDF grasslands near Riske Creek
Yellow-breasted Chat	BG riparian thickets, s. Okanagan
Brewer's Sparrow (breweri ssp.)	sagebrush habitats in BG, s. Okanagan
Grasshopper Sparrow	grasslands in BG/PP/IDF
Birds of CDF zone of Georgia Basin	
Horned Lark (strigata ssp.)	breeds (bred?) on grasslands in Lower Mainland
Purple Martin	along coast, usually at estuaries; needs cavities
Vesper Sparrow (affinis ssp.)	grasslands on s.e. Vancouver Island
Yellow-billed Cuckoo	(extirpated) thick riparian brush in Lower Mainland
Birds of east slope of Rockies and Prairies	
Peregrine Falcon (anatum ssp.)	throughout interior and n.e. BC, but numbers greatly diminished
Bay-breasted Warbler	mature spruce east of Rockies
Cape May Warbler	spruce east of Rockies
Connecticut Warbler	mature aspen forests east of Rockies
Birds of specialized Interior habitats	
Nelson's sharp-tailed Sparrow	sedge marshes east of Rockies
Western Grebe	marshy edges of large lakes in Okanagan, Shuswap and Creston
American White Pelican	only at Stum Lake in Chilcotin
Upland Sandpiper	tall-grass prairie in Peace River area and Chiltotin
Forsters Tern	marshes at Creston
Birds of offshore islands	
Pelagic Cormorant	offshore islands
Brandt's Cormorant	a few islets off s.w. Vancouver Island
Common Murre	Triangle Island, Cape St. James and a few other rocks off west coast of Vancouver Island
Thick-billed Murre	Triangle Island
Horned Puffin	Queen Charlotte Islands and probably also at Triangle and Solander Islands
Birds of Specialized Coastal Habitats	
Northern Goshawk (laingi ssp.)	forest (probably requires old-growth) in CWH, MH
Spotted Owl	old-growth forest in CWH, MS

Terrestrial Mammals

Ungulates

Written by L. Harding with input from Manfred Hoefs, Yukon Department of Renewable Resources (Yukon), and extensive notes provided by Dan Blower, BC Environment, Lands and Parks (influence of climate on BC ungulates).

Climate has a profound effect on ungulate survival in winter, and is a major factor affecting their distribution (see, for example, syntheses by Brandborg, 1955; Des Mueles, 1964; Geist, 1971; Hatter, 1950; Kelsall, 1968; Pruitt, 1958;Taylor, 1956). Winter snow depth and condition (density and crust) limit movements and control availability of forage, while heat loss (hence, food energy requirements) is directly related to temperature and wind. Powder snow is not as limiting on animal movement as is dense snow up to the point at which dense snow become sufficiently compact to support the animals' weight. Crusting snow, caused by temperatures fluctuating above and below zero, severely limits ungulate movements except for caribou, whose weight per unit area of footprint is much lower that other ungulates. Wind at high elevations often results in shallow or absent snow cover on ridges and windward slopes.

Each species has different strategies for coping with snow: Deer, whose movements are restricted with snow depths of about 50 cm, favour low elevation, south-facing slopes in mild snow areas. Bighorn and thinhorn sheep are limited at about the same snow depths, and hence seek similar winter ranges, but also use windswept high elevation ridges. Mountain goats have a different strategy, remaining at high elevation, but making trails through dense snow at upper elevation in old growth forest and moving onto steep cliffs or avalanche paths in late winter-spring. Elk can tolerate about 75 cm. of snow, and occupy similar habitats to deer, but more northerly and higher elevation. Caribou movements are impaired at about 80 cm. of soft snow, but their wide hooves and light weight allow them to walk on top of snow when it reaches a certain density, usually by mid-winter. In the Columbia mountains, caribou often migrate to low elevation early in winter, moving up to higher slopes later as snow becomes more dense, when they feed on arboreal lichens. However, the northern caribou paw through the relatively less dense snow of the north to forage on terrestrial lichens. Moose can walk through the deepest snow, up to about 95 cm.

Predicting ungulate response to climate change is not straightforward. In general, ungulates might move northward and upslope along with their preferred habitats. But more precipitation in areas of cold temperatures, notwithstanding some warming, would still mean more snow and harder winters for ungulates. Conversely, more precipitation falling as rain in the "warm snow zone" of the south coast could free up habitat for ungulates (mainly deer).

Earlier onset of mild spring temperatures might in some case remove winter energy budget bottlenecks, allowing some herds to flourish; however, the risk of a hard, crust-forming freeze after a rain increases under these conditions, as happened during the winter of 1996-97 in the southern part of B.C. Nor are these events consistent: ungulates have always fared well during successions of mild winters, only to be decimated during unusually cold ones. The large, normal fluctuations in ungulate survival will make it difficult to detect trends due to climate change for many years.

In northern British Columbia and southern Yukon, deer, elk and bison populations have expanded their ranges during the past three decades. Wood bison ("threatened" on COSEWIC) occur in very small groups with restricted ranges in both northern British Columbia and Yukon. Plains bison were re-introduced into northern British Columbia in 1973 and have expanded their range and numbers. These trends would in general be consistent with global warming, although many local exceptions are expected. Mountain goats are at the northern limit of their range in Yukon, which would probably expand northward with global warming. Caribou populations have declined throughout British Columbia due to a combination of hunting, logging and predation (Page, 1985); in Yukon, some caribou herds have decreased and some have increased, but trends for most are unknown (Department of Renewable Resources and Environment Canada, 1996). Global warming would further threaten caribou habitats, more so in the south where their alpine tundra habitats would diminish greatly. Muskox have re-entered the Territory from the west and established a secure population. They are tundra animals, and would lose habitat with advancing forest and shrub communities.

Small Mammals

A number of shrews, moles, mice and voles are rare, but not all have been fully assessed as to their conservation status, particularly in Yukon. Rare small mammals at the northern limit of their ranges may have opportunities to expand northward or up slope with global warming. Examples are the Pacific Water Shrew ("threatened" on COSEWIC list), Vancouver Island Water Shrew, Trowbridge's Shrew and Townsend's Mole, while live in the Coastal Douglas-fir zone; and the Western Harvest Mouse ("vulnerable on COSEWIC list) of the dry Interior (Nagorsen, 1995). The Tundra Shrew is at the southern limit of its range in British Columbia and could theoretically lose habitat, but will have ample opportunity to move upslope in those high, glaciated coastal mountains.

For the endangered Vancouver Island marmot to adapt to forests encroaching into its subalpine and alpine habitats, it will have to be able to exploit alternative habitat such as logging clearcuts, and there is some evidence that this may be the case.

Eight of British Columbia's bats - half its native species - are rare or endangered. All of these are at the northern limit of their ranges, whether coastal mountains or dry interior (Nagorsen, 1993), and will have opportunity to follow changing climates northward and upslope.

Nutall's cottontail rabbit ("vulnerable" on COSEWIC list) lives in the dry Interior and will gain potential habitat.

Carnivores

Grizzly Bear and Wolverine are "vulnerable" on the COSEWIC list, but these wilderness species are more threatened by trapping, hunting, roads and development than by habitat changes.

Fish

This section was compiled from notes provided by Alex Peden, *Liparis* Biological Services, Victoria, B.C.

Fish of warm climate river and lake waters may move northward, and fish of lower elevations may displace fish of higher elevations, unless barriers such as waterfalls impede their movement. Warmer-water fish that may gain habitat include *Mylocheilus caurinus, Ptychocheilus oregonensis, Richardsonius balteatus, Cottus asper* and *C. rotheus*. These coldwater fish may retreat to the north, or up slope: all native salmonids including whitefishes, plus *Spirinchus thaleichthys, Thaleichthys pacificus, Lota lota, Percopsis omiscomaycus, Pungitius pungitius, Culea inconstans, Cottus cognatus* and *C. ricei*.

Genetically distinct stocks characteristic of southern parts of their range could be exterminated if they can not disperse northward. These would include some salmonids, and may include other species for which genetic variability data have not yet been obtained.

Most introduced (alien, or exotic) species are warm water fish, and would increase range and abundance northward, provided there are no physical barriers. Examples include: *Ictalurus nebulosus, I. Melas, Lepomis gibbosus, Micropterus salmoides, M. dolomieui, Pomoxis nigromaculatus, Tinca tinca*, and *Carasius auratus*.

A number of native fish species tolerate slightly warmer, but not much warmer, water. Therefore, closely related species may sort out micro-habitats along watercourses. Temperature changes may affect their relationships within a stream, but will not alter their overall distribution. Table 11 gives expected response of BC red-listed freshwater fish species .

CONCLUSIONS

Some species are likely to gain habitats as their range expands north or upslope, except those with nowhere to go, such as species living along the Beaufort Sea coast, or in specialized habitats that can not move. Species at the southern limit of their ranges may retract out of British Columbia, but expand in Yukon. Alpine tundra species, especially those in southern British Columbia, are likely to lose habitat. Relative proportions of some taxonomic groups are shown in Figure 3.

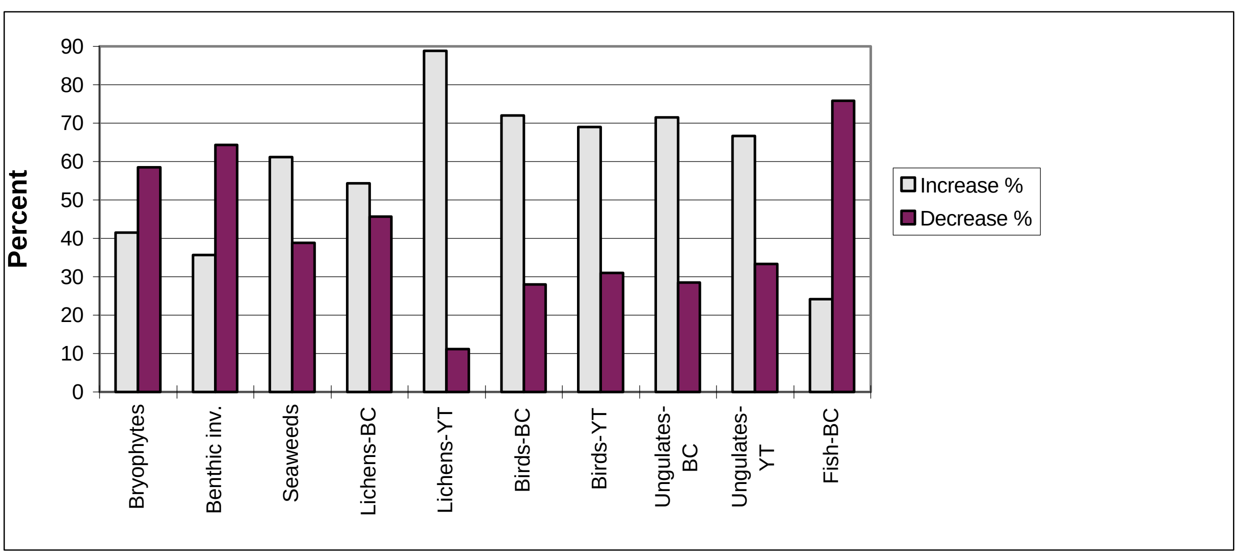
The ability of a species to shift its range and distribution will depend on its specific habitat requirements, its mechanisms of dispersal, and the barriers involved. For most invertebrates, many plants and some vertebrates, their limited means of dispersal will hinder their ability to move. Soil organisms and many plants will need continuity of habitat to move. Only plants with spores or "dust" seed

Table 11. Possible response of British Columbia endangered and vulnerable freshwater fish to global warming (COSEWIC, provincial classification).

Species	Comments
Speckled Dace, Rhinichthys osculus (vulnerable, red)	expect to spread further up small tributaries
White Sturgeon, Acipenser transmontanus (vulnerable, blue)	plenty of habitat upriver in Fraser system, if water temperatures become more suitable there; upriver spread in Columbia system prevented by power dams. Sea level rise could affect populations in lower Fraser system.
Broad Whitefish, Coregonus nasus (red)	warming effects positive, unless competition with lake whitefish, C. clupeaformis is enhanced
Cisco, Coregonus artedi (red)	Deep, large northern lake habitats will probably resist warming, but survival in very shallow lakes (e.g., Maxihamish L.) will depend on how warming affects the thermocline in summer
Least Cisco, Coregonus sardinella (red)	Deep, large northern lake habitats in B.C. and Yukon will probably resist warming, but survival in some will depend on whether warming enhances competition (e.g., with kokanee)
Giant Pygmy Whitefish, Prosopium sp. (red)	restricted to two very small lakes; any eutrophication through warming would be deleterious.
Pygmy Longfin Smelt, Spirinchus sp. (red)	restricted to 2 very large, deep lakes, both subject to sea level rise if ice caps melt, which would permit invasion and competition with S. thaleichthys. Eutrophication would also be a threat.
Chizelmouth, Acrocheeilus alutaceus (blue)	disjunct populations in s. Okanagan, upper Columbia and Chilcotin; could expand northward, but warming and pollution could reduce habitat in s. Okanagan.
N. Redbelly and Finescale Dace hybrids, Chrosomos eos x Chrsomos neogaeus (red)	likely a temporary, aberrant situation - and example of hybridization that could be more frequent with global warming as new situations bring closely related populations together
Brassy Minnow, Hybognathus hankinsoni (blue)	disjunct range is likely caused by previous climatic or geologic uphevals; warming could expand range to higher elevation
Fathead Minnow, Pimiphales promelas (red)	Peace or Liard R. fish still expanding s. into n.e. B.C. Could enter Fraser system if assisted (e.g., by roadside ditches)
Spottail Shiner, Notropis hudsonius (red)	Peace or Liard R. fish still expanding s. into n.e. B.C. Could enter Fraser system if assisted (e.g., by roadside ditches)
Emerald Shiner, Notropis atherinoides (red)	Peace or Liard R. fish still expanding s. into n.e. B.C. Could enter Fraser system if assisted (e.g., by roadside ditches)
Ninespine Stickleback, Punginitius punginitius (red)	Peace or Liard R. fish still expanding s. into n.e. B.C. Could enter Fraser system if assisted (e.g., by roadside ditches)

Pearl Dace, Margariscus margarita (blue)	Peace or Liard R. fish still expanding s. into n.e. B.C. Could enter Fraser system if assisted (e.g., by roadside ditches)
Nooksack Dace, Rhinichthys sp.	Undescribed species already under stress in Lower Fraser Valley would go extinct if habitat became too warm or eutrophic
Salish sucker, Catostomus sp.	Same situation as Nooksak dace, bur rarer; could expand into Olympic Peninsula
12 rare, undescribed Limnetic Stickleback populations, Gasterosteus sp. (2 are threatened; all are red-listed)	all are isolated, unique genetic populations with nowhere to go if warming made habitat unsuitable. Competition with alien fish is a current threat which would worsen. Competition with regular G. aculeatus would be likely.
Giant Black Stickleback, Gasterosteus sp. (vulnerable, red)	several highly variable populations adapted to specific water conditions on Queen Charlotte Islands. Any change of habitats (ppt., temp.) could cause loss of identifiable populations.
Spineless Stickleback, Gasterosteus sp. (no status)	would be lost if warming allowed introduction of predators or competition with other sticklebacks
Mottled Sculpin, Cottus bairdi (blue)	warming could cause replacement by C. cognatus in Flathead; could disperse upstream in Okanagan if transplanted above Okanagan Falls, in Kettle if transplanted above Cascade Falls and in Kootenay if transplanted above the falls and dams.
Shorthead sculpin, Cottus confusus (threatened, red)	very slow to disperse; if transplanted above Cascade Falls on Kettle, would eventually find equilibrium with Slimey and Mottled Sculpins; would also live in Okanagan, if transplanted
Cultus Lake Sculpin, Cottus sp. (red)	highly dependent on limnological conditions and status of thermocline, if surface waters warm. Nowhere to disperse.

Figure 3. Relative proportion of species likely to gain and lose habitat in selected taxonomic categories.



may match the rate needed to keep up with climate change. Because different species have differing dispersal ability, and respond individually to climate, communities will tend to fragment as species shift their ranges in different directions. The species that disperse most easily, and therefore will adapt more readily to climate change, are rapid colonizers of disturbed habitats. These are "weedy" or invasive species, whether native or alien, or generalists that can use a variety of habitats. The species least able to disperse and hence adapt quickly tend to be more characteristic of stable, climate communities. Moreover, the interaction between habitat destruction and climate change is synergistic: the combination of the two processes could threaten more species than the sum of their individual effects.

Land uses that leave intact soil, grassland cover, wetland riparian zones and forest canopies, will facilitate dispersal of many conservative dispersers to new habitats. Networks of undisturbed (or restored) forest and riparian habitats along watercourse will be especially important. Wetlands will be particularly difficult to protect, and managers (including private landowners) will have to be vigilant about livestock use and water withdrawals to protect species such as marsh-nesting birds. Environmentally sensitive land use will therefore be the key to conserving biodiversity in the face of a changing climate.

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Chapter 10

IMPACTS OF CLIMATE CHANGE ON THE PLANT COMMUNITIES OF ALPINE ECOSYSTEMS

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OVERVIEW

Climate models suggest that treelines will migrate upwards hundreds of metres to elevations common during the Holocene. However, recent studies of treeline movement have shown that precipitation patterns are at least or even more important as temperature in affecting tree establishment. Many of the recent tree invaders in the Pacific Northwest established during the warmer dry period between 1920 and 1940. Wetter winters and warmer drier summers are predicted for British Columbia and Yukon. Wetter winters could mean that more snow would fall in alpine regions which, if that shortened the snow-free period, could adversely affect tree establishment. Similarly, drier summers might result in catastrophic fires which would also retard tree establishment. In any case, different tree species will be affected differently, so we might see a change in tree species composition, irrespective of treeline movement. In addition, increased temperatures and snowpack have been shown to affect tundra and heath species differently, so that changes in species composition are also likely to occur above the treeline.

INTRODUCTION

Given the mountainous nature of British Columbia and Yukon, alpine habitats represent a significant proportion of the landmass (Table 1, Marvin Eng, pers. comm.). Some of that consists of rocks and ice and cannot support wildlife. Excluding that portion (estimated at 30% in the Central Alps (Körner, 1995)), there still remains 13.4 % of BC's landmass in Alpine Tundra (Table 1), which is far above the global average at 3% (Körner, 1995). When one includes subalpine habitats, that brings the total to 39.2% of BC's landmass that supports alpine and subalpine plant and animals (Table 1). This may be surprising since most of us live in the valley bottoms, and what alpine and subalpine habitat we visit is fragmented and found on isolated mountain tops. With climate change, alpine and subalpine ecosystems will be reduced in area, which may have drastic consequences for the unique species of plant and animals found there.

A simplified analysis of effects of climate change on alpine and subalpine areas involves the calculation of effects of temperature on the location of the treeline. In general, low temperatures result in alpine tundra at high elevations because trees are unable to grow under those extreme conditions. On average, temperature decreases about 6 ^{o}C per vertical kilometre (Barry, 1992). General circulation models (GCMs) predict that BC and Yukon may become 1-4.5 ^{o}C warmer following doubling of carbon dioxide concentration (IPCC, 1995; Taylor,1997). Hence, the boundaries of subalpine and alpine zones may move 330 to 660 meters upslope. This would virtually eliminate some coastal alpine zones. However, the use of temperature gradients is a simplification of successional processes, and does not adequately reflect what actually occurs. For example, in the Swiss Alps, a considerable lag time between climate change over the last forty years and the response of vegetation is reported, with rates of upward migration of alpine plant species less than half of what might be expected on the basis of temperature alone (Grabherr *et al.*, 1995).

Prediction of both climate and ecosystem change is particularly challenging in British Columbia, given the poor resolution of GCMs in mountainous terrain (Barry, 1994). The dominant vegetation types listed in Table 1 are reflective of a variety of climatic parameters including: depth of snow-pack, length of snow-free period, day-length during the growing season, moisture availability, and not just temperature (Meidinger and Pojar, 1991). In addition, episodic events such as storms, deeper than average snowpacks, and hotter and drier than average summers, can drive the establishment or elimination of local plant populations (Kearney, 1982).

This chapter reviews the literature on impacts of these various climatic effects on alpine and subalpine plant species around the world and relates what is known to the British Columbia and Yukon ecosystems. Of interest is to consider the more complicated scenario of climate change in BC and Yukon mountain environments and the impact on alpine and subalpine ecosystems.

CONTROLS ON MOVEMENT OF TREELINE SPECIES

As introduced above, the movement of trees into open alpine and subalpine habitats is the most obvious potential consequence of climate warming. Apart from simple temperature models, predictions of treeline processes have been developed using simulation models, historical dendrochronological or palynological studies, and ecological data on subalpine tree establishment.

Simulation models of alpine, subalpine, and treeline processes

Climate-Vegetation Models (CVMs) use ecological relationships and a variety of parameters describing climatic conditions to predict vegetation composition and/or productivity for a given area. Linked GCM-CVM simulations primarily model the dynamics of treed zones and their productivity. By examining changes in models of subalpine forested ecosystems, however, it is possible to extrapolate predicted changes in the essentially treeless alpine ecosystems. Most models do not attempt to address the upward migration of treeline, but presumably an increase in stand vigour and productivity at treeline will lead to the establishment of a new treeline at some elevation above the old one. Several CVM simulations predict that montane tundra in

Table 1. Alpine and subalpine biogeoclimatic zones and associated characteristics (Meidinger and Pojar, 1991; Marvin Eng, pers. comm.).

Biogeoclimatic zone **Area in BC** **Percentage of BC**	**Location**	**Mean annual temperature** **Monthly breakdown**	**Mean annual precipitation** **Percentage snow** **Depth of snowfall**	**Altitudinal range of lower limits (m) (West to East)**	**Associated vegetation**
Alpine Tundra **18,200,000 km^2** **19.2 %**	Throughout BC and Yukon, on high mountains	-4 to 0^o C <0^o C (7-11 mo)	700-3000 mm 70-80% 49-240 cm	1650-2250 (South) 1000-1400 (North)	Dwarf willows (*Salix* spp.), Heathers (*Phyllodoce* and *Cassiope*), Cushion plants (*Dryas* spp. + others), grasses, sedges and lichens
Spruce/ Willow/ Birch **7,300,000 km^2** **7.7 %**	Northern BC and Yukon subalpine: from 56.5-57^o N to 60-70^o N	-.7 to -3^o C <0^o C (5-7 mo) >10^o C (1-3 mo)	460-700 mm 35-60% 16-42 cm	1000-1700 (South) 900-1500 (North)	Deciduous shrubs (*Salix* spp., and *Betula*) Evergreen shrubs (*Juniperus*, and *Arctostaphylos*), grasses and sedges
Engelmann Spruce/ Subalpine Fir **13,600,000 km^2** **14.4 %**	Interior of BC, south of 57^o N	-2 to 2^o C <0^o C (5-7 mo) >10^o C (0-2 mo)	450-2200 mm 50-70% 23-154 cm	1200-2100 (SW) 1500-2300 (SE) 900-1700 (North)	Heathers (*Phyllodoce* spp. and *Cassiope* spp.), Flowers, Deciduous shrubs (*Alnus*), grasses
Mountain Hemlock **3,500,000 km^2** **3.7 %**	Coastal mountains of BC, in the subalpine	0 to 5^o C <0^o C (1-5 mo) >10^o C (1-3 mo)	1700-5000 mm 20-70% 34-350 cm	900-1800 (South) 400-1000 (North)	Coniferous trees (mountain hemlock, amabilis fir, yellow-cedar, Douglas-fir, western redcedar, Sitka spruce, whitebark pine), Deciduous shrubs (*Vaccinium* spp., *Menziesia*, *Rhododendron*, *Phyllodoc*e spp., *Cassiope* spp.), mosses

central and northern Europe will be invaded by trees following global warming (Keinast and Kräuchi, 1989; Nilsson and Pitt, 1991). Furthermore, Bugmann and Fishlin's (1994) simulation of forest succession in the Swiss Alps under a climate change scenario suggests that forests at higher elevations will experience greater changes in species composition than forests at lower elevations.

Similar approaches have been used to address the issue of climate change in Canada. Burton and Cumming (1995) modelled the possible consequences of global warming on the forests of British Columbia and Alberta. After 350 simulation years, productivity of the Mountain Hemlock Zone increased by 30-40%, and productivity of the Engelman Spruce-Subalpine Fir Zone was increased by 5-10%. The Spruce-Willow-Birch Zone was not included in the study but other spruce-dominated zones showed up to a 65% increase in productivity.

The CVMs used in the above studies differ widely in their underlying assumptions, geographic location of the area being modelled, and the spatial scale of investigation. Despite this diversity, a consistent theme is the sensitivity of high altitude tundra and forests to climatic change in computer simulations.

Paleoecological studies of treeline migration

Increases in alpine and boreal tree growth, relative to rates before 1850 AD, are reported in at least 20 dendrochronological studies throughout North America and Europe (reviewed by Innes, 1991; Ettl and Peterson, 1995). The increase in growth rates is probably a consequence of the upward trend in carbon dioxide concentrations and temperatures since *c.* 1860 (Innes, 1991), though Graumlich (1991) found no direct correlations between tree-ring widths and increases in carbon dioxide concentrations. Instead, growth in lodgepole pine was correlated with winter precipitation and that of foxtail pine was associated both with summer temperatures and winter precipitation (Graumlich, 1991).

Nonetheless, palynological evidence and the presence of sub-fossil wood at many European and North American sites that are currently above treeline indicate that the treeline responded dynamically to changes in the environment (reviewed by Rochefort *et al.*, 1994). During the early to mid-Holocene, treelines were up to 200 m higher in Sweden (Kullman, 1990), 150m higher in California (La Marche, 1973), 70m higher in Colorado (Carrara *et al*., 1984), and 130m higher in southwestern BC (Clague and Mathewes, 1989) than at present. Climatic changes in the Holocene involved changes to atmospheric circulation and precipitation as well as temperature, but the roughly synchronous change in treeline elevation at many different locations underscores the importance of temperature in controlling treeline position at a broad scale (Rochefort *et al*., 1994) though as mentioned above, individual variation among trees and sites of growth can affect local patchiness (Ettl and Peterson, 1995). The mid Holocene may provide a useful, if conservative, analogue for treeline shifts following global warming if climate change occurs as projected by the General Circulation Models (Innes, 1991).

Recent seedling establishment and enhanced growth in the subalpine

The absence of trees in alpine ecosystems has been attributed to various combinations of winter desiccation, damage from wind and blowing snow, a negative carbon balance, short growing seasons, fires, insufficient shoot ripening in woody plants, and frost heave (Grace, 1989; Crawford, 1989; Wardle, 1971, 1974; Stevens and Fox, 1991). Most explanations involve an interaction between climate (micro, meso, and/or macro climate) and physiology, suggesting that a change in climate should result in a change in treeline position, especially given how close many species at treeline are to some physiological limit on survival and/or reproduction (Körner, 1995; Rochefort *et al.*, 1994).

Recent increases in tree seedling recruitment at or above treeline have been reported in many parts of the world, including Canada, the United States, Sweden, Finland, Russia, and New Zealand (reviewed by Graumlich, 1994; Peterson, 1994; and Rochefort *et al*., 1994). This phenomenon is well documented in the Pacific Northwest (Peterson, 1994), with reports of recent tree seedling establishment in alpine and subalpine meadows in British Columbia, Washington, and Oregon (Table 2). Similar tree seedling invasions at or above the tree limit

Table 2. Evidence for upward altitudinal treeline migration in the last century.

Location	Species	Biogeoclimatic Zone	Timing of establishment	Correlation with climate or event?	Reference
Olympic Mountains **WA**	Mountain hemlock (*Tsuga mertensiana*) Subalpine fir (*Abies lasiocarpa*) Amabilis fir (*Abies amabilis*) Douglas fir (*Pseudotsuga menziesii*)	Mountain hemlock	After fire Unburned transect: mountain hemlock: 1930-1950.	Fire Drought, with reduced spring snowpack	Agee and Smith (1984)
Olympic Mountains **WA**	Mountain hemlock (*Tsuga mertensiana*) Subalpine fir (*Abies lasiocarpa*)	Mountain hemlock	mountain hemlock: 1921-1945 subalpine fir: 1956 - 1985	Drier than average summers Wetter than average summers and more snow	Woodward et al. (1995)
Garibaldi park, BC	Mountain hemlock (*Tsuga mertensiana*) Subalpine fir (*Abies lasiocarpa*)	Mountain hemlock	mostly subalpine fir: 1919-1939	Not described	Brink (1959)
Jasper National Park, Alta.	Engelmann spruce (*Picea engelmannii*) Subalpine fir (*Abies lasiocarpa*)	perhaps Engelmann spruce/ Subalpine fir	subalpine fir: 1930 - 1950 1965 - 1973	Higher than average mean minimum summer temperatures. Summer precipitation not important.	Kearney (1982)
Mount Baker **WA**	Mountain hemlock (*Tsuga mertensiana*) Subalpine fir (*Abies lasiocarpa*) Amabilis fir (*Abies amabilis*)	Mountain Hemlock	1920-1955	Warmer and drier period: supported by dendrochronological evidence showing increased mountain hemlock growth between 1910-1945	Heikkinen (1984)
Mary's Peak, OR	Noble fir (*Abies procera*)	Not commonly in BC or Yukon	throughout study	not clear	Magee and Antos (1992)
North Cascades WA	Mountain hemlock (*Tsuga mertensiana*) Subalpine fir (*Abies lasiocarpa*) Alpine Larch (*Larix lyallii*)	Mountain Hemlock ESSF ?	1923-1945	Warmer and drier period: no direct data, but confirmed by Nisqually glacial retreat between 1910 - 1953	Franklin et al. (1971)
Olympic Mountains WA	Mountain hemlock (*Tsuga mertensiana*) Subalpine fir (*Abies lasiocarpa*)	Mountain Hemlock	1924-1934 1944-1949 1954-1961	Presumably because warmer and drier, but no data.	Fonda and Bliss (1969)

are reported from the Rocky Mountains in Alberta (Kearney, 1982) and Colorado (Daly and Shankman, 1985).

Many young trees established at treeline in the Pacific Northwest following the end of the Little Ice Age (*c.* 1880), with a peak in the unusually warm and dry period between 1920 and 1950 (Table 2). Despite an increase in greenhouse gases and a continuation of climate change since the 1950s, few trees have become established since that time. There is no experimental evidence that pinpoints establishment requirements for treeline conifers; rather, spatial and temporal correlations have been used to examine factors related to seedling establishment.

For example, the association of subalpine tree establishment between 1920 and 1950, during a warmer and drier period, suggests that a longer than average snow-free period is required (Franklin *et al*., 1971). Vegetation surveys of the western north Cascades showed that mountain hemlock and subalpine fir are found on well drained sites, presumably because they are snow-free long enough to drain (Douglas, 1972). Woodward *et al*. (1995) agreed that establishment of mountain hemlock was associated with dryer than average summers, but that establishment of subalpine fir was associated with increased precipitation of snow as well as rain. These climatic patterns balanced the otherwise dry nature of subalpine fir habitats and moist to wet characteristic of mountain hemlock habitats (Fonda and Bliss, 1969; Woodward *et al*., 1995).

It is clear from these studies, that different tree species will respond individually to the changes in climate that are occurring now and that will occur in the future. This makes it very difficult to predict the nature of future treeline migration.

Projections for future treeline changes resulting from climate change

A doubling of current carbon dioxide concentrations is predicted to result in not only warmer summers and winters, but in increased winter precipitation in British Columbia and Yukon (IPCC, 1995; Taylor, Chapter 1); this will result in a deeper snowpack in alpine and subalpine ecosystems. If the warmer, drier summers also result in a longer snow-free period, then treeline migration into subalpine areas is likely to occur as it did in the last major drought between 1920 and 1950. This is especially true for mountain hemlock in the Mountain Hemlock biogeoclimatic zone which would be selectively favoured over subalpine fir (Woodward *et al*., 1995). The drier summers may also result, however, in catastrophic fires which would retard tree establishment for hundreds of years (Huff, 1995; Dan Smith, pers. comm.). In addition, if the increased winter precipitation results in a shortened snow-free period and wetter microsites, then sedge meadows (*Carex nigricans*) may be favoured (Douglas, 1972), and treeline migration may not occur.

If it does occur, treeline migration is unlikely to be uniform, even within a relatively small area. In areas where the treeline is a relict, established during periods of more favourable climate in the past, global warming may not have much of an effect on the elevation of treeline at all (Weisberg and Baker, 1995). Furthermore, microsite differences, such as wind exposure, aspect, shading, soil depth, snow accumulation, and soil moisture, can have strong influences on tree and seedling response to climatic change (Ettl and Peterson, 1995; Holtmeier and Broll, 1992; Kullman, 1990). Competition among seedlings within the subalpine heather habitats are no doubt important in seedling growth and establishment, as demonstrated by the effect of fire (Agee and Smith, 1984) and silvicultural site preparation (Zasada, 1972; Noble and Alexander, 1977).

IMPACT OF CLIMATE CHANGE ON TUNDRA VEGETATION

If the treeline migrates upward, would an effective mitigation effort to maintain open alpine environments be to remove invading trees? Would the heathers and cushion plants remain unaffected by climate change in British Columbia and Yukon? This section of the chapter summarizes results from experiments in the field that will help to answer these questions.

There is limited experimental information on alpine ecosystems. The response of arctic plants and ecosystems to *in situ* environmental manipulation, however has been studied since the mid-1980s (e.g. Chapin and Shaver, 1985; Chapin *et al.*, 1986; Tissue and Oechel, 1987; Van Cleve *et al.*, 1990; Coulson *et al.*, 1993; Havström *et al.*, 1993; Welker *et al.*, 1993; Wookey *et al.*, 1993; Parsons *et al.*, 1994; Wookey *et al.*, 1994; Scott and Rouse, 1995; Wookey *et al.*, 1995). Similar experimental studies in the alpine and subalpine are much rarer (e.g. Galen and Stanton, 1995; Harte and Shaw, 1995).

Arctic and alpine tundra are distinct biomes, but do share several characteristics including low mean annual temperatures, lack of erect trees, and short stature of plants (Körner, 1995). In arctic experiments, the plants are often the same species (or closely related to) as those of the alpine tundra of British Columbia. Hence we can cautiously extrapolate to alpine ecosystems results from arctic data.

Implications of elevated temperatures and altered nutrient cycling for tundra ecosystems

Experiments that modify the microclimate often use greenhouses and/or plastic tents to enhance temperature in cold regions, typically increasing mean air temperature by about 5 °C (e.g. Chapin and Shaver, 1985; Coulson *et al.*, 1993; Devebec and MacLean, 1993). There are some concerns, however, about unwanted side-effects of fully closed greenhouse designs, such as greater diurnal and annual temperature variation (Kennedy, 1995). Alternatively, open top plastic or plexi-glass enclosures, including cones, hexagons, and tents, avoid some of these experimental artifacts and typically increase mean daily temperature by 1-2 °C (reviewed by Marion *et al.* submitted). Other *in situ* approaches include climate-controlled greenhouses (Tissue and Oechel, 1987), overhead infra-red illumination (Harte and Shaw, 1995), buried electrical heating tape (Van Cleve *et al.*, 1990), and snowpack manipulations (Galen and Stanton, 1995; Scott and Rouse, 1995).

Evidence to date suggests that plant communities will shift in species composition, especially towards the dominance of shrubs at the expense of herbaceous plants. Artificially elevated temperatures at a dry alpine site in the Colorado Rocky Mountains increased shrub (*Artemisia tridentata* and *Pentaphylloides floribunda*) biomass and decreased aboveground biomass of herbaceous plants. Biomass of grasses was not significantly altered (Harte and Shaw, 1995). Experiments in arctic tundra have also resulted in enhanced growth of shrubs and dwarf shrubs, including representatives of the *Betula, Cassiope, Dryas, Empetrum, Ledum, Salix,* and *Vaccinium* genera which are all found in alpine and subalpine ecosystems in British Columbia and Yukon (Chapin and Shaver, 1985; Wookey *et al.*, 1993, 1995; Coulson *et al.*, 1993; Havström *et al.*, 1993; Parsons *et al.*, 1994).

Alpine plants may undergo changes in reproductive output even when vegetative growth is unaltered by climatic changes. Simulated environmental change at arctic sites resulted in increased seed yield and clonal propagation in *Eriophorum vaginatum* (Tissue and Oechel, 1987), *Polygonum viviparum* (Wookey *et al.*, 1994), *Dryas octopetala* (Wookey *et al*., 1995), and *Empetrum hermaphroditum* (Wookey *et al.*, 1993). The upward migration of alpine vegetation will be dependent on the successful reproduction of pioneer species, dispersal of propagules into vacant and unglaciated habitats, and successful seedling establishment, all within the accelerated time frame of current climate changes.

Nutrients are often a limiting factor for plant growth in arctic tundra communities, and the effect of fertilization on tundra plant growth and reproduction often exceeds that of experimental microsite warming (Chapin and Shaver, 1985; Chapin *et al.*, 1986; Henry *et al.*, 1986; Parsons *et al.*, 1994; Wookey *et al.*, 1994). The effect of nutrient limitation on plant growth is particularly important in the subarctic, but the relative importance of cold climate increases with increasing latitude and altitude (Havström *et al.*, 1993; Wookey *et al.*, 1993; Callaghan and Jonasson, 1995). It is possible that a similar relationship exists in mountainous areas, with climatic limitation of plant growth becoming relatively more important at higher elevations; this is speculation on the part of the authors as we know of no studies that have examined this question in detail.

The nutrient status of soils in cold regions may increase following global warming due to increased decomposition and mineralization (Van Cleve *et al.*, 1990; Bonan and Van Cleve, 1992). Increased available nutrients could stimulate growth and reproduction in the subarctic, and, by extension, in the subalpine. Synergistic interactions between the effects of temperature and fertilizer treatments in several studies illustrate the potential complexity of plant responses to climate change (Chapin and Shaver, 1985;

Wookey *et al.*, 1993, 1995; Parsons *et al.*, 1994).

Other factors affecting tundra vegetation response to climate change

There is little evidence to support speculations about the direct effects of increased CO_2 concentrations on tundra species and communities. Exposing *Eriophorum vaginatum* plants to *in situ* elevated levels of CO_2 increased tiller production, but did not boost photosynthesis, growth, or biomass (Tissue and Oechel, 1987). Increased atmospheric CO_2 concentrations can have short-term effects on plant photo-synthesis, water-use efficiency, respiration, and growth, however extensive research is still required to elucidate the long-term plant community responses to atmospheric CO_2 addition (Amthor, 1995).

Interactions with other organisms will possibly mediate tundra plant community response to climate change, especially at lower latitudes and elevations where vegetation is better developed and plant competition is stronger. For example, in a tundra heath warming experiment, a thick moss layer inhibited soil warming, presumably moderating the growth response of other plants to the experimental treatment (Coulson *et al.*, 1993). As well, enhancement of shrub growth could significantly alter the microclimate experienced by small plants growing under the shrub layer (G. Henry, *pers. comm.*).

The increased winter precipitation expected in British Columbia because of climate change could have two results: 1) a deeper snowpack, and 2) expansion of glaciers, reducing available alpine habitat. Relatively rapid changes in plant community composition following experimental snowpack modification have been documented in both alpine (Galen and Stanton, 1995) and arctic tundra ecosystems (Scott and Rouse, 1995). Plants will be competing under changing climatic conditions, and for establishment sites that will become scarcer over time. This is especially true in the coastal mountain ranges of British Columbia, where there is already very little alpine tundra habitat that is available for plant establishment (Dan Smith, pers. comm.).

CONCLUSIONS

British Columbia and Yukon are unusual, at a global scale, for having relatively intact treelines that can undergo natural processes. Around the world, most treelines and adjacent alpine and subalpine zones are inhabited either by people or their livestock, preventing natural regeneration and upward treeline migration (Wardle, 1974). In British Columbia and Yukon, an upward movement of the treeline may eliminate some habitats and associated wildlife.

It is likely that upward movements of the treeline in alpine areas will not be uniform throughout British Columbia and Yukon, since it is dependent on the individual response of subalpine tree species to changing climate. If future climate change mimics past climatic conditions, then we can expect a landscape similar to the one seen during the Holocene. However, the changes occurring now are not necessarily the same. Despite continued increases in carbon dioxide concentrations, subalpine trees established in new, higher, habitats are primarily those established during the dry period between the 20s and 40s. Now and into the future, winter snow accumulation may offset the effect of warmer and drier summers.

Even without treeline migration, changes in climate as predicted for British Columbia and Yukon will affect community composition of heath and tundra vegetation. Studies in other alpine and arctic habitats suggest that shrubs will dominate at the expense of herbaceous plants.

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GLOSSARY

alpine - habitat occurring above the limit of normal tree growth, and where they only exist in a stunted growth form.

dendrochronological - pertaining to the use of tree-rings of known age for correlating tree growth to conditions in the year of growth.

heath - a tract of land dominated by low-lying shrubs of the family Ericaceae.

herbaceous - plants that have no woody above-ground parts.

palynological - pertaining to the use of fossilized pollen grains, usually in lake sediments for assessing species composition of historical plant communities.

subalpine - intermediate habitat between alpine and forested mountain ecosystems.

treeline - the altitudinal or latitudinal limit to tree growth.

tundra - habitat situated above the treeline.

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Chapter 11

THE IMPACTS OF CLIMATE CHANGE ON SANDPIPER MIGRATION

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OVERVIEW

Birds are the most mobile vertebrates in the world. Each year billions of birds migrate between breeding grounds in Canada and winter quarters in the southern USA, Central America and South America. The direction, frequency and strength of winds are known to strongly influence the success of bird migrations. A computer simulation of the northward migration of the Western Sandpiper, one of the most abundant shorebird species in British Columbia, is used to show that predicted changes in upper atmosphere winds during migration will decrease their overall capacity to reproduce by about 3%.

INTRODUCTION

Wind is an important factor influencing the direction, routes, and departure times of migrating birds (Parslow 1969, Able 1973, Richardson 1979, 1991, Alerstam 1990, Piersma et al. 1990, Piersma and Sant 1992). For some species, wind is essential for migration (e.g. Piersma and Jukema 1991). The potentially large saving in energy and time of flying in favorable winds, the large cost of flying against winds (Liechti 1995), and the consequences on survival and reproduction by birds would favour individuals that migrated when conditions were most appropriate. Flying costs a great deal of energy that birds must replenish at migratory staging sites (Tucker 1971, Alerstam 1990, Butler and Woakes 1990) and flying in favourable winds should provide substantial energetic savings compared to flying in calm or head winds.

Recent climate model projections suggest that greenhouse gas-induced climate change will result in changes in the circulation strength of upper atmosphere winds (Boer et al 1992). As many as 25 billion birds representing 434 species migrate between temperate and tropical regions of the world (Cox 1985). The implications of shifts in wind patterns as a result of CO2 emissions is profound for migratory birds considering that an estimated 12-20 billion birds migrate between breeding grounds in North America and winter quarters in southern USA, Central America and South America (Cox 1985). Most migrating birds are unable to make these migrations in a single flight and rely on winds for assistance during flight. During stopovers, birds replenish energy reserves needed to continue the migration (e.g. Helms and Drury 1960, Biebach 1985, Klassen et al. 1990, Lindstrom and Piersma 1992, Holmgren and Lundberg 1993). Birds that take advantage of favourable tail winds will spend less time and energy on migration and arrive on the breeding grounds in the best physical condition for breeding. Thus, winds during migration are a strong selective force on the evolution of behaviours that establish the overall timing of the migration. The time of arrival on the breeding grounds is one obviously important factor, as this determines breeding success. Minimizing the combined risks of predation and starvation during the migration is also important.

In a recent paper, Clark and Butler (in prep.) used dynamic programming protocols (Mangel and Clark 1988) to develop a simulation of the migration of the Western Sandpiper (*Calidris mauri*) along the west coast of North America. The model calculated the decisions individual birds should make during migration so as to maximize their reproductive fitness. These optimal decisions were then used in a simulation model to predict the average timing of northward migration for this species.

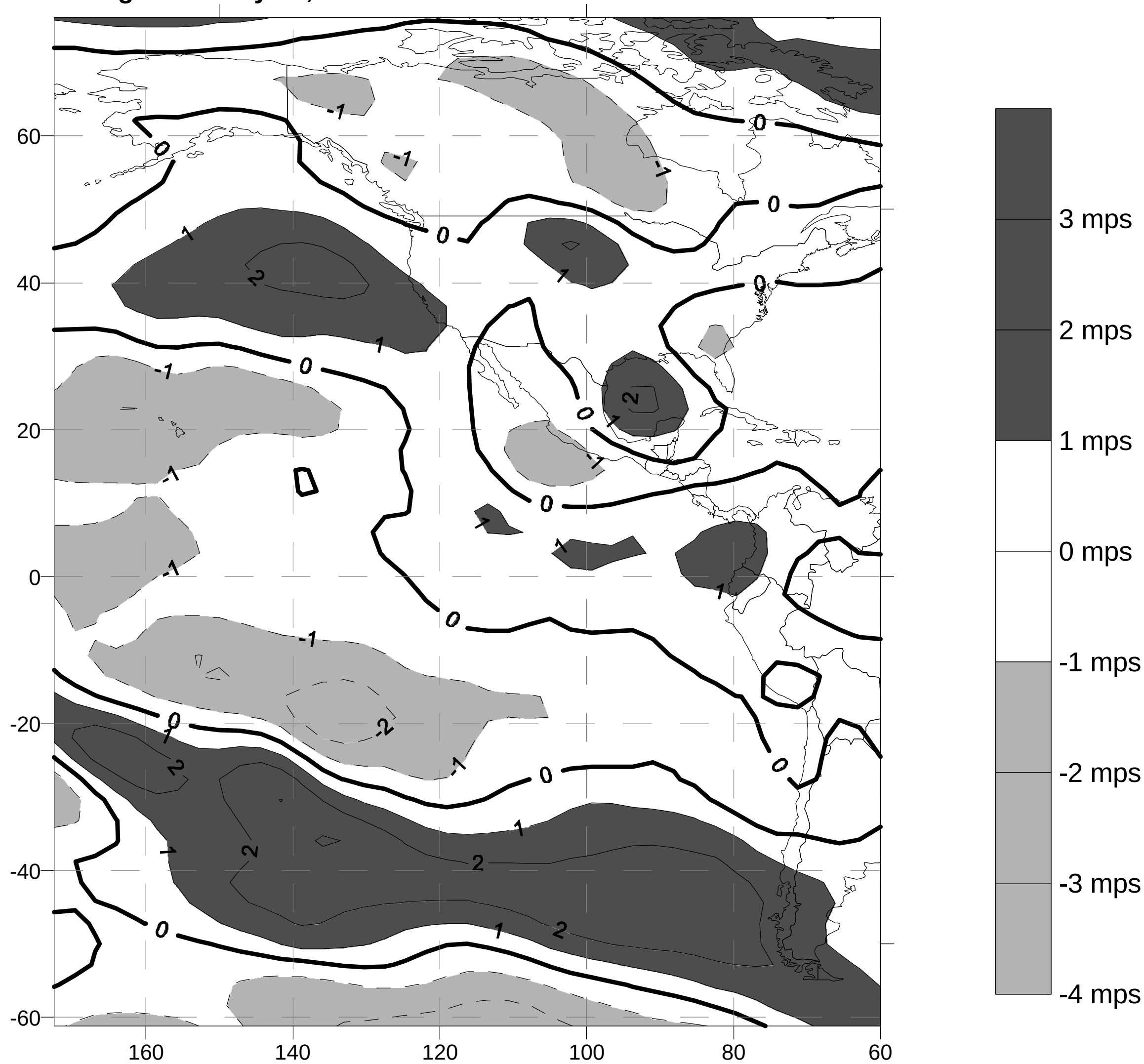
The Western Sandpiper is the most numerous shorebird on the Pacific Coast of North America during migration. Between 250,000 and one million individuals have been counted on single days on mudflats in San Francisco Bay, Grays Harbor, and the Fraser, Stikine and Copper River deltas (Iverson et al. 1996). The migration route, length of stay at staging sites, speed of migration, body masses, and breeding schedule of the western sandpiper are known in detail (Holmes 1971, Senner 1979, Butler et al. 1987, Iverson et al. 1996, Butler et al. 1996). The Western Sandpiper breeds in western Alaska and eastern Siberia and spends the winter along the Pacific Coast from southern British Columbia to Peru, and southeastern USA and the Caribbean (Wilson 1994). It migrates north through northern Mexico in late March, following the Pacific Coast of North America to the breeding grounds where it arrives in late May (Butler et al. 1996).

THE MODEL OF MIGRATION AND PREDICTED EFFECTS

The reader is directed to Clark and Butler (in prep.) for details of the model and Mangel and Clark (1988) on dynamic programming procedure. The main inputs to Clark and Butler's (in prep.) model were data pertained to: 1) the ``breeding window'', defined as the average breeding success of a female that arrives at the Alaska breeding grounds on a given date with variable energy reserves for survival during inclement weather and to produce eggs, 2) the environmental characteristics of stopover sites along the Pacific flyway including the distance between sites, food availability, predation and migration risks, 3) the physiological characteristics of the birds, including maximum energy reserve loads, flight speeds and costs, and metabolic costs during stopovers and 4) the frequency distribution of favorable or unfavorable winds during migration. Clark and Butler's (in prep.) model incorporating data on wind, energy reserves, and time remaining until the start of the breeding season, closely matched data collected in the field . We altered only the force of favourable winds in the model to predict the effect of doubled CO2 emissions for this paper.

Mean monthly wind data for April were simulated using General Circulation Model (GCM) output from the Canadian Centre for Climate Modelling and Analysis (Boer et al 1992). Grid point wind data at 850 millibars (roughly 1500 metres) covering the length of the migration route were obtained for base climate conditions (1xCO2) and for a doubling of atmospheric CO2 concentrations (2xCO2). The vector difference between the two wind simulations was calculated for each grid point. For the northern migration, a favorable tailwind blows from the southeast. By plotting the southeast component of the difference between the simulated 2xCO2 and 1xCO2 winds, we were able to identify geographic areas where increases (decreases) in the average speed of the tail wind are projected to become more (less) favourable to sandpiper migration, as well as the magnitude of those projected changes (Figure 1).

Figure 1. Projected changes in the speed (m/s) of the tailwind component of mean April winds at roughly 1500 metres under conditions of doubled CO2. Source: Canadian Centre for Climate Modelling and Analysis, Environment Canada.



The predicted upper atmosphere winds along the Pacific Coast of North America during the spring migration of western sandpipers following a doubling of upper atmospheric CO2 indicated that wind speed would increase by about 2m/s along the California coast (Fig. 1). A trivial change would occur along the rest of the coast (Fig. 1). When these wind speeds were incorporated into the Clark and Butler (in prep.) model, the fitness of female sandpipers was estimated to decline by about 3%. Our finding underscores the potential impact of changes in global weather patterns, and in particular in the frequency and force of favorable winds, on migratory birds. It also indicates that a change in one part of the migratory pathway can have consequences on the breeding grounds thousands of kilometers to the north. Current conservation efforts directed at preserving important staging sites along present day migratory routes might prove to be insufficient if the consequences of climate change are not considered. Our analysis did not include effects of changes to food availability at staging sites which would likely compound the impact of climate change. At present, the relative importance of winds on the success of migration, the speed and direction of predicted changes in global weather patterns from climate change, and the rate of adaptation by species to predicted changes in weather are poorly known. Birds have been shown to possess the capacity for rapid change to their migratory behavior in experimental conditions (Berthold 1990), but how this adaptability translates to real situations is unknown

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Part 5

THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON ECONOMIC SECTORS, MANAGED ECOSYSTEMS AND LIFESTYLES IN BRITISH COLUMBIA AND YUKON

Chapter 12

IMPACTS OF CLIMATE CHANGE ON THE FISHES OF BRITISH COLUMBIA

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OVERVIEW

Climate change may cause pink, chum, and sockeye salmon stocks from the Fraser River to decline in abundance from the recent high levels and probably to below the long-term mean. These species represent about 40% of all salmon landings and will be affected in freshwater by the higher temperatures and lower summer and fall stream flows. Some increased productivity may occur in northern British Columbia and the Yukon. However, the overall abundance may still be lower as the marine ecosystems are affected by a weakening of winds and reduced nutrient flows into the surface which will reduce food levels and increase predation. Steelhead may do better in freshwater, but the decrease in ocean productivity will increase marine mortality and the net change may be lower abundance. The abundance of Pacific herring may remain about the same. Halibut are known to fluctuate in abundance naturally and these cycles should continue with relatively minor impacts from climate change over the next 50 years. Sablefish and many rockfish species are naturally long lived and should not be seriously affected over a 50 year period if the fishery does not exert a stress that prevents the population from replenishing itself. Pacific cod will be affected by the warmer temperatures and reduced ocean productivity and stocks may remain at low average levels. Pacific hake should remain at present levels if they are not over-fished. In freshwater, perch, pike, bass, and other warm water species should not be harmed if they reside in larger rivers and lakes. In the north these species may increase in abundance. Trouts, chars, whitefish, and graylings may do better in the north provided percids and centrarchids are not introduced into the lakes and rivers. In the south there may be increased competition from these species and from introductions of exotics. The most important impact in freshwater and in saltwater will be to the dynamics of the ecosystem and these changes may be large and occur quickly. Global warming changes will be confounded by natural variation and by fishing effects further complicating management.

INTRODUCTION

The effect of global greenhouse warming on the fishes of British Columbia is difficult to assess because modelled global warming changes are unclear at regional levels, interactions within ecosystems are poorly understood and it is unclear how natural climate variability affects the population dynamics of most fish populations in the province. In general, it is proposed that surface air temperatures will increase, with increases on land higher than in the ocean. An average increase in British Columbia could be 2°C by 2050 (Slaymaker 1990). The warming of the oceans should increase sea levels, probably 50cm by 2100. Bakan (1990) proposed that the warming could increase biological productivity in the coastal areas off the west coast of North America, but Hsieh and Boer (1992) argued that productivity would be reduced. They modelled the impacts of global warming and found that a reduced temperature gradient in the lower troposphere between the equator and the poles would weaken winds and thus weaken the coastal upwelling of nutrients from bottom water. Less wind and warmer surface temperatures may also deepen the mixed surface layer and reduce productivity. There are also impacts that can be considered to be unknowns. Modelled impacts of global warming tend to be viewed as linear changes, but recent studies have shown that the productivity of some British Columbia fishes undergo rather abrupt shifts in productivity in response to apparently natural changes in the climate and the ocean.

Although there is considerable uncertainty about the exact physical changes and the exact responses of the various marine and freshwater species, it is possible to speculate how certain species may respond over the next 50 years. As with all speculations, there is a level of personal bias included and we acknowledge that the speculations of others may differ from ours. In some respect, differences in opinions are as useful as agreements because they alert biologists and managers to the importance of detecting the signals of global warming and separating these signals from natural fluctuations and fishing effects.

We know that temperature has a major impact on the physiology and behaviour of fishes. However, it is not only temperature that affects the relative abundance and distribution of fishes. There is a carrying capacity for the various species in aquatic systems that is a function of the biology of the species and its interrelationships with its environment and associated species. Specific factors that regulate the carrying capacity are poorly known for virtually all species, but we do know that there is some stability in the relationships among species. If this were not the case and there were no stabilizing influences, then the lakes and oceans would contain only a few species that would undergo large, random fluctuations in abundance. We also know that within a particular equilibrium relationship, there are natural fluctuations in abundance that can change the relative abundance of species, but these changes oscillate about a mean and tend to maintain the same general composition i.e. Pacific hake may fluctuate from 500 million fish to one billion fish in the Strait of Georgia, but they always are substantially more abundant than coho salmon that range from one to two million fish.

Fishing is another significant man-made change. There is no question that fishing has changed the composition of fish populations and probably is having stronger evolutionary impacts than the processes of natural selection. Unfortunately, we have a weak understanding of the long-term effects of fishing on the structure and behaviour of fish populations. In part, this lack of understanding results from the relatively short time that many species have been fished commercially. In British Columbia, for example, a number of our groundfish species did not become fully exploited until the 1970s and 1980s. Impacts of global climate change, therefore, must be interpreted as they are layered onto the impacts of natural changes and interpreted through the confounding impacts of fishing.

In this report, we look at some of the key marine and freshwater fishes in British Columbia and attempt to assess the response of these species to global warming impacts over the next 50 years. Our selection of species is based on their economic importance as reported in British Columbia commercial catch statistics (Tables 1, 2, 3). For each species or species group, we attempt to comment on the possible impacts in relation to the biology of the species as well as the potential management implications. For each of these species, we provide a summary comment, which is our assessment of what may happen. Having said this, we want to pass on some wisdom from Dr.

Table 1. Major marine fish species in British Columbia (tonnes).

Species	1995 (preliminary)	Percent Change from:	
		1994	1991-94
Sockeye	41,800	-79%	-69%
Chum	10,900	-50%	-48%
Pink	14,000	483%	2%
Coho	13,300	-41%	-33%
Chinook	5,400	-62%	-70%
Steelhead	10	0%	-56%
Salmon	85,580	-67%	-58%
% of Total Value	25.0%		
Herring	29,100	-25%	-45%
Spawn-on-Kelp	22,400	31%	93%
Herring	51,500	-8%	-20%
% of Total Value			15.0%
Halibut	31,200	-10%	15%
Sablefish	27,400	-15%	-2%
Pacific Cod	1,100	-48%	-76%
Lingcod	2,600	-37%	-33%
Hake	12,000	-21%	-12%
Rockfish	12,700	-32%	-29%
Sole	2,800	-62%	-61%
Other	1,900	27%	-38%
Groundfish	91,700	-67%	-58%
% of Total Value	26.8%		

Table 2. Important freshwater, sports caught fishes (1990 survey of recreational fishing in Canada)

Species	Total Catch
Rainbow trout	5,070,000
Cutthroat trout	880,000
Kokanee (landlocked sockeye salmon)	1,258,000
Dolly varden char	316,000
Lake trout	255,000
Brook trout	201,000
Whitefish	291,000
Northern pike	71,000
Walleye	78,000
Yellow perch	65,000
Arctic grayling	132,000
Bass	169,000

Table 3. Rare and endangered freshwater species in British Columbia.

Name	No. of Locations	Scientific Name
Lake lamprey	1	Lampetra macrostoma
White sturgeon	4	Acipenser transmontanus
Sculpin	1	Cottus ps
Cisco	2	Coregonus sp
Whitefish	1	Coregonus nasus
Pygmy whitefish	1	Prosopium sp
Grayling	1	Thymallus arcticus
Pygmy longfin smelt	1	Spiriuchus sp
Shiner sp	2	Notropis sp
Dace sp	4	Rhinichthys sp and Margariscus sp
Sucker	1	Catostomus sp
Stickleback	7	Gasterosteus sp and Punqitius sp

Bill Ricker, who once responded when asked what would happen to British Columbia salmon in the future by saying that he "has learned to expect the unexpected."

PINK SALMON

Pink salmon are the most abundant of the Pacific salmon in British Columbia waters and in the all-nation catches of Pacific salmon. They have the shortest life span, approximately two years from hatching, and are the smallest. Pink salmon form distinct spawning brood-lines with some stocks spawning in years with even numbers, i.e., 1996, and some with odd numbers, i.e., 1997. The largest stocks of pink salmon occur in the Fraser River, where spawning occurs only in odd-numbered years. Farther north, spawning occurs in all years with a tendency for the even year spawning stocks to predominate. Although pink salmon occur farther south than British Columbia, the center of distribution is north of British Columbia. Fraser River stocks, therefore, are close to the southern limit of the range.

Because of their anadromous life history, pink salmon will be affected by changes in freshwater and changes in the ocean and the impacts in each of these habitats are equally important. Recently it has been shown that trends in pink salmon productivity shift in response to climate driven changes in the ocean. Because the mortality of young pink salmon is so high (~95-98%) shortly after they first enter the ocean, small changes in marine survival can result in large changes in the adult returns. A further consideration is the use of hatcheries to increase fry production and thus eliminating freshwater mortality impacts.

There are some obvious impacts of global warming on pink salmon, but it must be remembered that this species is abundant and widely distributed, and thus it has evolved to be able to survive extreme fluctuations in the environment. This plasticity may mean that while changes will occur, the impacts that are a result of global warming only (and not natural fluctuations or fishing effects), may be gradual over the next 50 years. Warmer fresh water and oceans and changes in the pattern of Fraser River flows will probably reduce the abundance of pink salmon, although the individual size may increase from improved growth in the warmer water. Warmer temperatures will reduce the incubation time and the longer period in fresh water will improve growth. In the smaller rivers where flows are a function of winter precipitation, the increased precipitation may increase water flows resulting in higher egg and alevin mortality. In the northern half of the province, the impacts of increased temperature may be less because both mean annual temperature and the range of temperatures decrease with latitude. The marine effects are obviously relevant to hatchery reared fish. Reduced coastal productivity resulting from reduced upwelling may reduce the total carrying capacity for pink salmon, and it may not be possible to build stocks to historic levels in a poor productivity regime by producing more fry.

Summary

The productivity of pink salmon stocks from the Fraser River and southern rivers may decline, while the total abundance of pinks in the north may not be seriously affected. Large abundance fluctuations may occur for natural reasons and these changes may be larger than changes caused by global warming, particularly in the north.

CHUM SALMON

Chum salmon are the second most abundant Pacific salmon species both in British Columbia and in the all-nation catch. They are widely distributed in British Columbia and they are reared in hatcheries in order to supplement the number of fry that enter the ocean. Chum salmon spawn over a seven month period and the fry spend a very short period in fresh water. In general, chum fry are the first of the recently hatched Pacific salmon to enter salt water. Most remain in the ocean between 2 1/2 to 3 1/2 years. In their first ocean year they may remain in the coastal areas until later in the year.

The center of distribution of chum salmon is north of British Columbia, with southern stocks close to the southern limit. The Strait of Georgia is an important rearing area for the ocean age 0 chum salmon, thus changes in the productivity and temperature of the Strait would be expected to have an impact on the productivity of chum stocks. In recent years, it has been shown that chum salmon productivity follows trends that shift in relation to climate related changes in the ocean. Thus changes in upwelling and the intensity of winds may reduce the carrying capacity for chum in the ocean to levels below what might occur during natural changes.

Increases in temperature in freshwater rearing areas and increased winter flows may increase freshwater mortalities for stocks in the Fraser River and other southern rivers. However, chum are a very adaptable species and spawning tends to be in the lower portion of rivers and streams, thus the changes in salt water may be more influential than changes in fresh water. It is possible that earlier and larger spring flows in rivers may improve survival in the ocean, if the initiation of the spring bloom occurs at a more favourable time. In recent years, relatively large numbers of ocean age 0 chum salmon have remained in the Strait of Georgia until late in the year, even though the surface temperatures have increased over the past 20 years. This may be an indication that the timing of plankton production is more favourable as a result of larger flows in April.

Summary

Chum salmon productivity may decrease in the south, but the declines may be more related to changes in salt water than in fresh water. In the north, natural fluctuations in abundance may be greater than impacts due to global warming.

SOCKEYE SALMON

Sockeye salmon probably are the fish that is of most interest to British Columbians. It may also be the Pacific salmon that is most affected by global warming. The Fraser River stocks have averaged about 80% of the British Columbia sockeye production and 25% of the catch of all salmon in British Columbia. These sockeye stocks can be considered to be at the southern edge of the range for this species and susceptible to changes in both the freshwater and marine environments. Most sockeye return to the Fraser River in July and August and spawn in the fall. After hatching, alevins emerge in the spring when they migrate into nearby lakes. After a year in the lake, most sockeye migrate in the spring, into the ocean where they grow and undergo extensive migrations before returning to spawn two years later. There are variations to this generalized life history (Foerster 1968), but it is the combination of a prolonged dependence on fresh water followed by a period of extensive ocean migrations that makes Fraser River stocks susceptible to the impacts of global warming. In the north, in the Skeena and Nass rivers, sockeye have similar life histories, but the impacts may not be identical because the ocean effects may differ.

In the south, warmer river water and reduced flows in the late summer may increase mortalities and reduce spawning success. Warmer waters in the winter will accelerate incubation and hatching and cause alevins to enter lakes earlier. Henderson et al. (1992) concluded that warming of sockeye rearing lakes would lower plankton production and reduce the size of smolts going to sea. These smaller smolts may also experience reduced food when they enter the ocean and the resulting slower growth may expose juveniles to predation longer and increase mortality in the early marine period. Welch et al. (1995) proposed that global warming would increase winter temperatures sufficiently that sockeye juveniles would migrate out of the North Pacific into the Bering Sea, effectively reducing the winter feeding area. It is known that there are large interannual fluctuations in survival (Burgner 1991) and large, natural decadal shifts in marine survival (Hare and Francis 1995; Adkison et al. 1996; Beamish et al. 1997). The mechanisms involved are not understood, but the shifts in abundance clearly show that changes in the ocean environment have profound impacts on the productivity of the stocks.

It is possible, that changes affecting the northern stocks may not have a major impact on the stocks in the next 50 years. This speculation is based on the cumulative effects of freshwater and marine events in the early 1990s that have produced historic high returns to some of the northern sockeye stocks in Canada and Alaska.

Summary

Sockeye salmon productivity may be reduced for Fraser River and other southern stocks, but may be less affected in the north and may even increase. Natural shifts in productivity will continue and such changes need to be recognized as changes not caused by global warming.

COHO

Coho spawn in numerous smaller rivers and streams as well as in larger rivers. After hatching and emergence from the gravel, most coho remain in fresh water for one year. The smolts enter salt water in the spring where they generally remain in the coastal areas in the general vicinity of the spawning areas for approximately 1.5 years. Coho are common south of British Columbia as well as to the north.

Coho abundance has fluctuated in many areas over the past 20 years. It is commonly believed that over-fishing and freshwater habitat degradation are the main reasons for the declines. Recently, it has also been shown that there are natural changes in the marine carrying capacity that result in synchronous changes in marine survival of a large number of stocks. Where freshwater habitat loss has been severe and stock abundance reduced to very low levels, it has been common practice in Canada and the United States to try to rebuild stocks by improving egg to smolt survival using hatcheries. At present, the number of hatchery produced smolts is quite large and exceeds wild production in a number of areas, particularly in the south.

In the Strait of Georgia, where there is an important sport fishery, coho marine survival declined rather abruptly in the late 1970s and early 1980s, but coho catch was stabilized, possibly because of the increased hatchery releases. As hatchery releases in Canada and the United States continued to increase in the late 1980s, there was not a corresponding increase in adult production. In the early 1990s, there was a change in behaviour of coho in the Strait of Georgia. Movement offshore was more common resulting in consecutive years of poor catches in the strait. At this time, in the southern part of the province, marine survival continues to decline.

Global warming induced temperature changes in fresh water will alter the timing of hatching and emergence and may improve growth, but generally should not have major detrimental impacts on survival over the next 50 years. Stream flow changes in the extremes may increase mortalities, but overall, the most important changes in fresh water may be associated with the timing of entry into salt water. The size and time of entry of coho has been associated with marine survival in a number of studies. The direction of change may depend on the location of the particular stocks as well as the changes in the ocean which would be linked to the climate related changes in fresh water. The changes in the ocean temperatures and currents would not be expected to produce the same impacts throughout the distribution of coho based on the observations that the change in marine survival off Oregon, Washington and the Strait of Georgia after 1977 differed from impacts farther north. It is tempting (and dangerous) to speculate that the recent trends of low marine survival in the south and higher survival in the north, may continue in response to a synergism of global warming and natural impacts. A problem common to all these estimates of impacts is that the impacts occur at all levels throughout the ecosystem and we simply do not understand these interactions. In particular, we have already stressed this species with changes to its freshwater habitat and we produce large numbers of coho in hatcheries in order to maintain fisheries. We do know that coho are particularly resilient in fresh water and susceptible to natural shifts in marine carrying capacity. The continued production of large numbers of hatchery reared smolts probably ensures that the maximum returns for the particular ocean carrying capacity are obtained.

Summary

The productivity of wild and hatchery coho stocks over the next 50 years may continue to follow the fluctuations in abundance, characteristic of the last 20 years.

CHINOOK SALMON

Chinook salmon have a complex life cycle (Healey 1991) and are less abundant than the other species of salmon, except for steelhead. In British Columbia, chinook salmon occur in a range of freshwater habitats, but in general they prefer larger rivers. There are two distinct life history types that Healey (1983) views as distinct races. The ocean type, spends less than a year in fresh water after emergence from the gravel, while the stream type over-winter before going to sea. Presently, there are large releases of hatchery fish which are virtually all the ocean life history type. The stream type chinook enter salt water earlier and at a larger size than the ocean type. Stream type fish also become more common towards the northern end of the distribution.

Chinook remain in the ocean for several years where they may grow to exceptional sizes. Most return to spawn at total ages of 3 to 6 years, that is, 2 to 5 years in the ocean. The stream type undergo more extensive migrations that the ocean type. Many hatchery reared fish remain in the vicinity of the release area, although there are some important exceptions.

Global warming impacts will affect the timing of the return to fresh water to spawn in some of the smaller streams. The delays in spawning may change the behaviour, even select for later spawning fish, but it is not anticipated that large numbers of stocks would be eliminated from spawning in the next 50 years. Warmer rivers will shorten the incubation time, which may result in a longer growing season in fresh water. While fish may feed longer and grow to larger sizes, they may also enter the ocean earlier. This may change the percentage of life history types that survive more than change survival as there already is an extended period of entry into salt water for the various rearing types.

Impacts of global warming in the ocean will be difficult to separate from natural shifts in ocean carrying capacity. A general warming of the ocean will have an impact on predators and prey distributions. In the Strait of Georgia there was an abrupt decline in marine survival after the 1976-1977 regime shift, but the mechanisms responsible remain unknown. On the west coast, the warm periods after the 1989-1990 climate change resulted in an influx of predators that caused large increases in juvenile mortalities. As we have said, it is impossible to forecast the actual changes in the marine ecosystems, thus, the degree to which chinook marine survival may be affected is unknown. The abruptness of change in the Strait of Georgia and the west coast is of concern because it indicates that signals of change need to be detected quickly and managed effectively. It is clear, that with the large hatchery releases, the size of our coastal fisheries will be a function of marine survival. If the productivity of coastal waters declines as might be expected under the Hsieh and Boer (1992) scenario, then total abundances may be lower than the mean in the 1980s in the southern part of the province. However, ocean conditions may differ in the northern part of the province and off Alaska and abundances close to the mean levels of the 1980s may occur.

Summary

Changes in the percentages of life history types that survive to spawn may occur. Some smaller stocks may be reduced to very low abundances, but in general the total abundance in the province may remain close the mean levels of the 1980s. There will be large and rather abrupt fluctuations in abundances in aggregates of stocks.

STEELHEAD

Steelhead have recently been shown to be more similar to Pacific salmon than to freshwater trouts. Despite this taxonomic similarity to salmon, there are some major differences in their life histories. The freshwater fish is called a rainbow trout and the anadromous or migratory fish is referred to as a steelhead. These migratory fish have summer and winter forms depending on their time of entry into fresh water during their spawning migration. The center of abundance is south of

British Columbia which is the farthest south of all Pacific salmon.

Steelhead spawn in the spring and the young may remain in the streams and rivers for 2 to 3 years before going to sea. In the ocean, steelhead undergo extensive migrations, tending to move directly out from the coast and not along the coast as do the other salmon species. Most steelhead remain at sea for 2 to 3 years before they return to spawn. Unlike other salmon, steelhead may spawn two or three times, but the percentage of all steelhead that are repeat spawners once is low and twice is extremely low. In general, steelhead prefer higher temperatures in fresh water than the other Pacific salmon species and juveniles can survive in pools in intermittent streams.

Recently, Smith (pers. com. Environment Canada, Pacific Wildlife Research Centre, Delta, B.C.) observed that the abundance of steelhead in British Columbia streams changed synchronously after the 1976-1977 regime shift. This indicates that like most other species, climate shifts cause rather abrupt changes in the carrying capacities for steelhead. Other unpublished data provide convincing evidence that changes in abundance of one stock after about 1990 were related to reduced marine survival.

Because steelhead are adapted to warmer fresh water, an increase in the temperature of rivers and streams may not be harmful for steelhead in British Columbia. Increased winter stream flows may cause some mechanical damage to spawning habitat, but the low flows in the summer may have more of an impact if the reductions are severe. However, the larger rivers also support steelhead stocks, and impacts of reduced flows in the larger rivers should not be a major problem for steelhead in the next 50 years. Changes in temperatures and flows may alter the current percentages of winter and summer forms and may even be more favourable for steelhead in general.

Because steelhead smolts move into the open ocean quickly, the changes in the coastal areas may be less important than in the offshore areas. A reduction in productivity, therefore, may increase marine mortality and may limit abundance at a lowered carrying capacity.

Summary

A warming of fresh water may not be harmful to steelhead in British Columbia, but may change the composition of summer and winter forms. A decrease in ocean productivity may reduce the carrying capacity and thus reduce abundance.

PACIFIC HERRING

Pacific herring are a small, relatively short-lived pelagic species that are important prey for many species. Herring enter the current fishery at age 2+ or in their third year of life and few live past age 7 or 8 years. Herring migrate into the intertidal area to spawn in the late winter or early spring with first spawning occurring at age 2+. After hatching, the larval herring remain in the surface waters and after a few months form the large schools typical of adult behaviour. The current fishery removes between 30,000 and 40,000 tonnes of adults, but earlier fisheries harvested more than 200,000 tonnes in some years (Hourston and Haegele 1980). There was a collapse of the herring fishery in the late 1960s that we now believe resulted from the excessive removal of fish at a time of very poor recruitment. However, the stocks recovered very quickly after the fishery was closed in 1967 and fishing resumed in the early 1970s. By the late 1970s stocks were again considered to be healthy. It is clear from the history of the fishery that the ocean environment can have a profound impact on recruitment. It is also clear from the distribution of herring from California to Alaska that they survive and reproduce in a variety of habitats and a range of temperatures.

We know that temperature, salinity and ocean circulation patterns are influential in survival of eggs and larvae (Stocker and Noakes 1988) and we know that the movement of major herring predators such as Pacific hake can affect the survival of juveniles and adults (Ware and McFarlane 1995). On the west coast of Vancouver Island, recent increases in sea surface temperatures have been associated with poor recruitment, but in the Strait of Georgia there was an abrupt shift to warmer temperatures in 1976-1977 and herring abundance increased to levels believed to be close to historic high levels. It is tempting to conclude that this species is quite adaptable and may increase in abundance in some areas and decrease in others, possibly maintaining catch levels observed in the 1980s. An important consideration is the commercial fishery removals. The current fishery appears to be well managed with specific "cutoff" levels below which no fishing is allowed. In addition, the demand for product is much less than in the 1950s and 1960s. Thus it is unlikely that the overfishing that occurred in the 1960s would be a factor.

Summary

Herring stocks will fluctuate in abundance in response to changes in temperature, salinity and ocean productivity shifts that will affect egg and larval survival. However, the overall average abundance may not change from the current levels.

PACIFIC HALIBUT

Pacific halibut are a large, fast growing species that under natural, unfished conditions probably lived to ages of 30 to 40 years. At present, the species is fished throughout its range in what may be considered a mature fishery. As a result, few halibut live longer than 20 years and most fish in the population are removed by the fishery before they are 15 years old. Pacific halibut spawn in deeper water along the continental shelf early in the year and the pelagic larval and juvenile fish are carried by the currents into the Gulf of Alaska and Bering Sea. As the fish age, they settle on the bottom and begin a reverse migration that results in mature halibut being distributed from California to Alaska with the center of abundance about the middle of the Gulf of Alaska. It is now accepted that there are natural trends in the abundance of halibut and the management strategy is to remove a percentage of the harvestable biomass that ensures that there is an adequate spawning biomass. This strategy ensures that there will always be an adequate supply of eggs and accepts that the total abundance will fluctuate in response to natural, environmental conditions.

Because the species is currently distributed throughout a range of habitats and thus temperatures, it is unlikely that global warming will change the distribution of adults within the next 50 years. A characteristic of halibut populations is the periodic occurrence of strong year classes that ultimately represent a large percentage of the biomass of the population. Because the fish is relatively long-lived, halibut probably have evolved to be able to survive long periods of conditions that are unsuitable for reproduction. This means that the ecosystem changes associated with global warming will affect the survival of halibut. It is unlikely that temperature changes will have the most immediate impact as the species already reproduces over a range of temperatures. Changes in currents and upwelling will, however, affect reproduction and may affect the relationship between predators and prey of halibut in the first few years of life. It is important to remember that these impacts will occur north of British Columbia because the movements of the larval halibut are out of our waters.

As for most species, the mechanisms that affect marine survival are unknown, thus it is not possible to interpret specific environmental changes, even if such changes could be forecasted. In general, however, it is believed that strong onshore flows, resulting from strong northward flowing currents are favourable for reproduction. A concern is that there could be a weakening of winds which could affect both the amount of onshore transport as well as the food required for the larval and young juveniles. If the impacts of global warming weaken onshore transport and reduced productivity, then halibut year-class survival may be poor and there may be prolonged periods of poor recruitment. A concern would be that the period of poor recruitment may persist for periods longer than currently experienced and that unless changes are made to management, abundance would drop quickly and fishing would be curtailed or even eliminated until there is evidence of good recruitment. Currently recruitment is not assessed until age 8, thus if global warming impacts are detected, recruitment may have to be assessed for younger ages and the incidental bycatch of juvenile fish in US waters will become even more of a concern.

Summary

Mature fish should not be affected, but larval and juvenile fish probably will be affected. The major impact may be through changes in the strength of wind driven currents. If recruitment is reduced, it will be important to detect the change in trend quickly to ensure that a minimum spawning biomass is preserved.

SABLEFISH

Sablefish are a long-lived species that are commonly fished at depths from 300 m to 600 m, although they range outside of these depths. McFarlane and Beamish (1996) propose that sablefish live up to 60-70 years because their ability to reproduce successfully is restricted by their biology and habitat. Their length of life, therefore, represents the longest period of unsuccessful reproduction over evolutionary time. If this hypothesis is valid, sablefish are adapted to survive in conditions that are generally unfavourable for reproduction. One limiting factor would be the ability of the fragile eggs to remain suspended in mid-depths and for the larval sablefish to find copepod eggs and nauplii. The other major consideration is the abundance of suitable prey for the juveniles that feed near the surface for several years. Because sablefish appear to be able to adapt to natural short-term and long-term shifts in ocean conditions, it is probable that global warming will not have major impacts on the abundance of sablefish in a time frame of 50 years from now. This does not mean that specific global warming impacts on survival of eggs, larvae, and juveniles will not occur, rather that there will be time to detect changes in the population dynamics and to consider management options.

An immediate concern is the impact of fishing on the population structure and the natural ability of sablefish to survive in unfavourable conditions. Fishing impacts over the past 30 years have reduced the percentage of older fish in the population. Presumably, the remaining fish still have the ability to live for extended periods, however, there may be some changes in their biology if the fishery is in some way exerting a selective force on the genetic composition of the population. If the impacts of global warming are negative and reproduction is less successful or fails, it may be important to ensure that a percentage of the existing population is allowed to live to the older ages that existed prior to commercial fishing.

Summary

The mature fish will not be affected in a time frame of 50 years. Reproduction probably will be affected and there may be longer periods between successful year-class survival, but the impacts can be detected in time for management action.

PACIFIC COD

Pacific Cod in British Columbia waters are a fast growing, relatively short-lived bottom dwelling species. Fish caught in the commercial fisheries generally range from age 2 years to 5 years, but most fish are age 3 and 4 years. Pacific cod in British Columbia are at the southern end of their range and thus, their abundance is small relative to the population sizes in the Gulf of Alaska and the Bering Sea. Catches of Pacific cod have traditionally followed trends suggesting that the fluctuations were more a response to the environment than to fishing pressures. However, the relative importance of fishing effects and the environmental effects on the abundance of Pacific cod is still poorly understood. In recent years (1994-1995) the abundance of cod was so low that fishermen could not catch the quotas and the fishery was closed in 1996. The reasons for the low abundance are unknown, but believed to be related to changes in the ocean environment. It has been known for a long time that Pacific cod egg survival is related to temperature (Alderdice and Forrester 1971). Optional temperatures range from about 3.5 - 4.0°C with a range from 2.5 - 8.5°C. Thus, temperature increases of even 1 or 2 degrees caused by global warming, should have a detrimental impact on Pacific cod spawning success and may virtually eliminate the commercial fishery.

Summary

Global warming probably will reduce Pacific cod abundances below levels that will permit a commercial fishery.

LINGCOD

Lingcod are a large, fast growing species that have maximum ages of approximately 15 years (Cass et al. 1990). The center of abundance probably is off the coast of British Columbia where they are commonly found in most of the shelf areas and in the nearshore areas, particularly around reefs. Lingcod spawn in the late winter in shallow, rocky areas where there are strong tidal currents. After spawning, males guard nests until the eggs hatch in about 7 weeks. Because of their large size, there are few natural fish predators, except possibly other lingcod. However, sea lions can be a significant predator of males during the period of nest guarding.

It is known that lingcod have periodic strong and weak year classes, indicating that the environment can have profound impacts on survival. It is also known that stocks in the

Strait of Georgia have collapsed in recent years after supporting commercial and recreational fisheries for decades. The reasons for the collapse are still debated, but there is little doubt that overfishing played a major role.

The possible impacts of temperature, salinity, productivity and current changes resulting from global warming will undoubtedly affect the population dynamics of lingcod as they have in the past. However, any impacts would be expected to be most important during the hatching and larval stages as adults have few predators. Changes in the timing of production of food for larval fish resulting from changes in the timing of freshwater discharge, probably would not have a major impact, as the larval fish quickly begin to feed on larval and juvenile herring which may not undergo major declines in abundance.

Summary

Lingcod probably will not undergo major changes in abundance in the next 50 years as a consequence of global warming impacts.

PACIFIC HAKE

There are two important and separate stocks of Pacific hake in British Columbia. The smaller stock is resident in the Strait of Georgia and the larger stock migrates north into the Canadian zone off the west coast of Vancouver Island in the summer. The biology of these stocks differs slightly, but in general, hake are relatively slow growing fish that mature at an age of 3 to 4 years and live to ages of 12-15 years. Hake are mid-water species, that spawn at depths of up to several hundred meters in February and March. Hake have strong and weak year classes that are almost cyclic in the offshore stock, with strong year classes occurring every 3 to 4 years. In the Strait of Georgia, the juvenile hake tend to concentrate in the scattering layer and offshore, juveniles tend to occur farther south than the adults off Oregon and California. In Canadian waters, the catches of hake far exceed the catches of any other species.

In recent years, in the Strait of Georgia, there has been an increase in hake abundance that may be related to an earlier abundance of plankton resulting in a closer matching of plankton production and spawning activities. Conditions causing the improved survival appear not to be related to reduced Fraser River total flows, but to earlier spring flows and possibly to inflowing bottom water changes. These conditions may persist as the impacts of global warming increase. Offshore, the projected increase in temperatures may result in more hake moving into the Canadian zone and possibly in the spawning and rearing area off California moving north. However, upwelling and nutrient changes may reduce plankton productivity and thus year class strength. In general, biologists studying hake feel that the abundance will improve as a result of global warming and if a greater percentage move north in the summer, the abundance off Vancouver Island may increase over the next 50 years, assuming the stocks are not overfished.

Summary

Pacific hake stocks in the Strait of Georgia and off the west coast of Vancouver Island should remain at present levels or increase, if they are not overfished.

SOLE

Commercial catches identified as sole represent a number of species including petrale sole, Dover sole, rock sole and English sole. In general, these fish are moderately long-lived, slow growing, bottom dwelling species. They reproduce in the winter, with some species producing pelagic eggs and others attaching their eggs to the bottom. The moderate longevity (about 20-40 years) and the occurrence of strong and weak year classes, indicates that ocean environment conditions are important factors, controlling the survival of eggs and larval. Studies in the 1960s and early 1970s on petrale sole showed that temperature was associated with year class strength. As this species is at the northern end of its range in British Columbia waters, a warming of the ocean possibly will result in an increase in their abundance. However, other stocks such as rock sole are at their southern distribution and they may move north, out of British Columbia waters. Recruitment probably will be affected because these species are sensitive to changes in ocean conditions as indicated by studies of temperature related effects on reproduction, their relatively long life, and the occasional strong year classes. In the absence of fishing, these species probably would be most affected by distributional changes in the next 50 years. However, in the presence of a mature fishery, it will be necessary to manage for recruitment variation to ensure that there is an adequate spawning population if intervals between strong year classes become longer.

Summary

Distributional shifts may occur with some species increasing in abundance and others decreasing. Recruitment patterns probably will be altered, but the impact can be managed, once it is known if there is increased or decreased survival.

ROCKFISH

Catches of rockfish represent between 15 and 20 species that are caught in the slope, shelf or in the inshore areas. Two of the most common species are Pacific ocean perch and yellowtail rockfish. The red snapper or yelloweye rockfish is a common species in the sport fishery.

It is difficult to generalize about the possible impacts on all rockfish because the biology of the species differs. However, many of the species can be considered to be slow growing, long lived species that have occasional strong year classes. Maximum ages vary from 30 to 50 years to over 100 years, indicating that there probably are long periods when the ocean environment is generally unfavourable for reproduction. If this assumption is valid, then it is apparent that most of these species are adapted to survive in generally unfavourable conditions for long periods. As some species live longer than 50 years and most live longer than 25 years, an immediate intensification of global warming would not be expected to cause large, natural reductions in biomass in the next 50 years. However, recruitment would be affected as well as the distributions of some species. Also, the management of the various fisheries would need to be adjusted to ensure an adequate spawning biomass existed. The uncertainty of temperature and current changes at the surface and near the bottom along the coast make it difficult to speculate on changes in recruitment, but temperature alone should not have a major impact. As with most species, changes to the abundance and distribution of copepods and other plankton will be important.

Summary

The biomass of the various species of rockfish may undergo gradual changes in the next 50 years and recruitment and distributions may be affected. Fisheries need to be managed to ensure an adequate number of spawners exist when conditions are optimal for reproduction.

FRESHWATER FISHES

The impact of global warming on freshwater fishes is a function of the size of the freshwater habitat as well as the physiology of the species. In long rivers, a species may be able to migrate, but the same species may be resident in a small lake and the impact may be different if the lake becomes too warm at some critical time of the year. In general, it is believed that improved fish production may occur in more northern located lakes as a result of increased temperatures (Schlesinger and McCombie 1983). Increased precipitation should be positive except in coastal streams and rivers where mechanical damage may occur to some spawning and rearing areas. Shorter winters and longer ice free periods should also improve production, but the impacts will be species specific. The important species listed in Table 2 are a mixture of coolwater and warmwater species. The warmwater species, northern pike, walleye, yellow perch and bass should benefit over the next 50 years and may actually increase. Yellow perch and small mouth bass abundances may improve and the distributions may shift north as a result of shorter winter cold periods (Shuter and Post 1990). Warmer surface waters may also improve growth, particularly for the age 0 fish if prey abundances remain unchanged. Presumably northern pike survival would respond in a similar manner. It is inevitable that introductions of exotic species that survive in warmer water will occur. This is a major concern with global warming as exotic species have a history of displacing resident species. Of particular concern is the specific changes in areas where there are currently rare and endangered species (Table 3). Obviously, these sites and these populations need to be monitored.

Trouts, chars, whitefish and graylings that remain in fresh water have evolved to succeed in cold habitats, as reflected by their temperature adaptation patterns. They require oxygen-rich, clean water in habitats not abusively altered by humans. They thrive in parts of ecosystem mosaics that are in early stages of ecological succession. In such natural and rigorous settings they encounter only relatively ineffective competition and predation, but plentiful food in variable amounts.

Lake trout and lake whitefish are longer lived species that inhabit the deeper waters of lakes. The long life provides resiliency during periods of poor year class strength, thus reductions in year class strength would not have immediate impacts on adult abundance. In general, salmonid species have evolved behaviourally to migrate between different habitats, i.e., scoured riffle and reef gravels, turbulent riverine and coastal waters, naturally enriched tidal and upwelling zones, offshore diffuse upwelling areas, and at fluctuating thermocline depths. Migration tends to occur down migratory corridors in spring and fall when the local, more sedentary competitors and predators are “ seasonally disadvantaged”.

Many salmonid habitats at lower latitudes and altitudes may be altered adversely through climate warming to the disadvantage of the cold-adapted, non-aggressive, salmonids. An increase in temperature and reduction in the amount and variability of precipitation that would benefit such species as yellow perch, walleye and smallmouth bass, would then act to suppress resident salmon populations.

Toward the southern edge of their geographic range, salmonids must have a behavioural capability to escape excessively warm waters in summer. They have limited capability to adapt physiologically because upper lethal temperatures are part of their adaptation patterns. For refuges in warm seasons, salmonids may use spring holes, deeper hypolimnetic waters, streams at higher altitudes, or more northerly waters. Where such refuges are not available or accessible, salmonids may disappear. Whether any lakes and rivers, at lower altitudes of southern British Columbia will lose salmonid taxa simply and entirely due to climate warming and related changes in the aquatic habitats, has not been studied carefully. Perhaps climate change would act to tip the scales ecologically in favour of competitors like the percids and centrarchids which would then suppress and extinguish local salmonid taxa.

At higher latitudes and altitudes, climate warming will presumably increase and enhance the habitat for salmonids as these ecosystems would have few effective competitors and predators. Natural climate stress was presumably endemic with salmonid taxa further south, and may interact multiplicatively with new harmful man-made stresses. In the past, climate stress may not have been a natural burden on any of British Columbia’s salmonid stocks. If climate change were now to occur then this new cultural stress would likely act to scale up the adverse effects of the existing complex of man-made stresses. Thus, it would have a disproportionately large impact, in already stressed habitats. The issue of whether the adverse effects of cultural stresses usually interact synergistically should get more attention by researchers. Narrative science could be focused retrospectively on past extinction events to provide some relevant evidence. It would now be feasible and timely to generate quite comprehensive versions of the temperature adaptation patterns for all salmonid species. This would help with the retrospective narrative science and contribute to the empirical basis for creating a World Salmonid Watch.

CONCLUSION

It is important to remember that the impact of climate change on the abundance trends of fishes is only one of several factors that regulate abundance. Managers attempt to model the abundance trends in relation to fishing effects in order to sustain fisheries. A successful model could, in theory, account for global warming impacts along with the other impacts without understanding them. For many species of fishes, the natural mortality rate is an inverse function of age. This means that longer lived fishes will be affected by natural changes differently than shorter lived fishes. If the atmospheric-freshwater-ocean regime is stable for a particular time, it is possible to estimate the age specific mortality rates for the species of interest. However, at least some parts of the freshwater-ocean-atmosphere system are prone to oscillations on a decadal scale, which may not be cyclical. These natural changes occur globally, thus they will have impacts on the freshwater and marine ecosystems that support fishes on Canada’s west coast. Under natural conditions it may be expected that the different life histories of these fishes will result in different times of adjustment to a new set of environmental conditions. Clearly, management should never operate on the assumption that any estimated set of parameters for a complex set of relationships in a particular regime will remain “ fixed” into the future. If we remind ourselves that this is the natural situation in ecosystems and that we have disturbed these relationships through fishing, we begin to see how difficult it is to determine the impacts that will be specific to global warming. Suppose that a population's ecological inertia may be characterized by a rule that it takes three generations to adapt fully - physiologically, behaviourally, and ecologically, to the new regime. Should we expect the same relative abundances as aquatic ecosystems shift? It seems clear that the more we think about the impacts of global warming, the more we realize that we need to rethink current management approaches.

A wise person knows the risks of attempting to forecast nature. Yet, there is a social and moral responsibility of stewardship of our aquatic resources that requires that we consider the range of possible responses and identify signals to look for. One impact will be an awareness of how little we actually know. It is a tired example, but we are painfully aware of the impacts of the collapse of fisheries off the east coasts of Canada and the United States. We are now realizing that the collapse of stocks was related to natural changes in the ocean conditions that altered the dynamics of fish populations (DFO 1996) as well as to overfishing. We should realize that there is an urgent need to understand more about how nature operates in our aquatic ecosystems. It is evident from this summary of possible impacts of global warming on our fisheries, that it is going to be difficult isolating specific global warming impacts unless our basic understanding of the interactions of fish, their ecosystems, and fishing impacts improves.

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Chapter 13

IMPACT OF CLIMATE CHANGE ON BIOGEOCLIMATIC ZONES OF BRITISH COLUMBIA AND YUKON

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OVERVIEW

If climatic changes occur as predicted by climate models such as the Coupled Global Climate Model version-1 (CGCM-1) of the Canadian Centre for Climate Modelling and Analysis, profound impacts on ecosystems of British Columbia and Yukon could result. Insights into the impacts can be gained from knowing modern climatic characteristics of dominant species, use of systems models and examining characteristics of ecosystems of past warm climates. Important trends to be expected with climate change include up-slope migration of tree lines and ecosystem boundaries, disappearance of forested ecosystems in regions of already warm and dry climate, northward migration of forest types in the interior, replacement of biogeoclimatic zones by zones with no modern analogues, and increased fire frequency. On the coast, Douglas-fir dominated stands will expand at the cost of Coastal Western Hemlock (CWH) forests. Sitka spruce may play a much greater role in CWH forests than it does today. The Mountain Hemlock zone will shrink as western hemlock expands up slope. Interior steppe and pine savannah vegetation may expand up slope and northward, displacing Interior Douglas-fir (IDF) ecosystems northward and up slope too. Montane Spruce and Engelmann spruce - Subalpine fir vegetation may merge, be invaded by open patches and experience more fires. Central interior B.C. zones may expect expansion of steppe vegetation and Douglas-fir dominated stands at the expense of lodgepole pine and spruce. Further north, white spruce and lodgepole pine are likely to predominate whereas black spruce will become less abundant. Forest will invade alpine and Arctic tundra and shrub tundra communities.

There are insufficient data on climatic characteristics of ecosystems, species and ecological processes to predict impacts in more than a general way. The impacts predicted above are for a two-times-atmospheric carbon dioxide scenario, but carbon dioxide concentrations will likely to continue increasing and greater disruptions of the ecosystem pattern should be expected.

INTRODUCTION

British Columbia and the Yukon exhibit considerable physiographic, climatic and ecological diversity with complex origins (Hebda, 1995; Meidinger and Pojar, 1991; Cwynar and Spear, 1995). Given this environmental variability, the impact on ecosystems of climate change will be considerable, though it may be difficult to predict in detail. In this chapter, I examine the potential impact of climate change on B.C. and Yukon ecosystems from the perspective of the fossil plant record of the last 10,000 years (called the Holocene Epoch), modern species characteristics, and vegetation model simulations. I combine insights into sensitivity from paleoecological studies (mainly as summarized in Cwynar and Spear (1995) and Hebda (1995)) and observations of modern trends (Rochefort et al., 1994) with data from a past warm climate analog in the early to middle Holocene spanning 10,000 to *ca* 4500 years ago. I consider these zone-based predictions in the context of climatic characteristics of major tree species with particular emphasis on Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco). I conclude with a discussion of the need for data to improve the reliability of predictions.

This summary is not to be seen as a comprehensive analysis of the potential impact of climate change on regional ecosystems. Rather it is a preliminary application of several approaches for predicting impacts in this complex region, and a consideration of the nature of changes that might be expected on a zone by zone basis where data warrant.

PREDICTING IMPACTS

Meaningful estimation of impacts of climate change on ecosystems depends on two critical factors. The first is a sound model of future climate scenarios. The second is a comprehensive knowledge of the climatic response characteristics of the ecosystems in question, especially their constituent species. I emphasize that ecosystems do not respond to forcing as coherent units, rather, the individual constituent species do (Hebda and Whitlock, 1997). Whether or not elements of an ecosystem within a specific area will respond to climate change will further depend on specific local conditions, that is whether the combination of ecosystem characteristics, including local climate, are such that they are sensitive to the amplitude of climatic change.

Climate Models

I will use the Coupled Global Climate Model version-1 (CGCM-1) of the Canadian Centre of Climate Modelling and Analysis, University of Victoria (F. Zwiers, personal communication November 1996). This transient model has the important advantage of gradually increasing CO_2 as per observed historical trends and adding further CO_2 as per Intergovernmental Panel on Climate Change (IPCC) predictions (Houghton et al., 1990). It models changes in CO_2 in a realistic manner. Equilibrium models simply look at the difference in equilibrium conditions between 1X and $2XCO_2$ states. Thus the transient model presumably approximates more closely the natural situation. Other reasons for choice of model are inclusion of aerosols, a multifaceted climate system including a complex and dynamic ocean, and the convenience of readily accessible output. The grid resolution is 3.75 x 3.75 degrees providing about 20-25 grid points for the B.C.-southern Yukon region.

I approached the choice of future climate scenarios in a simple manner, choosing time horizons of approximately 25 years (2020-2025 AD) and 50 years (2045-2050 AD) into the future, with the 50 year horizon occurring at about the time of the predicted doubling of atmospheric CO_2. The transient CGCM-1 ran until the year 2100 and included values beyond $2XCO_2$ but data were not available at the time this paper was written. Five-year intervals were chosen to smooth out variation in model output. For the preliminary analysis in this contribution, mean annual temperature (MAT) and mean annual precipitation (MAP) were chosen as the variables for comparison to control conditions. In the model the control state has CO_2 concentration set at pre-industrial levels (about 1850). MAT and MAP are crude measures for a variety of other climatic parameters such, frost-free days and spring precipitation which may directly limit success or failure of species. I acknowledge the importance of these other climatic parameters (see Lenihan and Neilson, 1995) but also recognize the complexity of their role in shaping species distributions, ecosystem composition, structure and distribution.

Preliminary CGCM-1 output (G.Boer, personal communication, October 1996) for B.C.-Yukon predicts MAT differences, from the control state (=1XCO_2 about 1850 AD) of +1 °C to +3 °C (increasing largely south to north) for the 2020-2025 interval and differences of +2 °C to +4.5 °C for 2045-2050 AD with most of B.C. warming 2 °C - 3 °C and northern B.C. and Yukon warming 3 °C - 4.5 °C . The model predicts only minor changes in MAP over the 50 years to 2050 AD. Little or no change is shown for 2020-2025. By 2045-2050, the southern half of B.C. will be wetter by 0 - 150 mm (mostly 0-70 mm) per year with greatest rise in precipitation concentrated on the southwest coast. Northwestern B.C. and adjacent Yukon become slightly drier than the control state, whereas northern B.C. and other parts of southern Yukon become slightly wetter 0 -150 mm (mostly 0-72 mm) MAP or do not change at all. In general, precipitation changes fall into the -10% to +20% range. Seasonal distribution characteristics of precipitation were not available at the time of writing of this summary. However in an analysis by F. Zwiers (personal communication, November 1996) of extreme events, derived from an earlier equilibrium model, daily precipitation change and number of precipitation days all suggest no large increase or decrease in summer precipitation in the region.

Ecosystem and species characteristics

Ecosystem response to climate change will depend on the climatic characteristics and sensitivity of constituent species and key ecological factors such as fire and soil moisture (Spittlehouse, 1996). For British Columbia and Yukon these characteristics are not well known. For example there is no summary of climatic characteristics for major forest tree species, especially at the limits of their range. Ecological treatments, such as Krajina et al. (1982), address climatic characteristics in a descriptive way or define them in terms of the climate of biogeoclimatic zones in which the species play an important role (Krajina, 1969). Knowing species characteristics is especially important because it is likely that future climate conditions will have primary impact on basic species requirements (bud break, seedling survival etc.) not just subtle species-species interactions.

As part of this synthesis, a preliminary Douglas-fir climate plot was constructed for sites in B.C. and Alberta (Figure 1). For this first-order compilation only MAT and MAP values were used. Climatic data from the Environment Canada network, and from provincial and other stations were put into a GIS system at the British Columbia Institute of Technology, by K. Brown. Geographic locations for Douglas-fir were compiled from verified site records such as herbarium specimens or provincial ecological plots (provided by Ministry of Forests staff). The MAT and MAP for each verified occurrence was established by using the AML program, which calculates values using the three nearest points to the Douglas-fir locality.

This preliminary approach has weaknesses because, at this stage, the derived climate data for individual localities are not corrected for elevation, nor factors such as aspect, or orographic effects. The results are superior to using biogeoclimatic zones to approximate climate characteristics of species because the climate response plot derives from actual climatic and occurrence data throughout the range of the species.

The plot for Douglas-fir in B.C. and Alberta reveals two climatic groups (Figure 1). One occurs within a relatively narrow temperature range (6.0-10.5°C) and a wide precipitation range (600-3800 mm.), whereas the other exhibits relatively narrow precipitation characteristics (300-1300 mm) within a wide temperature range (1.2-9.5°C). These more or less represent the coast and interior varieties, respectively, of Douglas-fir. The plot reveals that Douglas-fir has the potential to grow in relatively cold dry climate in interior settings. The plot can be used to suggest, where, under warmer climates after climate change, Douglas-fir could grow. Conversely, Douglas-fir species-climate data from this study could be combined with data from the forest-grassland transition (Nicholson and Hamilton, 1984) to suggest which regions the species might abandon with climate change.

Ecosystem climatic characteristics are better known (Table 1)(Table-4 in Pojar and Meidinger, 1991). Using parameters such as climatic ranges, limiting factors or mean climatic values, one can examine the impact of climate change on zones assuming zonal biotic assemblages remain coherent. In some cases, such as in the coastal Douglas-fir zone (CDF), one or two species play such a major role that the zone's future can be closely linked to the predicted future of the species. In other cases, such as the Coastal Western Hemlock zone (CWH), past history of the zone (Hebda and Whitlock, 1997) and its complex modern composition and geographic variation suggest that such an approach would be inappropriate.

Figure 1. Mean annual temperature and mean annual precipitation characteristics of verified Douglas-fir localities in British Columbia and Alberta.

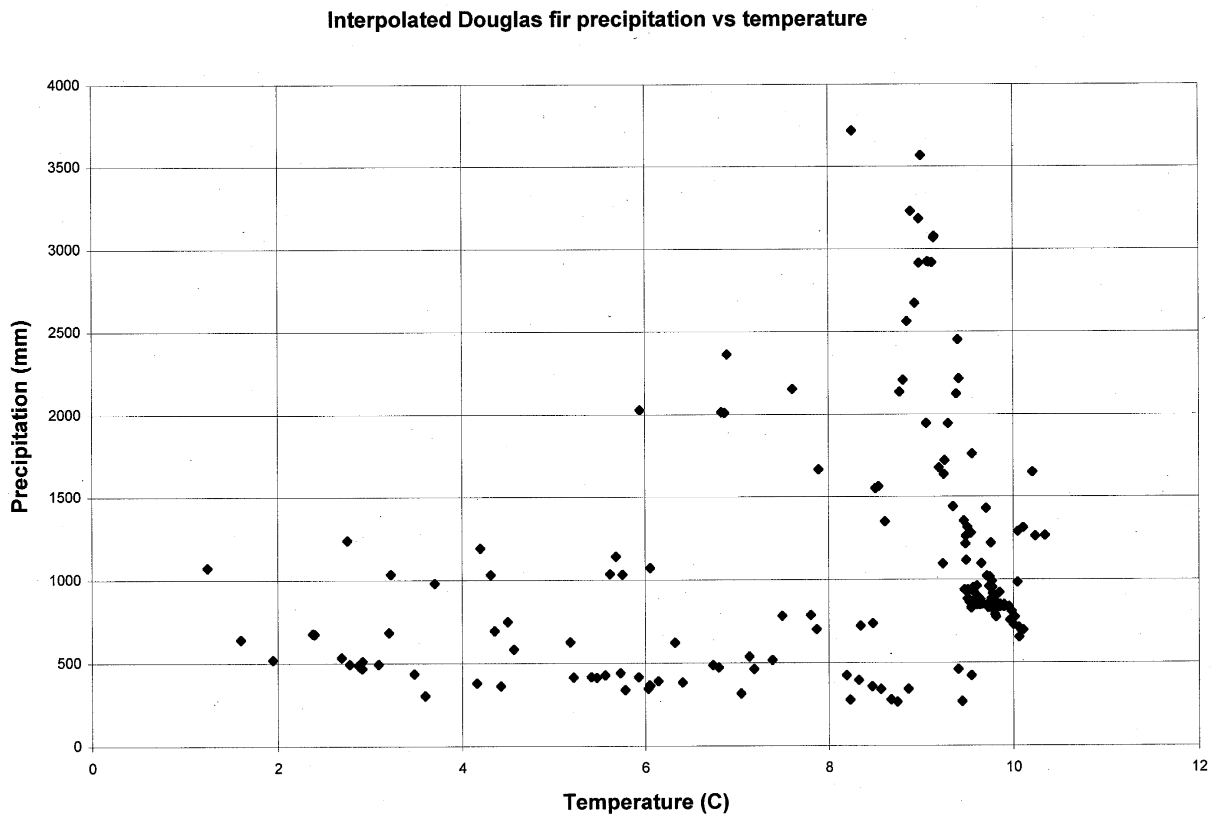


Table 1. Mean annual precipitation (MAP) and temperature (MAT) ranges for British Columbia Biogeoclimatic zones as reported in zone chapters in Meidinger and Pojar (1991). Zone names in brackets.

Zone	MAP (mm)	MAT (°C)
CDF (Coastal Douglas-fir)	647 - 1263	9.2 - 10.5
CWH (Coastal Western Hemlock)	1000 - 4400	5.2 - 10.5
MH (Mountain Hemlock)	1700 - 5000	0 - 5.0
BG (Bunchgrass)	no data	no data
PP (Ponderosa Pine)	280 - 500	4.8 - 10.0
IDF (Interior Douglas-fir)	300 - 750	1.6 - 9.5
ICH (Interior Cedar - Hemlock)	500 - 1200	2.0 - 8.7
MS (Montane Spruce)	380 - 900	0.5 - 4.7
SBPS (Sub-Boreal Pine - Spruce)	335 - 580	0.3 - 2.7
SBS (Sub-Boreal Spruce)	440 - 900	1.7 - 5.0
ESSF (Engelmann Spruce - Subalpine-Fir)	400 - 2200	-2.0 - 2.0
BWBS(Boreal White and Black Spruce)	330 - 570	-2.9 - 2.0
SWB (Spruce - Willow - Birch	460 - 700	-3.0 - -0.7
AT (Alpine Tundra)	700 - 3000	-4.0 - 0

Several constraints need to be kept in mind when using modern climatic characterizations of both species and ecosystems. First, given significant climatic changes in the past few centuries, it is not clear whether today's species distributions are in climatic equilibrium with modern climate. Second, factors other than climate, such as human activity, have dramatically altered the natural landscape with respect to disturbance characteristics and ecosystem fragmentation.

Integrating the numerous climate-species relationships into a coherent prediction is a daunting and challenging task. The systems-analysis-and-response approach uses computer models to consider various climatic, biotic and ecological factors, ranging from the individual level to the whole system level (i.e. carbon fixation, respiration rates, fires) (Melillo et al., 1990; Burton and Cumming, 1995). This strategy provides important insight into ecological processes and broad zone- or biome-scale predictions but may not address issues of ecosystem response at specific sites or in areas with complex ecological characteristics. Furthermore the systems approach is only as good as the computer model and the data fed into it.

Some of the limitations of the systems approach and lack of modern response data can be addressed by application of the paleoecologic analog (Melillo et al., 1990; Brubaker, 1992; Jetté, 1995). By "hindcasting" or using the past as a key to the future we can gain important insight into impacts of climate change. B.C. and the Yukon have experienced warmer climates than today during the last 10,000 years (Hebda, 1995; Cwynar and Spear, 1995). The approach has the advantage of providing real data on ecosystem conditions and species distributions at specific sites under warmer than present climate. There are, however, limitations to the paleoecological method itself (Hebda and Whitlock, 1997). Furthermore the biogeographic setting for future warming is not the same as in the early Holocene. For example lodgepole pine (*Pinus contorta* Dougl.), an important modern-day tree species in the Yukon, was not present in the region during the early Holocene warm interval. Furthermore numerous exotic plant and animal species have become established in the region and their role in future ecosystems is not easily predictable.

IMPACTS ON BRITISH COLUMBIA BIOGEOCLIMATIC ZONES

Predicted impacts are based, primarily on insights gained from the paleoecological record and on previously published work by Hebda (1994), Spittlehouse (1996), Rizzo and Wikem (1992) and Burton and Cumming (1995), Lenihan and Neilson (1995). My analysis emphasizes paleoecological data, on a zone by zone basis, where available (Hebda, 1995; Cwynar and Spear, 1995).

For Douglas-fir specific climatic characteristics developed from herbarium specimens and verified occurrences (especially at the northern limits of range) are used to enhance predictions derived from the paleoanalog approach. The predictions are refined further in the context of modern climatic characteristics of zones and species.

Before beginning a zone by zone account the following general trends should be expected for all zones:

- up-slope migration of tree lines and ecotones
- disappearance of forested ecosystems in regions of already warm and dry climate
- northward migration of forest types in the interior
- replacement of biogeoclimatic zones by zones with no modern analogues
- changes in disturbance regimes, eg. fire frequency, insect and disease outbreaks, windthrow.

I have divided the biogeoclimatic zones into four groups representing broad climatic categories.

- Coast: with generally mild and moist climates,
- Southern interior: with warm to hot summers and low to moderate precipitation
- Central and Northern interior BC and Yukon: with long, cold winters, low to moderate precipitation and with affinities to the Boreal Forest
- Tundra and Forest and Barren: with long cold winters and short cool summers and a range of precipitation.

In my predictions I separate the impacts on the geographic region, in which a biogeoclimatic zone occurs, from the ecosystem itself. Zonal vegetation or derivatives may move to adjacent areas while new assemblages develop within the area previously occupied by the zone.

Coast

This region comprises 3 biogeoclimatic zones Coastal Douglas-fir (CDF), Coastal Western Hemlock (CWH) and Mountain Hemlock (MH) of which the CWH covers by far the largest area. The southern part of the area is well covered by paleoecological studies, the northern part is not. Climate change impacts of this region have been little modelled (Burton and Cumming, 1995).

Coastal Douglas-Fir (CDF)

The CDF region and the CDF type forests will exhibit very different responses to climate change. A recent paleoecological study by Allen (1995) at Heal Lake near Victoria, indicates that CDF region is highly sensitive to climate change. Two possibilities derive from Allen's study and those of others in the zone (Hebda, 1995). Warm, dry conditions will favour the replacement of forest by woodland or meadow and knoll communities such as those characteristic of the Victoria area (Hebda and Aitkens, 1994) or warm and mesic conditions may lead to the development of Garry oak woodlands and forest. Garry oak stands were once much more extensive under apparently warmer climates (Hebda, 1995) but the precipitation characteristics associated with this interval are not yet understood. Studies now under way north of Nanaimo by me and my colleagues should reveal whether the full range of the CDF region exhibited similar response characteristics as the Victoria area did.

CDF type vegetation however may not disappear, instead its derivatives, still dominated by Douglas-fir, will likely spread westward and northward on Vancouver Island and a related zone may develop in the warm and relatively dry parts of the adjacent mainland. Several studies demonstrate that these regions once supported stands with more Douglas-fir than today (Nagorsen et al., 1995; Hebda, 1995 and references therein). The spread of Douglas-fir may be facilitated if fire disturbance increases, the species being well adapted to burning (Cwynar, 1987). The limits of the new CDF vegetation will depend on the amount of warming, and the extent to which effective moisture regimes of spring and summer change. Established trees may persist for many decades, though problems with insufficient cooling for winter bud break may pose problems (Burton and Cumming, 1995). Based on published and unpublished preliminary paleoecological data, the CDF zone could cover the south east half of Vancouver Island, though the southeast coastal zone might lose much of its tree cover to drought-adapted xeric communities. Climate changes to 2025-2030 may be insufficient to drastically affect the zone, but changes by 2045-2050 should have widespread impact.

Coastal Western Hemlock

The CWH zone has a wide geographic distribution but its temperature range is relatively narrow (Meidinger and Pojar, 1991). A good sense of what might happen to this zone comes from examination of the warm dry early Holocene paleoanalog (Hebda, 1995).

Allen (1995) examined a site in the CDF/CWH transition on south east Vancouver Island, now classified in the very dry variant of the CWH zone. During a climate 2°C warmer than today with less effective moisture, this site was occupied by forest dominated by Douglas-fir. Sites much deeper in the CWH zone occurring in moister and cooler variants also supported more Douglas-fir (Hebda, 1995). Douglas-fir today grows throughout much of the southern CWH, even in regimes of 3000 mm MAP or more. The species would not have to extend its range to become a forest dominant, rather expanding in-place populations, would effectively take over the forest from within.

An important factor in changes in the CWH forests will be the frequency and intensity of fire. Fires will likely increase, especially with warmer drier summers. Under such conditions Douglas-fir could expand rapidly (Cwynar, 1987). Preliminary studies by K. Brown (personal communication, September 1996) of CWH sites on south Vancouver Island reveal much more fire activity than today in the early Holocene warm, dry interval. Disturbance of the substrate and opening of the canopy because of logging practices may have the same result as increased fire frequency.

Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is an interesting species of this zone. Today though it has a wide geographic range (Krajina et al., 1981), it plays a minor role in the forests except along the shore in the spray and mist zone. However between 10,000 and 7000 years ago it dominated forests at many sites in the CWH along the coast, suggesting that it might increase with climate warming. Not enough is known about the climate and ecological characteristics of this species to be certain of its response. Sitka spruce may have the genetic capacity to fare much better in future forests that today. However, leader weevils (*Pissodes strobi* (Peck)) might be even more of a problem than now, if warming takes place (D. Spittlehouse, personal communication, January 1997).

The impact of climate warming in western redcedar (*Thuja plicata* Donn.) is problematic. The species is a characteristic and dominant element of the moist and mild CWH. Western redcedar expanded widely in response to moistening and cooling climatic trends of the mid Holocene (Hebda and Mathewes, 1984). However, today it grows well in the warm and relatively dry CDF zone of southeast Vancouver Island where western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) does not. This apparently superior adaptation to drought may imply a greater role in CWH derived forests of the future than it has even today.

Forested wetlands constitute a considerable area of the CWH zone (Banner et al., 1988). Warming climates will result in changes in wetland character and likely reduction in wetland area (Hebda, 1994). Fossil pollen studies suggest that CWH bog forests may revert to rich swamp forests with fewer typical bog plants like *Sphagnum* spp. and more abundant swamp plants like skunk cabbage (*Lysichitum americanum* Hultén and St. John) (Banner et al., 1983; Hebda, 1995). Forest productivity will likely increase, and species such as Sitka spruce might be favoured over less productive pines and cedars.

The net impact in the CWH will likely be a significant reduction in its range and changes in its characteristics. The zone, as we known it today, may ultimately disappear being replaced by a biogeoclimatic zone or zones (depending on the region) containing some of the same species but in quite different roles.

Burton and Cumming (1995) used an enhanced patch model of forest succession (ZELIG++) to predict that CWH and CDF forest might undergo "catastrophic collapse" because winter chilling requirements would no longer be met under $2XCO_2$ conditions. They note, however, that the ZELIG++ model poorly predicts modern coastal forest floristics. Though paleoecological studies suggest that more open forests should be expected under warmer and effectively drier conditions, they do not reveal any forest collapse in the moister parts of the CWH zone.

Mountain Hemlock

The paleoecologic history and potential sensitivity of this cool moist zone are not well known because few sites have been studied within it. Pellatt and Mathewes (1984) showed for the MH zone on Queen Charlotte Islands that western hemlock grew with mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) in the early to mid Holocene. The lower boundary of the MH must have then been at a higher elevation than today. Warmer temperatures will favour the growth of western hemlock at higher elevations than it does today. Furthermore if growing season moisture deficits develop or increase, invasion of today's MH zone must be expected by drought-tolerant species such as Douglas-fir. I have observed this species growing within the MH zone today on dry sites of south Vancouver Island. Whereas the lower boundary of the zone may move upward, and drought-tolerant species may expand their role, there will be little opportunity for the zone to increase its area. Today the MH zone extends to the highest available elevations along many parts of the coast and alpine areas are limited except perhaps in the coast-interior transition. Burton and Cumming's (1995) analysis suggests significant increases in productivity of the forest of this zone after warming.

Southern Interior Zones

This group of zones ranges from non-forested valley bottom steppe communities of the Bunchgrass (BG) biogeoclimatic zone, adjacent to the savannah of the Ponderosa Pine (PP) zone, through the warm dry forest of the Interior Douglas-fir (IDF) zone to the cooler and generally moister Montane Spruce (MS) and Engelmann Spruce-Subalpine fir (ESSF) zones. The moist moderate mountain slopes in the eastern part of the southern interior support stands of the Interior Cedars Hemlock (ICH) zone, below the level of the ESSF zone.

This diverse region is not well represented by paleoecological studies but several of them reveal the history of important transitions between biogeoclimatic zones (Hebda, 1995). All the zones appear to be sensitive to climate change with PP, BG, IDF and ICH likely being highly sensitive. There are as yet insufficient data to gauge the degree of sensitivity of ESSF and MS zones.

Trends to be expected with climate

change include upward rise of zones, expansion of, and diversification of steppe ecosystems and increase in fires. The region supports abundant and varied exotic weed species which may play a significant role in future ecosystems (Hebda, 1994).

Bunchgrass and Ponderosa Pine zones

Warming temperatures, probably associated with increased summer drought will almost certainly lead to the expansion of these two zones. Several cores in the adjacent IDF zone and one in the ICH zone suggest that open plant communities are favoured under warmer climates (Hebda, 1995). Even under the apparently warmer than present but relatively moist climates of the middle Holocene (7000 - 4500 BP) steppe communities were more extensive than today.

The extent of the expansion of the new ecosystems which derive from these two zones can be estimated by examining the extent of early Holocene open vegetation. At all the IDF sites studied, steppe or savannah vegetation predominated (Hebda, 1995). The elevation limit of these communities is difficult to establish at this time but it must have been well above 1200 m and perhaps reaching 1500 m in the southern part of the range.

The northern limit of expanded PP-BG vegetation is difficult to predict. In particular the occurrence of BG communities on the Chilcotin Plateau in the vicinity of Riske Creek strongly suggests that BG vegetation could easily expand onto large parts of the plateau with relatively little warming (Figure 2), perhaps even as little as predicted by 2020-2025. Notably this expansion would include areas today within the IDF and Sub-Boreal Pine - Spruce (SBPS) zones. Pollen analysis of a site at Pantage Lake west of the Fraser River between Quesnel and Prince George, suggests that a mosaic of steppe and forest communities occurred in the Sub-Boreal Spruce (SBS) zone under warm and relatively dry climates. Consequently I suggest that steppe vegetation could expand to fill at least the area covered by the IDF zone and possibly warmer parts of the SBPS zone.

In the early Holocene, steppe vegetation may have been differentiated into altitudinal zones with grass- and wildflower-dominated communities in higher moister sites and sagebrush-dominated communities at lower elevations (Hebda, 1982). The role of Ponderosa pine (*Pinus ponderosa* Dougl.) during this time is not known. This species is relatively frost intolerant (Krajina, 1969) and may not have grown in the higher elevation steppe communities, but rather formed a mid-elevation savannah zone between very hot and dry sagelands at low elevations and dry and cool grasslands at higher elevations.

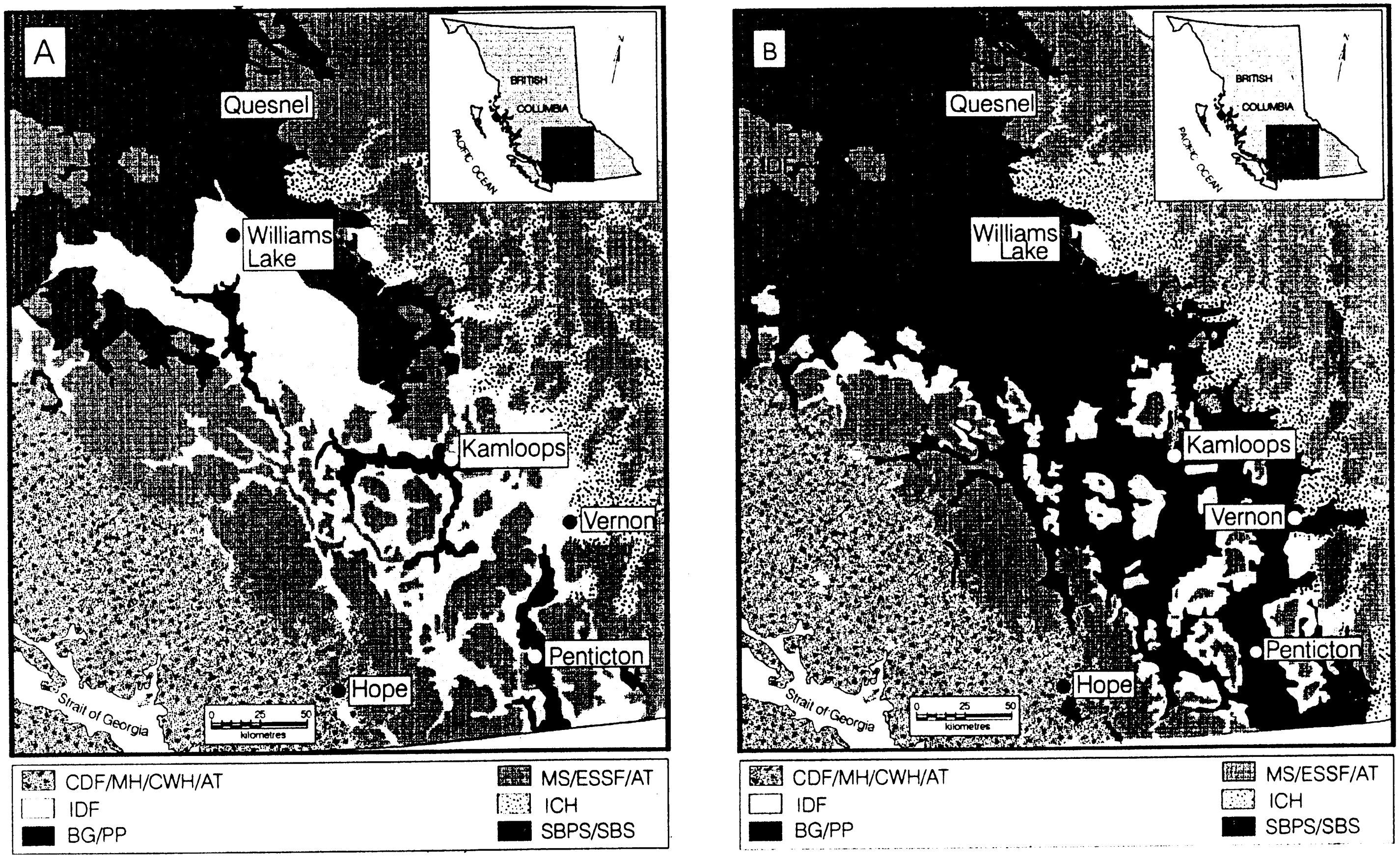
The future PP-BG Biogeoclimatic zones may take on a similar, alititudinally differentiated, form extending to 1500 m in most places and perhaps stretching to the tops of mountains on southern south-facing slopes. Whatever their range and general character, the zones most likely will contain numerous weedy species (Hebda, 1994), species which will likely expand over a greater area than they occupy today.

Interior Douglas Fir

Following from the discussion concerning the BG-PP zones, the IDF zone will be dramatically affected by climate change. Assuming warmer temperatures are accompanied by effectively drier summers, the principal controlling factor in the distribution of Douglas-fir stands will be moisture. Though studies are under way by my students in the ESSF zone no data are available to reveal whether Douglas-fir once predominated in forests at high elevations in southern B.C. Today Douglas-fir grows scattered, though not dominant, at sites much higher than the limits of the IDF. It is likely that with warming, Douglas-fir could out-compete spruces in particular and result in the replacement of the MS zone by the IDF type vegetation. With the likelihood of increasing fires, the new IDF zone could turn into mix of scattered Douglas-fir stands mixed with seral stands of lodgepole pine and extensive open areas.

The Douglas-fir climatic plot (Figure 1) suggests that the species could expand dramatically in SBPS and SBS zones in central B.C. converting large areas of these into IDF type ecosystems. The species now grows in these zones, so the source of seed is readily available. Douglas-fir is clearly adapted to the extremes of climate characteristic in the region. Douglas-fir certainly occurs throughout the SBPS and, provided that moisture remained sufficient, could expand to dominate the area now occupied by the zone, though major areas of seral lodgepole pine would remain. Spruces might disappear from all but the most moist and stable sites.

Figure 2. Possible changes to the distribution of biogeoclimatic zones of southern interior British Columbia resulting from climate warming at $2XCO_2$. See Table -1. for an explanation of zone abbreviations. **A.** The distribution of biogeoclimatic zones today, as down-loaded from the internet (see Meidinger and Pojar, 1991 for original map). Coastal and mid-high elevations zones have been combined and small zone patches have been eliminated for convenience. **B.** The distribution of biogeoclimatic zones of southern interior British Columbia as they might develop under climatic conditions predicted by computer models for 2050 AD. The PP/BG zones, combined, expand to occupy the IDF zone and the IDF zone replaces the MS zone. The extent of combined SBPS/SBS zones compared to present is not changed but their possible conversion to IDF is indicated by "?IDF". No changes are made to the boundary between the combined coastal zones and interior zones, nor the boundary between interior zones and the ICH. IDF type vegetation or a derivative of it may expand into these adjacent regions in the southern interior.



Considering the lower limit MAT's of SBS and SBPS zones, warming by 2050 would accommodate Douglas-fir as a dominant species throughout both zones on mesic sites and possibly see its expansion into the BWBS zone of northern B.C. Incidentally predicted MAT and MAP regimes for 2050 could accommodate Douglas-fir, though not likely as a dominant, as far north as the southern Yukon.

Burton and Cumming (1995) model a different scenario for the IDF zone, one which shows little change in composition, productivity and presumably extent. The reasons for this result are not explained but clearly such drastic differences between predictions merit attention.

Engelmann Spruce-Subalpine Fir and Montane Spruce

The climatic sensitivity of these two closely related and adjacent zones is not well known from the paleoecological record. Preliminary results from paleoecological studies of a bog at Pennask Summit along the Okanagan connector, west of Peachland suggest that forest composition and structure and the character of wetland ecosystems was different than today under warm early to mid Holocene climate. In particular spruce and especially subalpine fir were less abundant forest species. Instead of bog ecosystems, fens and possibly marshes occurred. Future ESSF and MS forests might then be expected to differ from modern ones. If the MS-ESSF zone experiences more summer drought than today, subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) might decline whereas Engelmann spruce (*Picea engelmannii* Parry) and hybrids would be favoured (Krajina, 1969). The result might be a merging of ESSF and MS biogeoclimatic zones into one zone. Fire plays an important role in these zones, with frequent fires leading to a landscape dominated by seral lodgepole pine stands. Increased fire frequency would further lead to the decline of subalpine fire and to mosaic of spruce and pine stands.

Studies of past tree lines (see Hebda, 1995) and Rochefort et al.'s (1994) analysis of continental subalpine tree distribution suggest that the upper limit of the ESSF will migrate into the AT zone with climate change. At some sites in western North America, this process may be already occurring (Rochefort et al., 1994). However, the extent of this upward forest expansion will depend on the degree of summer drought. Significantly increased soil moisture deficits, a possible outcome of the CGCM-1 model output could lead to the development of extensive grassland communities especially on south-facing slopes or soils on coarse parent materials. The result could be less extensive ESSF-MS forest cover especially in the southern part of the province, despite it's expansion in to the alpine zone.

The possible future of ESSF type forests in the northern third of the BC merits attention where they thrive under relatively warm montane conditions. Lenihan and Neilson's (1995) analysis of equilibrium $2XCO_2$ distribution of selected species implies major changes for this region.

Interior Cedar-Hemlock

The single paleoecological investigation of this zone suggests a high sensitivity to climate change (Hebda, 1995). During the warmer climates of the early and mid Holocene. pine, spruce, Douglas-fir/larch and fir predominated. Notable steppe openings occurred during the dry early Holocene stage of this interval. Western hemlock and western redcedar became dominant forest species only the last 4000 years during relatively cool and moist climate. It is not clear, however, whether the expansion of cedar and hemlock is solely the result of climatic change or the result of migration of the two species into the region from other areas.

Changes to the ICH will depend strongly on whether the regional climate becomes effectively drier. If it does, expansion of IDF type forests at the cost of ICH must be expected. Spruce dominated forests might be expected to persist at higher elevations so the upward expansion of ICH may be constrained.

In the ICH region of diverse species' composition, new forest types could be expected, perhaps more so than elsewhere. For example the ZELIG++ model predicts "phenomenal" increases in forest productivity largely because of improved climatic conditions for western hemlock (Burton and Cumming, 1995). The result may be a hemlock-dominated zone. The large patch of ICH in northwestern BC (Meidinger and Pojar, 1991) contains different species and may undergo different climate changes than the ICH in southeast BC. Clearly the ICH needs much more study.

Central and Northern BC Interior and Yukon

This region consists largely of a rolling to mountainous boreal landscape. The biogeoclimatic zones are related to the boreal forests of the continental interior but differ from them because of the importance of Cordilleran species, such as lodgepole pine, and irregular topography. The SBPS zone occupies central BC. The Sub-Boreal Spruce (SBS) zone occupies a large portion of central BC giving way to ESSF stands at high elevations. Subalpine vegetation in northern BC and adjacent Yukon consists of Spruce-Willow-Birch (SWB) vegetation or shrub tundra, forested at lower elevations but turning to parkland and scrub at higher elevations. Northeastern BC and valley bottoms of northern BC and the Yukon support the Boreal White and Black Spruce (BWBS) biogeoclimatic zone and equivalents. Forest and barren or taiga vegetation and Arctic tundra cover northern Yukon (Cwynar and Spear, 1995).

The southern part of the region is poorly represented by paleoecological studies, particularly in BC (Hebda, 1995). However several continental scale systems models have included parts or most of it in their analyses (Rizzo and Wikem, 1992; Lenihan and Neilsen, 1995; Burton and Cumming, 1995).

Trends to be expected include upward and northward migration of tree line, invasion of the region by southern species, development of ecosystems with no modern analogues, decline in wetland cover, especially bogs, increased fire frequency, increased forest productivity.

Sub-Boreal Pine-Spruce

Rising MAT's without increased MAP will likely lead to major changes in the region occupied by this zone today. As discussed previously, impacts may include the replacement of SBPS by IDF stands and open communities. Lack of paleoecological data hinders more definitive predictions. If the central interior remains relatively dry, as predicted by the CGCM-1 model, then pine-spruce stands might expand in the rain shadow along the east side of the Coast Range into, and perhaps to the limits of the SBS zone. Lenihan and Neilson's (1995) analysis of the response of lodgepole pine to $2XCO_2$ conditions predicts drastic declines in the dominance of the species from the SBPS and SBS regions and the development of non-analog ecosystems. The extent and intensity of disturbance by fire and logging will be critical factors in the future of the SBPS. Removal of forest cover may tip the balance in favour of steppe communities.

Sub-Boreal Spruce

The vegetation history record at Pantage Lake (see section on IDF) implies that at least part of this zone is highly sensitive to climate change. Warming of *ca* 1.4 °C , compared to control, with little increased moisture may be enough to turn southern sectors of the SBS into SBPS type stands and MAT's predicted for 2045-2050 AD could induce development of steppe communities with Douglas-fir stands in sufficiently moist sites. The extensive wetland communities characteristic of the zone will likely shrink and convert from bogs to marshes and fens.

The zone covers a wide area characterized by a relatively wide range of climate, consequently response will vary. Warming may lead to expansion of the some of the ICH species along in the eastern sector of the zone. However we have insufficient paleoecological and modern species climate data to speculate on the nature of the adjustments.

Burton and Cumming's (1995) model predicts increased forest productivity in this zone largely as the result of better lodgepole pine and trembling aspen (*Populus tremuloides* Michx.) growth.

Boreal White and Black Spruce

Vegetation histories and system models indicate that the boreal forest will suffer dramatic impacts with climate change (Hebda, 1995; Cwynar and Spear, 1995; Hengeveld, 1991; Rizzo and Wikem, 1992; Lenihan and Neilson, 1995). The CGCM-1 model confirms predictions of previous equilibrium models that major warming and likely increased summer drought must be expected in this ecosystem across Canada and in northwestern North America.

The vegetation and climatic history of the enormous region occupied by BWBS ecosystems of Yukon and B.C. is diverse and poorly known (Hebda, 1995). Lodgepole pine migration spanning several millennia complicates interpretation of past climate-vegetation relationships (Hebda, 1995). Generally, white spruce (*Picea glauca* (Moench) Voss)) dominated forests during the relatively warmer and dry climate of the early Holocene in a range from southern Yukon (Cwynar and Spear, 1995) to northern Alberta (Hebda, 1995). Black spruce (*Picea mariana*(Mill.) BSP) only became a dominant element of the BWBS forest in the last 6000 years or less, in response to cooling and increasing moisture (Hebda, 1995; Cwynar and Spear, 1995). Extensive muskeg developed in response to the same climatic trends.

Using the early Holocene climatic analog as a model, BWBS forest in northern BC and Yukon can be expected to convert largely to white spruce forests likely with significant component of lodgepole pine. Muskeg ecosystems will become much less extensive. The result might be parallel to converting the BWBS to SBS zone. In the dry sectors of the BWBS, such as in the semiarid zone of southwestern Yukon, combined warming and stable or lower MAP's could lead to the development of vegetation adapted to cool arid climate, such as open lodgepole pine forests (similar to SBPS but with little spruce) or cold steppe communities without modern analog. Today the semiarid zone receives less than 300 mm MAP, an amount below the lower limit of today's SBPS zone in central BC. Projected warming of up to 3 °C by 2050 without increased precipitation may generate conditions unfavourable for the growth of any tree species.

Computer simulations also suggest dramatic changes of a similar sort as derived from examination of the paleoecologic analog. Burton and Cumming (1995) predict reduced productivity and replacement of white and black spruce stands by lodgepole pine. Lenihan and Neilson's (1995) analyses vary according to climate model but suggest drastic changes in the BWBS and adjacent zones. In one $2XCO_2$ scenario most of the Yukon and much of northern B.C. converts to vegetation without modern analog. In an other scenario white spruce becomes predominant except in northern Yukon and in the semiarid region.

Spruce-Willow-Birch

This zone of parkland and high elevation shrub tundra is likely highly sensitive to climate change. Spooner (1994) discovered that an Alpine Tundra (AT)-SWB site in northwestern BC supported spruce-subalpine fir forests (ESSF-like) during the warm early and mid Holocene. He estimated temperatures to have been ca 4.5 °C warmer than now. According to Cwynar and Spear (1995) shrub tundra sites of the central Yukon all supported white spruce forests until mid to late Holocene moistening and cooling led to the expansion of black spruce and alder. These observations are consistent with results from computer models (ie. Lenihan and Neilson, 1995) and strongly suggest that SWB communities will be replaced by forest vegetation likely dominated by white spruce and possibly lodgepole pine or subalpine fir (depending on moisture regime).

Tundra and Forest and Barren

Forest and Barren (Yukon only)

The vegetation history of this region reveals trends like those to the south with early to mid Holocene white spruce forest being replaced in the mid to late Holocene by open ecosystems in which black spruce and peatlands played a greater role (Cwynar and Spear, 1995). These observations clearly indicate that this zone is sensitive to climate change, and will likely become forested, perhaps largely by white spruce and maybe even by lodgepole pine if warming is extreme.

Alpine and Arctic Tundra

The non-forested alpine zone is the subject of a separate contribution in this publication so I will deal with it briefly. Paleoecological studies of warmer-than-present early to mid Holocene climates all indicate that tree lines will rise with climate change (Hebda, 1995; Rochefort et al., 1994) in British Columbia and probably Yukon. The magnitude of the rise will depend on the amount of warming and local climatic and physiographic circumstances, but even small increases in tree-line elevation could lead to major losses in alpine habitats especially in southern BC (Hebda, 1994). Today, trees are invading alpine habitats in many parts of western North America (Rochefort et al., 1994) but whether this phenomenon is widespread in western Canada is not clear. For reference the CGCM-1 model predictions of 2-3 °C MAT warming by 2050 AD is as greater or greater than any climatic conditions interpreted from past elevated tree lines.

Considering predictions for forest-barren communities and results from system models, Arctic tundra vegetation in the northern Yukon will largely convert to forest or forest barren.

DISCUSSION AND CONCLUSIONS

The predictions in this paper are preliminary and speculative. More research is required into modern response characteristics and the early to middle Holocene paleoecologic analog to test and refine the predicted impacts. The BC-Yukon ecophysiographgic landscape is extremely complex and generalizations from a few scattered sites need to verified at other sites. Furthermore I did not have enough time to examine in detail the implications of paleoecological and systems model results. Each biogeoclimatic unit requires close attention on a geographically finer scale than was possible in my analysis. Additional climate output from the CGCM-1 model and other climate models is also needed, especially with respect to the seasonal distribution of moisture. Nevertheless the inescapable conclusion from my analysis, and those of others, is that our ecosystems will be profoundly impacted by climate change.

We must expect major shifts in the distribution of species. These will undoubtedly lead to the displacement of some biogeoclimatic zones, the disappearance of others and the development of new zones. This paper has only considered the impacts on dominant species, mainly trees. Similar impacts will occur on other plant and animal species. Consequently ecosystem response will be complex. Whether the changes will be gradual or sudden is not clear, but both types of responses are likely and have occurred in the past (Hebda and Whitlock, 1997). In some cases, there may be inherent ecological factors, such as soil characteristics, which may delay changes. In other cases, catastrophic processes or events, such as fire or extreme drought, may suddenly convert one zone to another, provided alternate, better-adapted species are locally available.

Upon consideration of zone by zone impacts, it is my opinion that most regions will undergo a shift of at least one biogeoclimatic zone (assuming these retain their character). Central and northern BC and the Yukon could be subject to shifts of two zones. I emphasize further that the predictions in this analysis are only for a $2XCO_2$ scenario. Climate change will not just stop at this point; warming will continue for many decades further. The impacts of such changes are difficult to imagine. There is clearly an urgent need to understand our ecosystems and constituent species, and their past history in manner as never before if we are to prepare effectively with ecological changes of the next century.

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Chapter 14

IMPACTS OF CLIMATE CHANGE ON AIR QUALITY IN BRITISH COLUMBIA AND YUKON

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OVERVIEW

The air quality of a particular region refers to the concentration of gaseous chemicals, aerosols and particulates found in the atmosphere. Climatic conditions including wind, precipitation and the temperature structure of the lower atmosphere have an important influence on local and regional air quality. The transport and removal of pollutants from the atmosphere are also affected by weather patterns. Topographic influences are also important since under certain atmospheric conditions, pollutants may accumulate in valley bottoms. The anticipated changes in air quality caused by climate change are for the most part small. The exceptions are in rapidly growing areas such as the Okanagan Valley and the Lower Fraser Valley where urbanization will exacerbate the impacts of climate change creating the potential for serious degradation in air quality.

INTRODUCTION

The concentration of gaseous chemicals, aerosols and particulates in the atmosphere is referred to as “air quality” which is strongly controlled by climatic conditions. Wind patterns, precipitation and the temperature structure of the lower atmosphere are the more important climatological elements that influence local and regional air quality.

In British Columbia and Yukon, the physical environment plays an important role in the modification of these climatological elements. The Pacific Ocean moderates the temperature and adds to the liquid water content of weather systems approaching from the west. Mountain ranges, the most important of which are the Coastal and the Rocky Mountains, form barriers and channel wind flow. Valleys within and between these mountain chains act as reservoirs for air pollutants.

The air quality in British Columbia and Yukon is predominantly a local issue due to the nature of the topographic constraints. Burning from forestry practices, the agriculture sector and other large scale events such as volcanoes and the long range transport of airborne pollutants broaden the local air quality concerns to the regional, national and international domain.

The assessment of the impacts of climate change on air quality begins with the identification of the important atmospheric processes that influence the concentrations of air pollutants. This is followed by the documentation of expected changes in the atmospheric processes caused by climate change. B. Taylor (1997) has provided an assessment of the expected changes in temperature and precipitation as predicted by Global Circulation Models (GCM) over the region of interest. A further analysis has detailed these impacts over four smaller climate regions, as identified by Environment Canada, within British Columbia and Yukon (Taylor, B., 1997).

The discussion of impacts of climate change on air quality will follow the pattern presented above using as a guide the changes already identified in the atmospheric processes from the Canadian Centre for Climate Modelling and Analysis Global Circulation Model (version II) (CCC GCMII).

A very important factor that has not been considered in these deliberations is the changing lifestyle that will occur over the next fifty to one hundred years. Modes of transportation will change, fuels to power the transportation sector will be different as will the source of energy to provide for human comforts. All of these factors will impact more on the air quality than climate change. The air quality conditions within an area have been related more to atmospheric processes than specific pollutants in an attempt to minimize the lifestyle question.

ATMOSPHERIC PROCESSES AND AIR QUALITY

The climate of an area is the history or accumulation of impacts from many atmospheric processes. Air quality, as indicated earlier, is the resultant of emissions of chemicals or other materials and atmospheric processes. It is important to identify the atmospheric processes that control air quality and how they are related to the climatology of an area (Oke, 1987).

The quality of the air is determined by the type and amount of chemicals or other material present in the atmosphere at any given time. The type of pollutants encountered is a product of the emission source which may be of natural or anthropogenic origin.

The distance that air pollutants travel will determine which atmospheric processes are important. Chemicals and other materials emitted from nearby sources will be controlled by local wind patterns and the stability of the lower atmospheric. Whereas, pollutants originating from sources great distances away will be controlled by large scale weather systems and wind patterns. Chemical and physical transformations will occur causing pollutant properties to change over a long trajectory (Committee on Monitoring and Assessment of Trends in Acid Deposition, 1986).

Air pollutants are also removed from the atmosphere by several processes. Weather conditions will influence which of the atmospheric processes dominate. In dry conditions, air pollutants are deposited by physical settling and contact with other surfaces. Snow and rain are very effective at scavenging chemicals and particles from the air. This process is called wet deposition. The venting of air pollutants upward out of the lower atmosphere can occur during thunderstorms. Other active weather systems can bring air pollutants such as ozone down into the lower atmosphere.

Climate change will influence the strength of emissions from some of the natural and anthropogenic sources of air pollutants. Large scale wind patterns and precipitation amounts and frequency will also be altered through changes in the climate. Even the types and rates of chemical and physical transformations occurring to the pollutants may be effected.

PRESENT CONDITIONS

The Region - British Columbia and Yukon

The Region has three areas or airsheds that must be considered separately when air quality is being studied. These are the eastern coastal area of Vancouver Island, the Lower Fraser Valley airshed and the Okanangan Valley airshed. Because of the urbanization in these areas, the air quality issues are complex and often exacerbated by topography. The impact of climate change in these areas warrants more detailed analysis.

Other areas within the Region have complex air quality issues which are more confined topographically and hence of a smaller scale. Whitehorse, Quesnel, Williams Lake, Smithers and Prince George could be considered examples. These communities usually have one or two major pollution sources which can be identified as point sources. Often these point sources are surrounded by a number of smaller emitters such as private residents, agricultural activities and smaller industrial endeavors (Johnson, 1992). These are often referred to as area sources. How the frequency and intensity of air pollution events will be significantly influenced by climate change will be discussed later.

The remainder of the Region consists of smaller communities which suffer from very local air quality concerns. Most of these concerns relate to wood smoke from both industrial and residential sources. Climate change will not have the same degree of impact on these very small, local air pollution events.

Burning from forestry practices, the agriculture sector, volcanoes, long range transport of airborne pollutants and other larger scale phenomenon affect all areas. Smoke, whether it comes from prescribed burning, wild fires, land clearing or farming practices, will influence the air quality of large areas. Climate change will have a significant impact on the frequency and intensity of these events.

Yukon/North BC Mountains

The Yukon and the northern mountainous area of British Columbia are subjected primarily to local air quality events. Confined by weather conditions and topography, the air pollution from small industry and residents combine to create localized problems. These events are common in the winter season when cold arctic air traps the emissions from the urban area into the lowest layers of the atmosphere. The steep mountain valleys provide the horizontal barriers forming an effective container to concentrate the airborne pollutants. A similar condition occurs in the warmer months when atmospheric conditions cause air from aloft to descend trapping pollutants in the valleys. Frequently, air pollutants trapped by these conditions have been transported into the area sometimes over long distances.

Studies from atmospheric measurement programs have identified this area as the recipient of air pollutants in the form of pesticides that have traveled across the Pacific Ocean. Another source of air pollution is smoke from wild fires burning in timber far to the south and east. The occurrence of these pollution events provide strong evidence for the importance of wind patterns in the transport of particulates and chemicals from distance sources.

Northwestern Forest

The Northwestern Forest region can be considered as a portion of the Canadian prairies as far as air quality is concerned. On the east side of the “divide”, the communities are subjected to weather patterns usually associated with areas to the east. A significant part of the region that is inhabited lies in the Peace River area often in wide, open valleys. Air quality is influenced by cold arctic outbreaks in the winter that trap pollutants close to the ground. Much of the air pollution comes from petrochemical processing and from residential fossil fuel usage. The summers are often free of significant poor air quality events as the weather conditions will vent pollutants out of the larger valleys. Occasionally, during periods of hot stagnant weather, descending air will trap pollution from forestry/agricultural sector fires or from nearby industry.

In a similar manner to their neighbors to the west and north, this region is subject to long range transport of airborne pollutants. Unlike the areas to the west, sources regions for the long range transport can be to the east as well as the west. Wind patterns will often bring air pollution from Alberta into this northwestern sector of the prairies.

South BC Mountains

This area is dominated by mountain valleys populated by small communities. All of the major cities in this area reside in the major river basins. An exception is the Okanagan Valley which will be dealt with separately.

The river valleys with their steep slopes dominate the conditions that influence air quality in most of these communities. In a similar manner to other areas, cold air traps pollutants in the valleys during the winter. Hot summer weather with light winds can also limit the ventilation of these valleys allowing air pollutants to accumulate reaching very high concentrations (Johnson, et al., 1987).

The Okanagan Valley in this region has many similarities to the Lower Fraser Valley from an air quality perspective. Comprised of three cities and a fast growing population, the air quality situation is becoming more complex with each passing year. Weather patterns that affect air quality are influenced by the large valley with air circulation patterns frequently modified by Okanagan Lake. Industrial and mobile emissions combine to create an urban SMOG which is apparent in the summer season trapped under hot stagnant weather conditions. The valley is large enough to be a receptor of smoke from agricultural activities within the local area as well as distant sources.

Pacific Coast

This area of the province captures several very different air quality regimes. Most of the mainland coast and most of Vancouver Island are dominated by local air quality issues that are created by local sources and driven by weather patterns that only effect small areas. This is due to the rugged nature of the region and the limited industrial and residential development in many areas. The exceptions to this description are the Lower Fraser Valley, east coast of Vancouver Island and Victoria.

The Lower Fraser Valley is home to nearly half the population of B.C. The Valley is triangular in shape, closed on two sides with the Strait of Georgia making the third side. Wind patterns follow the east-west orientation of the valley moving air pollution in and out of the valley with the prevailing flow. The dominant source of pollution in the Valley is the transportation sector which distributes pollutants throughout the area (Steyn, et al., 1996). Industrial sources are also present including a large agricultural component toward the eastern end of the valley. This combination of sources provides the potential for high concentrations of air pollution whenever the weather conditions dictate. In the winter, fine particulate from combustion sources or crustal material are problematic while summers months have episodic occurrences of smog. Often air pollutants will react with each other as is the case with the formation of smog. Another group of secondary pollutants are the fine particles formed when emissions from fossil fuel combustion react with ammonia (Barthelmie, et al., 1996).

Another area where population is growing rapidly and emission sources are complex is the eastern coast of Vancouver Island from Campbell River south to Victoria. This narrow band is made up of emission sources similar to those of the Lower Fraser Valley. Fortunately, the topography and weather conditions of the area do not allow for the build up of these pollutants on a large scale. Smaller areas around communities are often the locations where industrial air pollutants and accumulations of air pollutants from the burning of fossil fuels become trapped and create air quality concerns.

The City of Victoria is the third unique area within this region. Air pollution is limited to local situations where stagnant weather patterns, particularly in the winter, allow emissions from both industrial and residential sources to accumulate (Capital Regional District Task Group on Atmospheric Change, 1992). Generally, the exposure of the City of Victoria to the wind patterns from Juan de Fuca Strait maintain sufficient ventilation that pollution does not reach significant concentrations.

AIR QUALITY CONDITIONS UNDER CLIMATE CHANGE

Yukon/North BC Mountains

The GCM CCCII indicates that this region will generally be warmer and wetter through all seasons. Winter will be the season where air quality conditions will be the most affected. It is expected that air quality conditions will improve through decline in the number and intensity of cold arctic outbreaks hence a decrease on the use of fossil fuels for heating. The impact will be on the fine particulate concentrations and concentrations of volatile chemicals released during combustion (polyaromatic hydrocarbons). Without extended periods of cold weather, air quality in most localities will improve.

The remaining seasons will also be warmer and wetter which indicates more snowfall in spring and fall with increased rainfall in the summer. Air quality impacts will shift toward the environmental arena with more snow and rain bringing an increase in deposition of airborne pollution to the aquatic and terrestrial ecosystems. More precipitation in the spring and summer should also decrease the occurrence of wild fires which in turn should decrease the number of days during the summer when fine particulate create human health and visibility concerns. Wetter, warmer conditions in the summer may suggest the precipitation would occur in the form of showers. This type of weather provides for well ventilated conditions and hence better general air quality.

Changes in temperature and precipitation indicate an overall alteration of the wind patterns which control the trajectory of weather systems. Flows indicated by the GCM CCCII do not change dramatically with climate change scenarios however an enhanced southwesterly flow is anticipated. The importance of this large scale shift in wind patterns is in the expected increase that would result in the long range transport of air pollutants. With the shift to more southwesterly wind flows, the environment will be exposed to increasing concentrations of pesticides transported across the Pacific Ocean and from southern latitudes.

Northwestern Forest

This region will experience air quality impacts very much in common with Yukon/North BC Mountains. The main difference between the regions is the impact that an increased southwesterly flow will have. In the winter, this southwesterly flow is likely to increase the number of “chinook” events where milder air spills over the Rockies. Unfortunately, these periods are often accompanied by poor air quality as the milder air aloft traps polluted air near the ground. The enhanced southwesterly flow in the summer will likely increase the number of large, slow moving weather systems that pull polluted air from the prairies westward and northwestward toward the foothills of the Rockies.

South BC Mountains

The climate change scenarios seem to indicate that the winters will be milder and wetter with the spring, summer and fall warmer and only slightly wetter. The precipitation trends demonstrate considerable variance through the summer. Air quality conditions in the winter are likely to be similar to those of other regions previously discussed with generally improved conditions.

For this region, the summer is the season of interest. The forecast of warmer and potentially drier conditions in some areas could have a severe impact on air quality. It is conceivable that the frequency of wild fires would increase hence concentrations of fine particulate associated with the smoke would also increase. The Okanagan Valley is an area where warmer, drier summers could have a negative influence on the local air quality. The expected weather patterns are indicative of hot, stagnant atmospheric conditions which are associated with the formation of photochemical pollution (SMOG) and high levels of fine particulate concentrations.

Pacific Coast

This region appears to be the least impacted of all the areas. Increased precipitation would enhance the deposition of airborne pollutants however if the frequency of rainfall also increases then this impact will be minimal. The “spring shock” to the aquatic ecosystems may be greater with the increased amount of polluted snow available for spring thaw.

Many communities that now experience local air quality episodes caused by residential fossil fuel usage and agricultural practices may see an improvement due to climate change. Warmer conditions in this region imply fewer outbreaks of cold air and fewer periods of stagnant weather conditions during winter months.

The Lower Fraser Valley may experience the largest impacts in the region. Model predictions suggest warmer, drier weather in the summer producing periods of hot, stagnant weather which would be conducive to the formation of SMOG episodes. Slightly warmer and wetter conditions in the winter would have little effect on air quality.

DISCUSSION

The predictions for climate change in all of the regions of British Columbia and Yukon indicate generally warmer and wetter conditions. For most regions, these trends mean an improvement in local air quality. This is particularly true in northern areas where winters will not be as cold and periods of stagnant polluted air will decrease. Summer weather patterns appear to bring conditions that imply better ventilation. In general, the only decrease in air quality is associated with the long range transport of airborne pesticides and the possible impact of fine particulate from an increasing number of wild fires.

The Okanagan and Lower Fraser Valleys are of concern. Both areas continue to be under pressure from urbanization and both appear to be subject to changes in weather patterns that will increase the frequency of poor air quality episodes in the summer. It is possible that the “SMOG season” could be longer in both areas with the duration and intensity of SMOG episodes increasing (Taylor, 1996). The air quality through the remainder of the year will not be seriously impacted by climate change but will only be degraded by the continued pressure from urbanization.

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Chapter 15

EFFECT OF CLIMATE CHANGE ON AGRICULTURE IN BRITISH COLUMBIA AND YUKON

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OVERVIEW

Current climate change predictions indicate that weather throughout British Columbia and the Yukon will generally become warmer year-round, wetter in winter, and drier in summer. The impact of these changes on agricultural production is, however, specific to the various climatic regions. In general, the potential for crop production would be increased due to a higher potential for crop yield resulting from more favourable climatic conditions, an expanded range over which some crops can be grown, and the introduction of new, higher value crops. The degree to which this increased potential for crop production can be realised will be primarily dependent on the availability of water. The predicted climate change will enhance production where crops can be irrigated, however, limitations to the supply of irrigation water may seriously affect productivity. Where irrigation is not feasible, productivity may increase slightly, remain the same, or decrease, and would be very sensitive to actual rainfall distributions during the growing season. Considerable areas of land suitable for agricultural production are currently not in use in some regions due to lack of necessary infrastructure and increased costs associated with distant markets. Climate change may increase the land in agricultural production, however, the area currently in production is controlled primarily by economic rather than climatic considerations. Increased demand on existing water supplies, from agricultural and non-agricultural users, is expected to occur throughout British Columbia.

INTRODUCTION

Detailed study of the impact of climate change in British Columbia and the Yukon on agricultural production has been very limited. Some work has been done on the potential impact of climate change on agricultural production in northern British Columbia and the Yukon (Mills 1994). As a result, much of the information in this chapter is a preliminary evaluation by agricultural scientists of the potential impacts of a change in climate as projected by three General Circulation Models.

Agriculture production in British Columbia and the Yukon is very diverse. This diversity is due to the wide range of climatic conditions, soils and market conditions. In this study, agricultural land in British Columbia and the Yukon was divided into five zones: south coastal B.C., south interior B.C., north interior B.C., Peace River region of B.C. and the Yukon (Figs. 1, 2). Each region has relatively distinct climatic conditions and agricultural production systems.

In general, the prediction is that winters will be warmer and wetter, and summers will be warmer and drier. The drier summers would be a result of reduced precipitation in some regions, but also a result of increased evaporative demand associated with warmer temperatures in all regions resulting in a net increase in the water deficit. The expected impact of climate change on agriculture varies from zone to zone because of the distinct nature of the climate and agricultural production within the five zones.

The following provides an overview of the five zones, the nature of the agricultural production in each, and the expected impact of climate change on agricultural production within each zone. The impact is based on the median value of the monthly change in temperature and precipitation projected by three General Circulation Models (Table 1).

SOUTH COASTAL BRITISH COLUMBIA

The south coastal region includes the lower Fraser Valley and Vancouver Island (Fig. 1). The area of land in agricultural production is small, but animal and crop production is very intensive. For example, the lower Fraser Valley contains approximately 67% of the dairy cattle, 74% of the swine, and 79% of the poultry in British Columbia on less than 4% of the agricultural land (Statistics Canada 1992).

Current Agricultural Production

Crop production in this region is very diverse. Forage crops in support of the dairy industry are most common, including forage grass (used for hay, silage or as pasture) and

Table 1. Predicted changes in temperature (°C) and precipitation (%) for the five agricultural regions (Values are the median of three General Circulation Model projections, comparing a 1 x CO2 to a 2 x CO2 scenario). SC - South Coast; SI - South Interior; NI - North Interior; PR - Peace River; YK - Yukon.

	Temperature					Precipitation				
	SC	**SI**	**NI**	**PR**	**YK**	**SC**	**SI**	**NI**	**PR**	**YK**
Jan	+3	+3	+3	+3	+2	+10	+10	+10	+20	+20
Feb	+2	+2	+2	+2.5	+3	+10	0	0	+5	+5
Mar	+1.5	+2	+2	+2	+2.5	+5	+15	+5	0	+10
Apr	+2.5	+3	+3	+3	+2.5	+5	+15	+5	+10	+10
May	+2.5	+3	+3	+3.5	+3	+5	+10	+5	+10	+10
Jun	+2	+2.5	+2.5	+2.5	+2.5	-20	0	-10	+5	+10
Jul	+2.5	+2.5	+2.5	+2.5	+2.5	-10	0	-5	-5	+10
Aug	+2.5	+3	+3	+3	+3	-10	0	+5	-5	+5
Sep	+3	+3	+3	+3	+3	-20	-10	-20	0	+5
Oct	+1.5	+3	+2.5	+2.5	+2	0	+15	+10	+10	+10
Nov	+3	+3	+3	+2	+3	+10	+15	+10	+10	+10
Dec	+3	+3	+3	+3.5	+3	+10	+15	+15	+15	+10

Figure 1. Agricultural production regions in British Columbia.

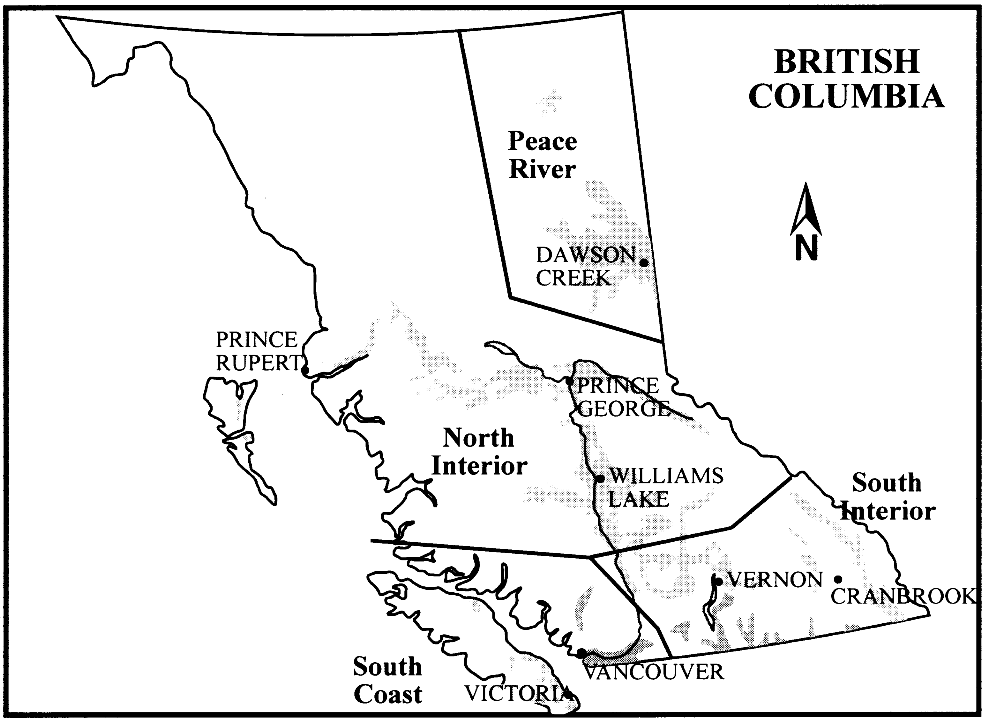
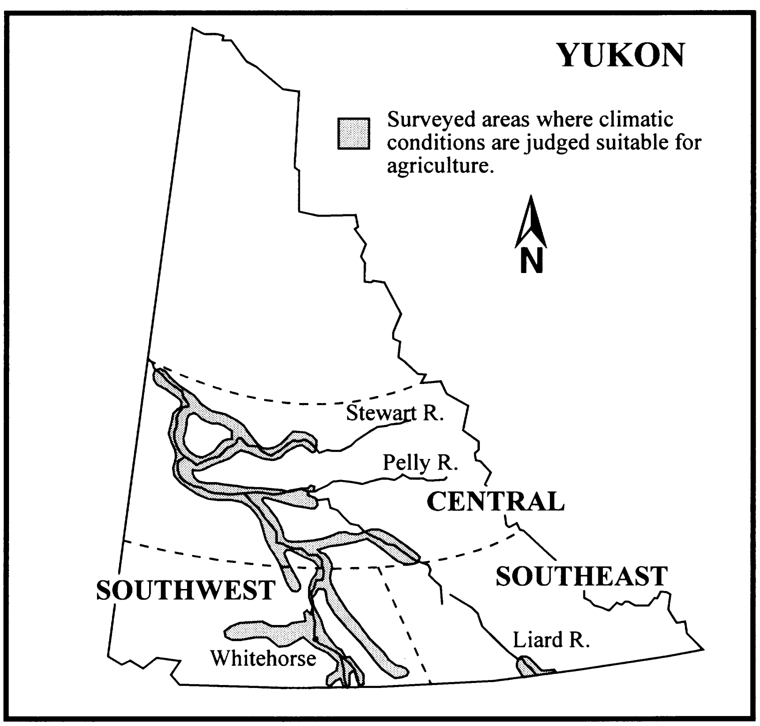


Figure 2. Potential areas for agricultural production in the Yukon.



silage corn. Large areas are also in small fruit production, including raspberries, strawberries and blueberries, and a range of field vegetable crops including sweet corn, potatoes, cole crops, and salad crops. Substantial greenhouse production of cucumbers, tomatoes and coloured peppers also occurs.

The region is characterized by wet, mild climatic conditions. The mean annual temperature is about 10°C. Mean annual precipitation varies substantially throughout the region from about 800 to 1700 mm, generally increasing in an easterly direction. Most of the precipitation falls as rainfall, and about 70% occurs from October to March when crop growth is limited. The frost free period ranges from about 175 to 240 days.

Climatic conditions are very favourable for production of a wide range of crops. The factors limiting yield vary somewhat with crop species. Several perennial crops such as forage grass and raspberries are vulnerable to winter damage from cold outflow winds from the British Columbia interior. Many annual crops are limited by temperature, but also by soil conditions: planting is often delayed by wet soil conditions. High value horticultural crops are commonly irrigated in response to a moisture deficit during the summer. Most forage crops are irrigated on Vancouver Island, whereas most forage crops are not irrigated in the Fraser Valley. Due to the favourable climatic conditions, virtually all land suitable for agriculture has already been brought into production. Significant areas of land have been removed from production due to urban development and land speculation.

Expected Impact of Climate Change

The predicted climate change is for a 2 to 3°C increase in temperature year-round, for wetter climatic conditions from November to May, and for drier conditions from June to September (Table 1).

The predicted change in temperature, assuming no change in climatic variability, could substantially benefit horticultural production in the region. Warmer summer conditions would increase productivity of these crops. Warmer winter conditions could substantially increase the length of the growing season, making many warm season crops such as coloured peppers and melons more economically viable, and increasing the potential for double cropping. The warmer winter conditions predicted for the British Columbia interior may result in less frequent and less extreme cold outflow winds, reducing the risk of winter injury. Some new crops, such as over-wintering cole crops, that currently are at too great a risk from winter injury may become common.

Forage crops would also benefit from the predicted temperature change. The warmer winters should result in a substantially longer growing season for forage grass, and the higher summer temperatures would be beneficial for silage corn production. New varieties may be introduced to take advantage of the longer and warmer growing season. For greenhouse production, the warmer winters would reduce heating costs and may make it economical to produce more tropical crop species, whereas the warmer summer would result in increased cooling costs.

Increased temperatures would also increase crop damage by pests. The warmer winter may increase winter survival of insects, and allow more insect cycles to occur within a growing season. The result may be a significant increase in the risk of insect damage to crops.

The poultry and swine industries rely on feed grown outside of the region, and therefore would likely not be directly impacted by climate change within this region. There may, however, be an impact of the warmer climate on building design for all animal operations.

The predicted change in precipitation patterns would likely impact crop production in a number of ways. The drier summer conditions will substantially increase the requirement for irrigation. Many horticultural crops are currently irrigated, and in most cases have an adequate water supply. The potential to produce horticultural crops without irrigation would be substantially reduced. In the Fraser Valley, many forage crops would require irrigation. Most of these operations do not currently have an infrastructure for irrigation, and many may not have adequate access to irrigation water. Where irrigation is not feasible, significant yield reductions are expected. It may be necessary to introduce new forage grass cultivars that are more resistant to heat and drought stress.

The drier summer will be very advantageous in reducing disease problems. Small fruits such as raspberries and strawberries are very vulnerable to fungal diseases and would benefit from a dry summer.

The climatic prediction is for wetter conditions from November through May. Field access is presently a significant limitation to annual crop production in many soils. A wetter spring may further delay planting, reducing the benefit of a warmer spring. In addition, though increased early growth of forage grass is likely to occur, the wetter spring may make harvest difficult, resulting in a substantial reduction in forage quality. Wetter conditions throughout the fall, winter and spring could result in increased flooding, increased problems with soil drainage and trafficability, increased soil compaction, and enhanced leaching of pesticides and nutrients. The impact of climate change on crop production in the region will likely be very sensitive to precipitation patterns in April and May, and therefore is difficult to predict.

The south coastal region is the most densely populated region in British Columbia. It is likely that the population will continue to increase at a rapid rate. The agricultural land base is declining in response to urban and industrial growth and development and this will likely continue. Land values are already high, and will likely continue to increase. There is an increasing pressure to produce a higher economic return on agricultural land. This pressure and the increased proximity and size of an urban market for agricultural products may result in substantial changes to agricultural production independent of climate change.

The increasing human population and drier summers will place increasing demands on water supplies. It may be possible that irrigation water supply may become limited in some areas. The combination of increased irrigation requirement, and possibly reduced irrigation water supply, could have a substantial impact on agricultural production. More efficient irrigation technologies may have to be developed or adopted to deal with a reduced water supply.

Overall, the predicted climate change should be beneficial for agricultural production. The potential for horticultural and forage production would be substantially enhanced by a warmer, drier growing season. Operations without adequate access to irrigation could suffer however.

SOUTH INTERIOR BRITISH COLUMBIA

The south interior region of British Columbia includes all agricultural land south of a line running west to east approximately 50 km north of Kamloops between Clinton and Barriere, but excluding the south coast region (Fig. 1). Agriculture is conducted primarily on land in valley bottoms, but also on some upland areas.

Current Agricultural Production

Agricultural land within the region can be broken into two general groups. The first group includes those areas with a very arid climate, and includes land in the south Okanagan, the Similkameen, and the along the Thompson and Fraser rivers. These areas generally have either intensive horticultural production (primarily apples but also other tree fruits and grapes), irrigated forage production, or low intensity grazing of beef on natural rangeland. The areas where fruit is grown tend to be limited to locations close to valley bottoms and often near the moderating influence of lakes. Due to severe moisture deficits, productivity is very low in the absence of irrigation.

The second group includes land with a less arid climate including the North Okanagan-Shuswap area, the Creston Valley, and the Cranbrook area. This land also includes some intensive horticultural production, but is dominated by dairy and beef production. The somewhat wetter climate allows for dryland crop production, and much of the area has access to irrigation water. Crops include alfalfa, forage grass, silage corn, and some cereal crops.

Mean annual temperatures in the southern interior range from about 7 to 10°C, but can be as low as 5°C, for example at Cranbrook, because of higher elevations. Annual precipitation ranges from about 240 to 550 mm, of which 60 to 70% and 70 to 80% occurs as rainfall in the drier and wetter areas, respectively. The frost free period ranges from 110 to 180 days.

Forage production (including rangeland) is primarily non-irrigated, with production limited primarily by water availability due to substantial growing season water deficits. Production is also limited by temperature and to some extent by the infertile and shallow soils in some areas.

Horticultural production is almost exclusively irrigated. Production of these crops is limited primarily by temperature conditions: season length and severity of winter. Production is also limited in some cases by soils that have low fertility, very coarse textures, steep slopes, and low organic matter contents. Irrigated forage production is limited by similar factors, but also in some cases by the supply of water for irrigation.

Expected Impact of Climate Change

The predicted climate change is for a 2 to 3°C temperature increase year-round, for wetter winters, and for summers that have the same or slightly lower precipitation (Table 1).

For horticultural production, the predicted temperature change could be very beneficial. Presently the upper limit for growing fruit trees is about 600 m above sea level in the Okanagan and Similkameen Valleys, and about 800 m in the Creston Valley (OVTFA 1994a). Assuming no change in climatic variability, suitable climatic conditions for fruit growing could advance upward about an additional 200 to 250 meters and northward about 160 to 215 km for the predicted 3°C temperature increase. This means that conditions for fruit growing now found in the Osoyoos-Oliver area could advance northward to the latitude of Kamloops and the Shuswap. Not only apples, but peaches, apricots and grapes could become important commercial crops in those northern areas.

In the southern areas, new apple cultivars that require a longer growing season may become more popular. The increased warmth would be expected to significantly improve grape production and quality. Winter cold injury, a major threat to apricot and peach production (Quamme 1987), should be reduced. Species and varieties that are not commercial crops now (i.e. nectarines and walnuts) may become economically viable.

The predicted temperature increase may also result in some production problems. Damage to apples can occur when temperatures rise above 37°C (OVTFA 1994b). Sunscald would increase and occur over wider areas due to climatic warming. In addition, temperatures in excess of about 30°C during the growing season of the harvest year can reduce current tree fruit production. An increase in the length of the growing season could cause some fruit species and/or cultivars to bloom at an earlier date when nights are of longer length, thereby increasing the risk of spring-time freeze hazard. Higher temperatures at or near the time of harvest for some fruit species could cause a rapid advance in both maturity and in post-harvest fruit deterioration.

The potential for forage production would be enhanced by the predicted temperature increase. The longer growing season and warmer temperatures would increase the potential for forage crops with a high heat unit requirement (e.g., silage corn) and allow them to be grown over a broader area. The longer season would also benefit hay production through an increase in the number of harvests per year and warmer drying weather. Earlier opening of mountain ranges and longer grazing seasons may be a stimulus for increased cattle production.

The predicted change in precipitation may limit the extent to which the increased temperature may enhance crop production. The drier summer conditions and warmer temperatures would significantly increase the moisture deficit during the growing season.

For horticultural crops, this would result in a significant increase in the requirement for irrigation. Currently, water supply is not a limiting factor in most areas. It is unclear, however, what the impact of the climate change might be on the availability of irrigation water. For example, under current conditions the surplus of precipitation over evaporation in the Okanagan Lake is relatively small (Coulson 1988). Therefore, small increases in evaporative demand due to warmer temperatures may have a significant effect on water levels in the lake. Any such limitation to the supply of irrigation water could result in a substantial reduction in horticultural production, or require the development of new, more efficient irrigation technologies.

For forage production, irrigation water supply is more often limiting. Many areas which now have a limited water supply will likely have difficulty obtaining sufficient irrigation water. Productivity in non-irrigated areas will likely decrease.

The wetter winter conditions may provide some benefits. Wetter soil conditions could reduce the depth of cold penetration protecting roots from extremely low temperatures, more cloudy conditions could reduce extremes of low temperature and increased winter precipitation will increase soil moisture in spring for early growth. Crops grown on sandy soils are especially vulnerable to early spring soil moisture deficits that may occur prior to the onset of irrigation.

The drier summer may also provide some benefits for tree fruit production. A drier summer may reduce cherry splitting, may reduce fungal diseases, and less cloudiness may result in an increase in net-photosynthesis with resulting greater fruit production and a higher quality crop.

There is limited potential to expand tree fruit production to higher elevations in existing production areas due to steep slopes. However, fruit growing may become feasible in valleys at higher elevations and in valleys further to the north, especially in places along large bodies of water. The ability to expand forage production is also likely limited. Higher growing season temperatures may allow production at higher elevations, however higher moisture deficits may compensate for this somewhat.

It is expected that a significant increase in population will occur in this region. This will result in increased demands on water supplies for non-agricultural uses, and may impact on the supply of water for irrigation.

Overall, there is the potential for substantial benefits to agricultural production in the region as a result of the predicted climate change. The potential to realize those benefits is very dependent, however, on the impact of the climate change on the water balance within the region. Reduced availability of water for irrigation could result in substantial losses in productivity. The increased water deficit during the growing season may have a substantial impact in the wetter areas of the region where dryland farming is currently practiced and where irrigation water is not readily accessible.

NORTH INTERIOR BRITISH COLUMBIA

The north interior region of British Columbia includes all agricultural land north of a line running west to east approximately 50 km north of Kamloops between Clinton and Barriere, excluding the Peace River region (Fig. 1). This region includes more than one-third of the potential agricultural land in British Columbia. This land is located primarily in lower elevation lands associated with river valleys, and as a major interior plateau in the north central region, which have soil and climatic conditions suitable for agricultural production.

Current Agricultural Production

Beef production is the principal agricultural activity in the region. A substantial area of the better land is in cultivated forage production (hay and silage) producing feed to maintain animals through the winter. Some cereal production occurs in selected areas for silage and/or grain. Irrigation is used to enhance forage production when available. Much of the land is used for grazing and is classified as natural rangeland.

Climatic conditions vary within the region, but are generally cool and dry. Mean annual precipitation generally ranges from 450 to 600 mm and average annual temperature from 2 to 5°C. Climatic conditions generally become cooler and wetter heading north and east and with increased elevation within the north central region.

Agricultural production is limited primarily by temperature and moisture deficit conditions and to a lesser extent by soil conditions. Cool temperatures and short growing seasons limit the range of suitable crop species and varieties available for production. Crop growth is limited substantially by the significant water deficits during the growing season within the region. Potential evapotranspiration is typically two to three times higher than precipitation during the growing season (May to September). Irrigation is required for intensive crop production throughout the region. In the southern portion of the region, many soils have limited fertility as they are shallow or coarse-textured. In the northern portion of the region, soils at lower elevations commonly are fine-textured with poor drainage and low in fertility and organic matter while soils at higher elevations are commonly shallow, stony, and have steep slopes.

Minimal agricultural production occurs in the far northern portion (e.g. north of Smithers) of this region (Fig. 1). Mills (1994) concluded that vast areas in this portion of the region are currently suitable for agricultural production, but are not under production due to lack of necessary infrastructure and increased costs due to distance from markets.

Expected Impact of Climate Change

The predicted climate change in the region is for generally warmer temperatures (2 to 3°C) year-round, increased precipitation in the winter, and decreased precipitation for much of the growing season (Table 1). The predicted increase in temperature is beneficial for agricultural production as much of the area has temperature limitations. The increase in temperature will effectively move current biogeoclimatic zones north and to higher elevations. In general, this will allow more land to be brought into agricultural production and increase production on land currently cropped. The potential to diversify the crops grown will also expand as growing seasons would be longer, and crops with greater heat unit requirements (e.g., silage corn) could be grown over a wider area. The increased incidence of forest fires associated with the warmer, drier summers may provide more forest-free areas with a greater potential for grazing.

In contrast, the predicted change in precipitation patterns will not be favourable for crop production. Water deficits during the growing season would be expected to increase due to a combination of decreased growing season precipitation (about 100 to 200 mm), and increased evaporative demand associated with the higher temperatures (about 500 to 800 mm). Areas with access to irrigation water can realize increased crop yields and diversity. However, for much of the region, it may be difficult to realize the enhanced potential for agricultural production due to severe summer moisture limitations. For much of the region, the period of crop growth may be similar in length, but earlier in the year, than under current conditions because of the moisture deficit.

The change in climate will also affect the supply of water for irrigation. In some cases, smaller streams will have less water or may even dry up during the drier part of the growing season. Care will be required to ensure that storage of water from the winter (snow melt and runoff) is increased to avoid severe water shortages during the growing season.

The longer growing season will also affect overwintering of animals. The winter feeding season will be shortened, perhaps by four to six weeks, requiring less feed storage. This would be compensated somewhat by the earlier end to grass growth during the late summer because of drier conditions. This would result in less forage production and lower forage quality late in the growing season. Wetter winter conditions could result in the requirement for more covered storage for hay. The cattle would be exposed to more precipitation (rain and snow) and the feeding areas will be more messy and muddy with an increased chance for runoff.

Climate change would be expected to result in a modest change in crop pests. Weeds and weed control will not change substantially because the cropping systems will not be expected to change much. Insect species diversity should remain the same but overwinter survival of insect pests may increase due to milder climatic conditions. This may result in higher insect populations in spring and potentially greater economic impact of insect damage for a given crop. An increase in the mean average temperature may result in an increase in crop diseases. Warmer winters would result in greater survival of disease organisms but drier, warmer summer temperatures could help control them.

Overall, it is expected that there will be an improvement in the potential for agricultural production in the region where irrigation is available but otherwise there may be limited net effect of climate change on agriculture. Additional land will become available for production, but productivity may be similar or even reduced due to larger moisture deficits. The actual impact on crop production may be very sensitive to changes in the distribution of rainfall during the growing season, and therefore somewhat difficult to predict.

It is expected that significant population increases may occur in this region. The increase in population will put a larger demand on the drinking and recreational water that is available, particularly with warmer summers and may result in increased conflict among the users of this resource.

PEACE RIVER

The Peace River region consists of the extension of the northern great plains region into British Columbia. This region accounts for approximately one-third of the improved farm land in British Columbia.

Current Agricultural Production

Agricultural production within the Peace River Region is more typical of what would be found in much of Alberta or Saskatchewan than in the remainder of British Columbia and consists primarily of production of cereals and oilseeds, pulse crops, alfalfa, and forage grasses used for hay and grazing and commercial forage seed production. Animal production is in the form of both ranching operations and as part of a diversified cattle/forage/grain agricultural system. These combine to include approximately 70,000 head of livestock within the region. In recent years efforts to diversify have resulted in the development of a significant exotic livestock industry has taken place within the region with over 5,000 head of bison, deer and reindeer at this time. Total livestock numbers could comfortably more than double with the land and feed base which currently exists within the region. Limited irrigation occurs along some major rivers, but this represents an extremely small proportion of the land base and is usually restricted to localized market gardens or similar ventures.

The climate in the region can be classified as cool, continental semi-arid. Mean annual temperatures generally range from approximately -1 to 1.5°C. Mean annual precipitation ranges from 480 mm in the south to 350 mm in the north, with approximately 65% as rainfall. Growing seasons are on the order of 100 to 110 days of frost free period with moisture deficits ranging from 250 to 300 mm. To counter this, the very long days make up the equivalent of several days of growth over the growing season and the dry mid-summer period promotes rapid grain ripening and maturity.

Crop production in this region is limited by temperature, precipitation and soil type. The cool, dry and relatively short growing season limits the varieties of crops which can be grown and the potential crop yields. Soils in the region are commonly medium to fine textured with good fertility and capable of excellent yields given good rainfall distribution.

Wet soil conditions in spring and fall can also limit production in some years. The finer textured soils drain slowly in spring, limiting field access early in spring. Harvest conditions are often cool and damp due not so much to high precipitation as to low evaporation during the September period. To counter these problems large scale equipment and newer technologies such as zero-tillage have been incorporated on a broad scale.

Mills (1994) estimated that there was as much as 1.2 million ha of potentially arable land in this region, as compared to the over 400,000 ha currently in production. The additional areas have not been brought into production due to lack of necessary infrastructure and increased costs due to distance from markets. Under current climatic conditions, approximately 50% of the land is used for arable annual crops and the remainder for grazing, forage production or forage seed production. Under climate change conditions a slightly higher percentage of perennial crop land would be expected as a response to possible increases in variability. Increased heat units should improve both the quantity and quality of a second cut of forage.

Expected Impact of Climate Change

The predicted climate change in the region is for generally warmer temperatures (2 to 3°C) year-round, increased precipitation in the winter and spring, and decreased precipitation in the growing season, particularly July and August (Table 1).

The predictions for climate change call for changes in both the type of crops grown as well as their regional distribution. Large areas which are currently used as rough grazing land have the potential to be improved into annual crop land even given today's climatic constraints. Due to the relative lack of population and very recent settlement, agriculture in this region is in an early stage of development relative to other agricultural areas, with significant development still occurring throughout the region.

The predicted increase in temperature should substantially increase the potential for agricultural production in this region. The frost free period could be increased by a minimum of 10 days. In the southern portion of the region where cereals and oilseeds are already the predominant crops, a shift to longer season, higher yielding, more drought tolerant varieties would be expected. Some horticultural production may be possible in southern areas as well. Warmer temperatures would allow the introduction of cereal production over a wider area, and more northerly areas would have increased potential for hardier annual crops or for improved forage production. The existing beef industry in the region would probably expand particularly if a regional meat packing/processing facility could be developed. This expansion would be aided by a substantial decrease in the requirement for wintering feed and shelter because of warmer winter temperatures. Warmer temperatures would also reduce difficulties with wet soil conditions in spring and fall.

The predicted changes in precipitation, in combination with warmer temperatures, could result in a greater moisture deficit during the growing season. It is difficult to predict the impact of this change on crop production because of sensitivity to actual rainfall patterns within the growing season however the combined effects could create a climate similar to what is presently found in parts of central or southern Alberta. The expected increase in the water deficit may reduce the potential increase in production associated with the temperature increase.

Assuming the water deficit does increase, and given the enhanced temperature conditions, expanded irrigation may become desirable. Large surface water resources exist in the region, although in many cases they are in deep river valleys. There is currently no infrastructure for large scale irrigation. Considerable cost would be involved in developing the necessary infrastructure, and to raise water from the deep valleys. It is not clear whether or not irrigation would be economically viable in this region.

YUKON

Agricultural production in the Yukon is limited to elevations below 800 m in the major river valleys. The primary agricultural production area is located near Whitehorse. Agriculture also takes place in the Klondike Valley near Dawson City, the Stewart Valley near Mayo and along the Pelly and Liard Rivers in central and southeastern Yukon as well (Fig. 2). Presently, there are some 5,000 ha of cultivated land in the Yukon and there are about 150 census farms.

Current Agricultural Production

Forages, cereals and vegetables are the primary crops grown. Livestock is limited to horses used by the big game outfitting industry and to game growers farming elk, bison and reindeer. There is little cattle, hog or dairy production.

Climate conditions vary across mountain ranges. The Whitehorse area is the driest part of the Yukon. Whitehorse receives about 260 mm of annual precipitation and the average annual temperature is -1°C. Southeast Yukon is somewhat more humid, and central Yukon has the warmest growing season.

The two limiting factors to agriculture in most of the Yukon are moisture and temperature. The present climate may be best described as cool, semi-arid, and is marginal for conventional agriculture. In the Whitehorse area, irrigation is required to ensure viable yields. Vegetable crops require frost protection in most locations.

Expected Impact of Climate Change

The projected climate change in the Yukon (at Whitehorse) is for increased temperature (about 3°C) and precipitation (about 10%) on a year-round basis (Table 1).

The increased temperature would have a favourable impact on agricultural production. Increased temperature would provide a longer growing season (possibly two to three weeks) and a greater potential for crop growth. In particular, a 3°C temperature increase in August would eliminate mid season frosts which presently are a major impediment to vegetable production.

The increased temperature would allow for increased diversity of crop production. At present, grain production is very marginal. A 2 to 3°C increase in temperature would provide enough extra growing days to allow maturation of barley, oats and perhaps wheat. In the central Yukon, assuming similar warming, grain production would be quite feasible. The ability to produce grain with newer adapted varieties would make livestock production more viable. As with the Peace River and northern interior regions, there would be increased fall grazing and a much reduced winter feed requirement. With the appropriate infrastructure developments (abattoir, etc.) this could create a much expanded basis for agriculture. Increased growing season temperatures in association with the existing long day lengths may allow for more extensive commercial production of cold hardy vegetables such as root crops, cabbage, broccoli and even potatoes. The overall effect would likely be a move away from simple hay production to increased field crop production, enhanced vegetable production, and the development of a limited livestock industry.

The increased temperature would provide for the movement of agricultural production to higher elevations. It is likely, however, that the lack of road access and infrastructure would continue to limit the spread of agriculture much beyond its present extent along major transportation corridors. However, an expansion of this infrastructure (roads and power lines) could lead to a further increase in land brought into agricultural production.

Given the current relatively low quantity of precipitation, the projected increase in the quantity of precipitation associated with climate change is small. It is possible that the climate change will in fact result in drier climatic conditions as a result of increased evaporative demand associated with the warmer temperatures. The net effect will be positive in areas where a supply of water and an infrastructure for irrigation exist because irrigation water coming from large rivers will not be a limiting factor. A positive impact is less certain in areas where irrigation is not feasible. This is particularly true in southeast Yukon where about 5% of the agricultural land is saline.

Overall, the projected impact of climate change should be positive for agricultural production in the Yukon. The agricultural industry has grown substantially over the past 15 years. Replacement of the current marginal climatic conditions for crop production with more favourable ones should substantially enhance industry growth by increasing the productivity of the land currently in production and making feasible the continued clearing of suitable land for future agricultural use.

GENERAL CONSIDERATIONS

Increasing carbon dioxide concentrations are expected to occur throughout the world. This increase is expected to have a substantial impact on the potential for crop production (Bowes 1993). Crop response to increased carbon dioxide concentrations is generally believed to be greater for the C3[1] crops which comprise the majority of crops grown in British Columbia and the Yukon. As a result, an additional increase in productivity is expected beyond that described earlier. There appears to be an interaction between climatic conditions and increased carbon dioxide concentrations. This interaction is, however, complex and apparently species specific, making prediction of the impact of climate change difficult.

It is not clear what changes are expected in terms of climatic variability. In many cases, climatic variability is of equal importance to changes in mean climate conditions in terms of controlling productivity. This is particularly true of perennial horticultural crops which can have severe losses from extreme low or high temperatures, often over a matter of a few days. In addition, many aspects of the agricultural infrastructure (buildings, drainage, etc.) are developed based on the occurrence of extreme values. Any increase in climatic variability can be expected to have an adverse impact on agricultural production regardless of climate change.

The issue of adaptation was generally omitted in the above discussion. It is not clear how quickly the effects of climate change would occur, or the climatic conditions that may occur in transition to the climate change prediction used in this discussion. This change will occur, however, over a reasonable time period. Agricultural production has generally been dynamic in responding to change, whether the driving force be changing economic conditions, development of new technologies, or changes in consumer preferences. Thus at the farm level, climate change may not require a rate of adaptation beyond that which already occurs. In some cases, however, more widespread adaptation may be required, for example the possible development of irrigation infrastructures where none currently exist, or the potential for failure of an entire industry within a region in response to changing climatic conditions or water availability.

Finally, it must be remembered that agricultural production in British Columbia and the Yukon does not occur in isolation from the rest of the world. In many cases, local changes in cropping patterns and animal production are due to changes in the global market. It is not clear what changes may be expected elsewhere in the world, and what impact these changes may have on agricultural production in British Columbia and the Yukon.

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[1] Approximately 95% of terrestrial plant species use the C3 pathway to fix CO^2 from the atmosphere whereas only about 1% of terrestrial species, mostly monocots, use the C4 pathway (Bowes 1993). The C4 pathway is more efficient in fixing atmospheric CO2, and presumably evolved as an adaptation to lower atmospheric CO2 concentrations.

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Chapter 16

IMPACTS OF CLIMATE CHANGE ON ABORIGINAL LIFESTYLES IN BRITISH COLUMBIA AND YUKON

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OVERVIEW

While climate change may have many and complex impacts on the lifestyles of all people, there are additional considerations for aboriginal people. Aboriginal lifestyles are strongly tied to resources on their traditional lands. Hunting, fishing, trapping and gathering still play a strong role in the economy, nutrition, culture and spirituality of many aboriginal people. Impacts of climate change on distribution and abundance of key fish and wildlife resources would result in impacts on aboriginal lifestyles. The reliance of the village of Old Crow, Yukon, on the Porcupine Caribou Herd, and the susceptibility of the Herd to impacts from climate change are presented as a case study.

Researchers have conducted numerous studies on this herd and have established important links between climate and range, between range and body condition, and between body condition and reproductive potential of the herd. Because of these linkages, we are able to model the potential effects of climate change on the herd. To date the analysis has examined: 1) increases in summer temperature and effects on insect harassment; 2) increases in winter snow depth and the effects on activity and energy costs of walking; and, 3) the effects of earlier, shorter springs on forage quality in relation to the energy cycle of the caribou. Initial results indicate that the combination of warmer summers, deeper winter snow and short, early spring conditions could theoretically reduce pregnancy rates by 20% and change a modestly-increasing population to a herd that declines by 4% per year.

INTRODUCTION

The potential impacts of climate change are of significance to aboriginal peoples whose lifestyles are closely tied to land and the use of living resources. Aboriginal people of the Yukon and British Columbia have a relationship with living resources that extends back in time for millennia. In many cases, the traditional activities of hunting, fishing, trapping, and gathering continue to provide for aboriginal peoples' nutritional needs and economic vitality, while also serving as the foundation for cultural identity and sense of spirituality. The impacts of changing climate regimes may threaten the sustainability of these lifestyles, potentially affecting the distribution, abundance, and overall condition of the living resources on which First Peoples depend.

Impacts of climate change need to be considered in the context of the other, better-known threats to traditional aboriginal lifestyles (e.g. urbanization, social and technological changes, and resource conflicts). One should also bear in mind that BC and Yukon aboriginal peoples have a demonstrated ability to adapt traditional lifestyles to changing environmental, technological and social conditions.

RESOURCES, BOUNDARIES AND ADAPTATION TO CHANGE

In former times, aboriginal lifestyles were almost wholly organized around seasonal cycles, the shifting availability of living resources, and longer-term shifts in animal distribution. The caribou hunters in the fall became duck hunters in the spring and fisher-folk in summer. "Nomadic hunters" generally traveled within specific traditional territories in which they developed an understanding of ecological patterns and resource availability.

The hunter and gatherer of days past also maintained the flexibility to shift those resource-use patterns in ways which today are less possible. In times of severe scarcity, aboriginal groups endured periods of limited food or were forced to shift their home ranges to find new resources. One example of the shift in home territory is the exodus of Inupiat (Alaskan Eskimo) families from north-central Alaska to the Canadian Western Arctic at the turn of this century. These migrations are reported as being the result, in part, of dramatic decreases in the Western Arctic Caribou of northwestern Alaska.

The imposition of western notions of private property; the implementation of state education and wildlife management policies; and aboriginal peoples' adoption of new technologies have together transformed settlement and land-use patterns of aboriginal peoples. Today, many aboriginal peoples live in villages, making forays to traditional hunting and fishing grounds and to family "bush camps". The settlement of land claim agreements and the continued encroachment of non-aboriginal resource-users have required that aboriginal people specify traditional territories with hard borders, thus limiting their ability to adapt to changes in resources.

Changes in abundance of fish and wildlife would obviously have impacts on people dependent on these resources. Shifts in distribution of vegetation and of animals could also affect traditional activities. These impacts may be major or minor, positive or negative, depending on the effects of global climate change on local abundance of key species.

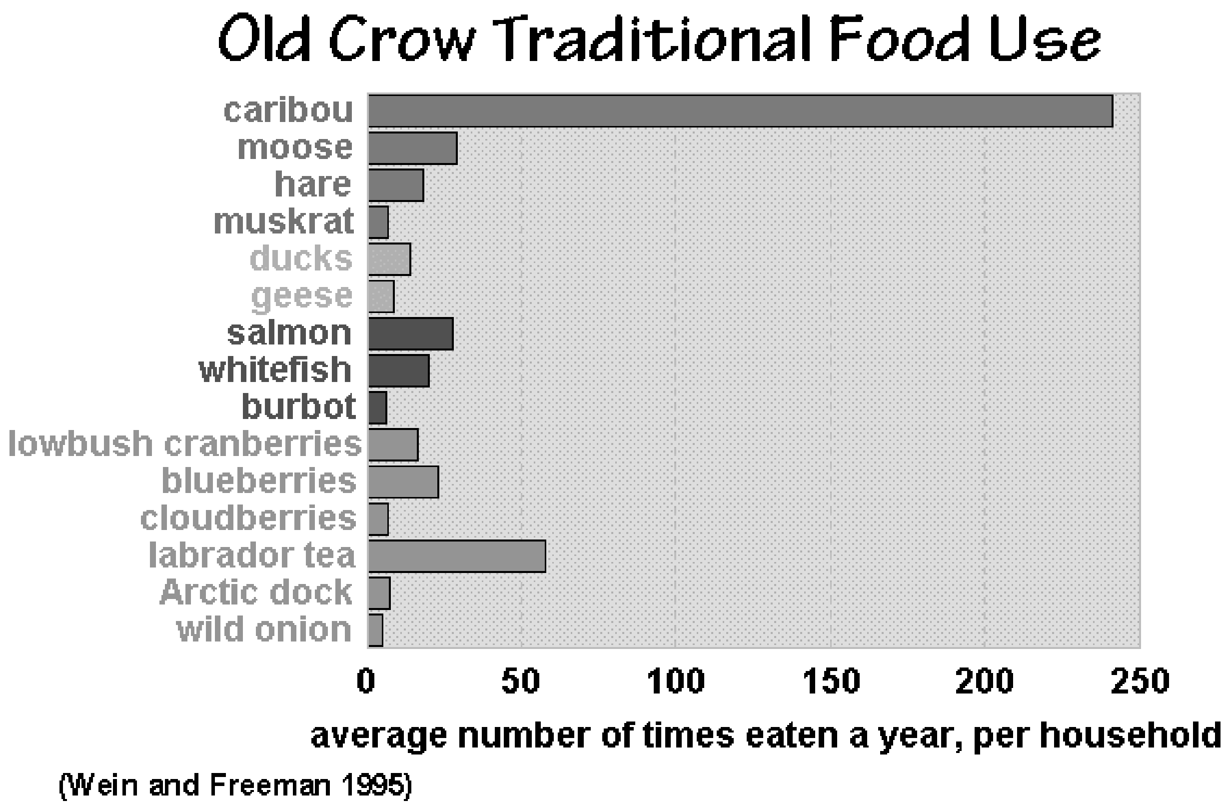
CASE STUDY: THE PORCUPINE CARIBOU HERD AND OLD CROW, YUKON

The well-being of the Vuntut Gwitchin people of Old Crow, Yukon is tied to the Porcupine Caribou. Along with several other aboriginal communities, the people of Old Crow depend on the Herd for food (Figure 1) and maintenance of traditional lifestyles. Predicting impacts of global change will allow for planning and mitigation such as enhanced protection of critical habitat.

This large, migratory herd of caribou occupies tundra ranges in spring and summer, moving south to taiga ranges in winter. The herd is harvested primarily by native communities in Alaska, Yukon and the Northwest Territories. Large caribou herds tend to be regulated not by predators, but by nutritional factors. In particular the Porcupine Caribou Herd does not seem to have a high intrinsic rate of increase compared to some of its neighboring herds. Growth over the last 20 years has seldom reached above 5% annually.

Researchers have conducted numerous studies on this herd and have established important links between climate and range, between range and body condition, and between body condition and reproductive potential of the herd. Because of these linkages, we are able to model the potential effects of climate change on the herd. To date the analysis has examined:

Figure 1. Caribou meat is a main part of the diet of aboriginal people who live within or close to the range of the Porcupine Caribou Herd, as illustrated in this example from a study of traditional food use in Old Crow, Yukon.



1) increases in summer temperature and effects on insect harassment; 2) increases in winter snow depth and the effects on activity and energy costs of walking; and, 3) the effects of earlier, shorter springs on forage quality in relation to the energy cycle of the caribou.

Increased summer temperatures, predicted to be from 2 - 4^{o}C for the northern Yukon, will increase both the seasonal abundance and the absolute abundance of harassing mosquitoes and parasitic flies (Figure 2). Harassed caribou spend significantly less time eating in the critical summer months, which results in poorer calf growth and the inability of mothers to replenish fat reserves prior to winter. Fall fat weight of an adult cow is directly correlated to that individual's probability of getting pregnant.

Increased snow depths in the winter will have a negative impact on the energetics of an individual caribou. The amount of time an animal has to spend digging through snow reduces the amount of time available to it to ingest food (Figure 3). As well, increased snow depth increases the energy cost of moving around in the winter and during spring migration. During spring, up to 25% of the day can be spent walking.

Climate change models predict that northern spring melts will be up to a month earlier and that the melt period will be shorter. These factors have a significant impact on the quality of food. The energetic demands of a lactating cow almost doubles within a week of calving. The calving period is predicted to be relatively inflexible, being determined by photo-period in the fall. The calving period of caribou is highly tuned to take advantage of newly growing, highly digestible vegetation. Plant quickly senesce, becoming more lignified and less digestible as summer advances. Earlier spring, under climate change, will throw this synchrony off and high demand for nutrients will no longer coincide with available nutrients. The condition of the adult cow going into the calving season, and her success in acquiring nutrients in the first month after calving, account for most of the variability in calf survival to one month of life.

All these factors have been considered in simulation modeling conducted by the Canadian Wildlife Service. These models predict the impacts of climate change on the productivity of the Herd (Figure 4). Initial results indicate that the combination of warmer summers, deeper winter snow and short, early spring conditions could theoretically reduce pregnancy rates by 20% and change a modestly-increasing population to a herd that declines by 4% per year.

Figure 2. Mosquito activity varies with temperature. When mosquitoes are very active, the caribou spend less time feeding. This reduces their summer food consumption.

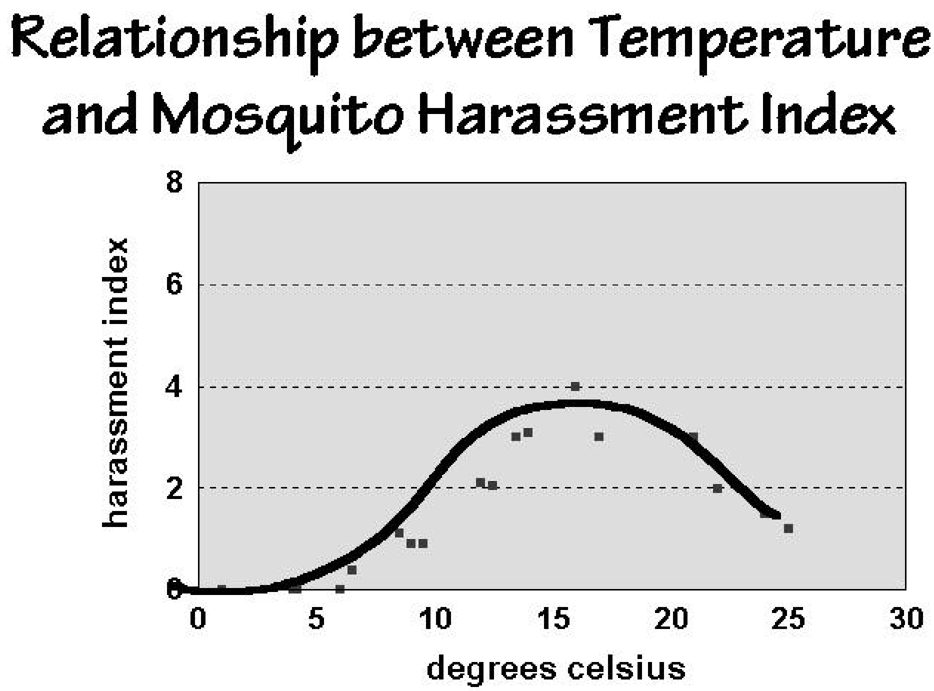


Figure 3. In deeper snow, caribou need to spend more time pawing through the snow to reach lichens. This reduces their winter food consumption.

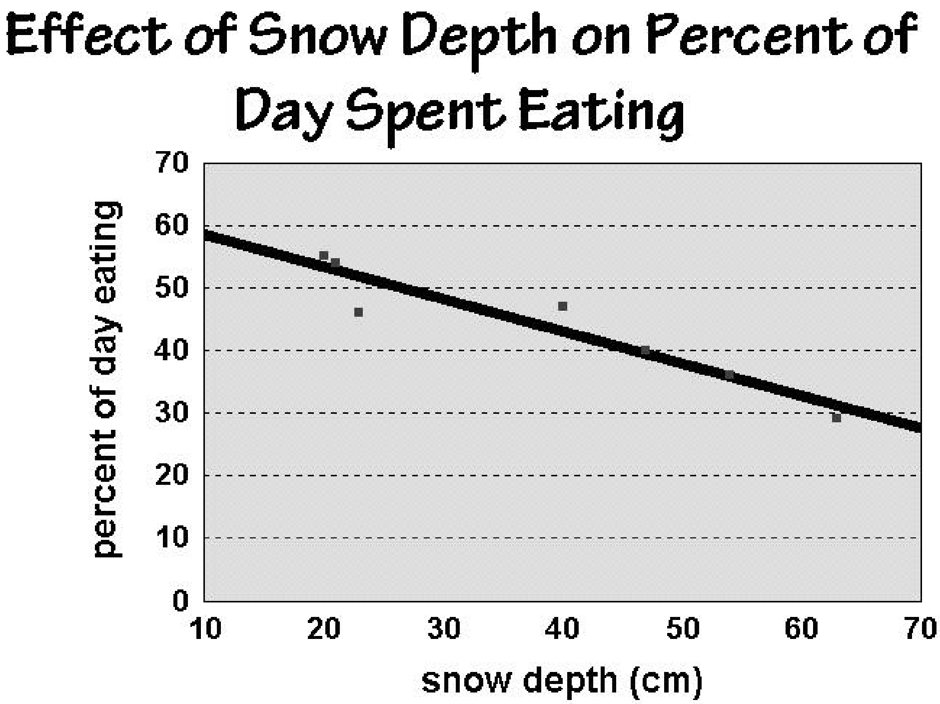
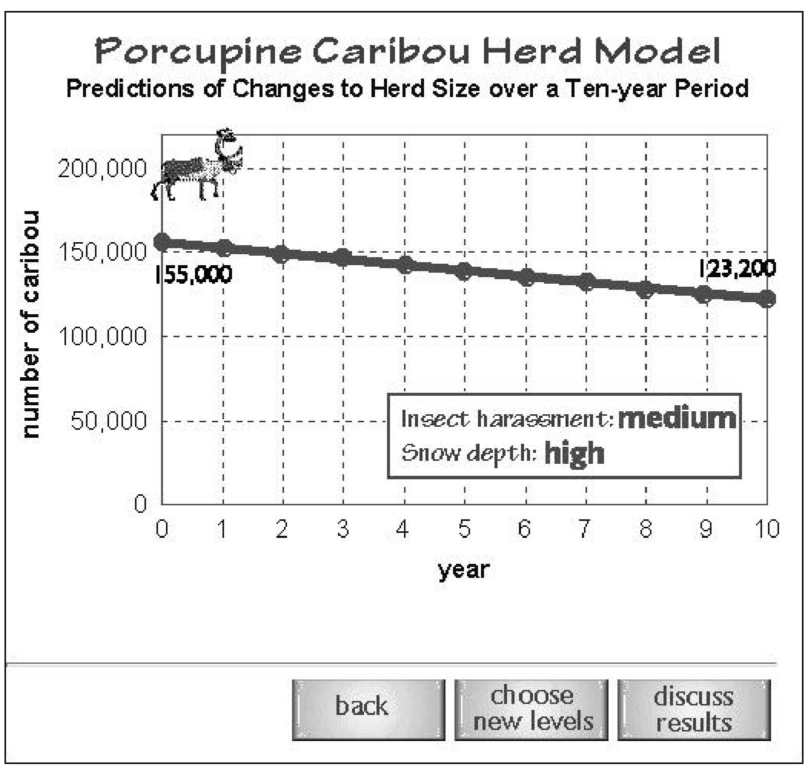


Figure 4. Example of output from model predicting impacts of climate change on Porcupine Caribou Herd population. From Environment Canada's State of the Northern Yukon World Wide Web site: http://www.pwc.bc.doe.ca/ec/nysoe/index/



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Chapter 17

IMPLICATIONS OF FUTURE CLIMATE CHANGE ON ENERGY PRODUCTION IN BRITISH COLUMBIA AND YUKON

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OVERVIEW

Hydro-generated electricity and natural gas are the dominant forms of energy produced in the B.C.-Yukon region. Other forms of energy including crude oil, refined petroleum products, biomass (from forestry operations) and coal are produced in smaller, but significant, quantities. At present, the contribution from alternative sources of energy such as wind, solar, and geothermal is not significant.

The implications of climate change on the energy subsectors, and the ability to predict the implications, vary by subsector. The wind and solar energy subsectors are directly dependent on climatic conditions (e.g. wind patterns, storm frequency, solar radiation, etc.). For other subsectors, the impacts can only be evaluated on a case by case basis with the support of modeling tools. Hydro-power generation, as an example, depends on water levels in the reservoirs. This in turn is a function of the timing and quantity of streamflow which in turn depends on the hydrological conditions of the basin. These conditions are created by a complex interaction of climate variables, vegetation and soil characteristics, the distribution of glaciers, etc.

The preliminary study identified the implications on the energy subsectors to include positive, neutral and negative effects. Potentially vulnerable activities of the energy sector include:

- *Energy production:* The production of hydro-generated electricity in the southeast region of B.C. could be particularly vulnerable to climate scenarios that lead to reduced runoff.
- *Energy distribution:* The distribution (transmission/transport) of energy appears to be most vulnerable to extreme climate events. The frequency of extreme events is expected to increase with climate change and this may result in greater system disruption and higher costs.
- *Energy demand:* The profile of energy demand is expected to shift somewhat with warmer temperatures (i.e. lower winter demand for space heating but higher summer demand for air conditioning). Although the impact of climate change on total energy demand in the region has not been modeled extensively, a net decrease in average amount of energy used for space conditioning is expected to occur. However, population growth within the region is expected to produce an overall increase in energy demand for space conditioning.

The energy experts interviewed for this study consider the sensitivity of their operations and businesses to future climate change to be small relative to the impact of current and anticipated climate change mitigation efforts. Based on the current understanding of the nature and gradual onset of the potential impacts of climate change, most energy planners in the region anticipate that they will have the lead times and technical capabilities to adapt to future climate change.

INTRODUCTION

As the production, distribution and consumption of energy are the dominant contributors of greenhouse gas (GHG) emissions, most discussions on 'energy and climate change' focus on ways to mitigate the effects of energy demand to prevent the onset of global climate change. In this paper, the reverse situation is explored. What are the implications to the energy sectors in British Columbia and the Yukon if future climate change was to occur?

This paper examines what is commonly known about how the energy sectors in B.C. and the Yukon could be impacted by future climate change. By way of a preliminary assessment, the predicted climate changes expected with a doubling of carbon dioxide (CO_2) is combined with information from energy experts and published literature. Potential impacts (e.g. reduced runoff, shorter winters) which may result from climate change and the associated implications for the energy sector are described. The paper attempts to determine which, if any, energy sector activities might be particularly vulnerable to future change as a starting point for the workshop discussions.

The paper is organized into the following sections:

- Predictions of Regional Changes in Temperature and Precipitation- under a double CO_2 scenario*;*
- Energy Production in B.C. and the Yukon - the types of production and their geographical location;
- Climate Change Scenarios, Impacts and Implications for Energy Production, Distribution and Demand;
- Energy Sector Responses to Possible Risks.

PREDICTIONS OF FUTURE TEMPERATURE AND PRECIPITATION

The climate of a specific region at a certain point in time is described by a number of parameters including, for example, temperature, precipitation, evaporation, wind speed and cloud cover. In order to discuss the potential impacts of climate change, the characteristics of the future climate must first be understood.

The most frequently asked questions raised when identifying impacts are: (1) What will the future climate look like at this location? Which climate parameters are expected to change? In which direction and by how much are they predicted to change from the present climate?; (2) When is climate change expected to start at this location? How fast/slow will it occur?

Climate simulation results (Taylor, 1997) were obtained for four climate regions, shown in Figure 1, using the following General Circulation Models (GCMs):

- Environment Canada's second generation Canadian Centre for Climate Analysis (CCC) GCM;
- Princeton University's Geophysical Fluid Dynamics Laboratory (GFDL); and
- NASA's Goddard Institute for Space Studies (GISS) GCM.

The GCMs simulate the Earth's atmospheric circulation and predict changes in climate parameters under a doubling in atmospheric CO_2.

Presented in Table 1 are the maximum and minimum values of the simulation results for temperature (expressed as degree C change in mean temperature) and precipitation (expressed as percent change in mean precipitation).

All three models predict warmer temperatures in all four regions for all seasons of the year. In general, the greatest temperature increases are expected during the fall and winter seasons. Under a double CO_2 scenario, the temperatures could be 2.0 to 6.5 C above the current mean temperature. Comparing the four regions, the largest temperature changes are anticipated to occur in the Yukon and North B.C. region.

The GCM results show both increases and decreases in precipitation for the four regions. All three models predict an increase in precipitation in all regions in the spring. For the other seasons, precipitation changes range from -30 % to + 50 % depending on the region and the season. As shown by the range in values, changes from current levels of precipitation could be large. While temperature and precipitation do not fully describe future climate conditions, they are two important parameters. The simulation results are considered to be first estimates which allow us to begin the exploration of potential impacts on a regional scale.

Figure 1. Map of British Columbia and Yukon with climate regions defined by Gullet and Skinner (Taylor, 1997)

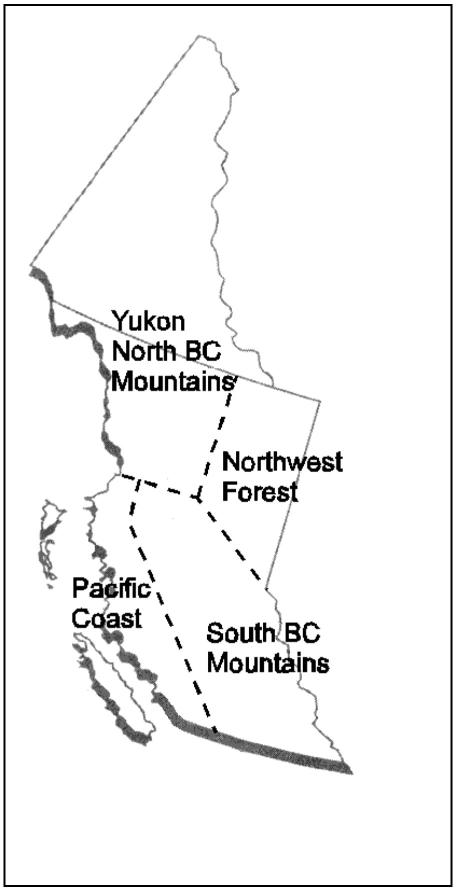


Table 1. Predicted minimum and maximum changes in temperature and precipitation (summarized from Taylor (1997))

Scenario	Northeast	South B.C.	Pacific Coast	Yukon/ North B.C.
Temperature (C)				
- winter	2.0 - 6.5	2.0 - 7.0	1.0 - 4.5	2.0 - 6.5
- spring	1.5 - 4.5	1.5 - 5.0	1.5 - 4.5	2.0 - 5.0
- summer	1.5 - 4.5	1.0 - 4.0	1.5 - 4.0	1.0 - 6.0
- fall	2.0 - 4.0	2.0 - 3.5	2.0 - 3.0	2.0 - 5.0
Precipitation (%)				
- winter	0 - +30	0 - +40	0 - +40	-10 - +25
- spring	0 - +20	0 - +20	0 - +20	+5 - +30
- summer	-15 - +20	-20 - +30	-30 - +30	0 - +50
- fall	0 - +20	-5 - +15	-5 - +15	0 - +50

With respect to the timing of future climate change, global emission forecasts suggest that the CO_2 concentration in the atmosphere will double by 2050 or within the next 50 years. Different theories exist on when and how fast these changes will appear. The possible climate responses range the spectrum from smooth transitions to very abrupt shifts.

ENERGY PRODUCTION IN B.C. AND THE YUKON

The energy sector is very generally defined as a combination of utilities and industries which are involved in the production and transmission/transport of different types of energy to meet the demand of residential, commercial/institutional and industrial consumers. As the implications of climate change impacts will vary by energy subsector (e.g. electricity, natural gas, biomass) as well as by location, a brief description of the main subsectors in B.C. and the Yukon follows.

Hydro-generated electricity and natural gas are the dominant forms of energy produced in B.C. and the Yukon. Other forms of energy, including crude oil, refined petroleum products, coal and biomass from forestry operations are produced in smaller, but significant, quantities. Other sources of renewable energy, including wind, solar, geothermal, currently contribute a minor percentage of the energy supply.

B.C. and Yukon's energy production is used to meet domestic energy requirements as well as to provide energy for export to other provinces and the U.S. Similarly, energy produced in other provinces and countries is used to meet some of B.C.'s and Yukon's demands. To keep the scope manageable in size, the discussion centres on energy sector activities occurring within the boundaries of B.C. and the Yukon.

In terms of future production, there are forecasts of growth for both B.C. and the Yukon. Global energy demand is projected to increase and it is anticipated that future energy policies will favour forms of energy with a low greenhouse gas intensity, such as renewables (e.g. hydro-electricity, biomass) and natural gas.

Electricity Generation

The amounts of electricity produced in B.C. and Yukon during the years 1990 through 1994 are presented in Table 2. B.C.'s production is several times greater than that of the Yukon which reflects the higher demands of the more populated province.

In both cases, hydro-generated electricity is the dominant form of electricity. Thermally-generated electricity (from fossil fuels) provides most of the remaining power. In B.C., the majority of the province's electricity is supplied by B.C. Hydro with the remainder being supplied by West Kootenay Power and several independent power producers (IPPs). More than eighty percent of the electricity generated by B.C. Hydro comes from hydroelectric installations in the Peace and Columbia River basins shown in Figure 2. (B.C. Hydro, 1994). As indicated by the following breakdown (for the 1992-1993 fiscal year) less than 5% of B.C. Hydro's power is typically thermally-generated:

- 38%: G.M. Shrum and Peace Canyon Generating Stations on the Peace River;
- 34%: Mica and Revelstoke Generating Stations in the Columbia River basin;
- 10%: Kootenay Canal and Seven Mile Generating Stations in the Columbian River basin;

Table 2. Electricity generation in B.C. and the Yukon (1990-1994)

Electricity Generation	1990	1991	1992	1993	1994
B.C.[1] (gigawatt-hours)	60,662	62,981	64,058	58,774	61,015
Yukon[2] (megawatt-hours)					
Hydro	422,809	405,314	421,233	289,385	260,172
Thermal	62,093	55,771	64,553	47,999	33,138
Wind	0	0	85	238	272

[1] Ministry Energy Mines and Petroleum Resources (1996);
[2] Yukon Bureau of Statistics (1996).

14.6%: Remaining 23 hydroelectric generating stations;
3.4%: Burrard Thermal Generating Station (fueled by natural gas)

Natural Gas and Crude Oil Production

Presented in Table 3 are the natural gas and crude oil production data for the years 1990 through 1994. Natural gas is produced in significantly greater quantities than crude oil, and again, production in B.C. is several times greater than in the Yukon. Natural gas production and exports have risen steadily since 1990. Petroleum exploration and development have been underway in northeastern B.C. and southeastern Yukon since the early 1950s. As shown in Figure 3, most of the commercial quantities of natural gas and crude oil are produced in this region. The extracted gas and crude oil are conveyed via pipe lines to gas processing plants and refineries in B.C. and Alberta as well as to the U.S.

Figure 2. B.C. Hydro's electricity generating system (B.C. Hydro, 1994)

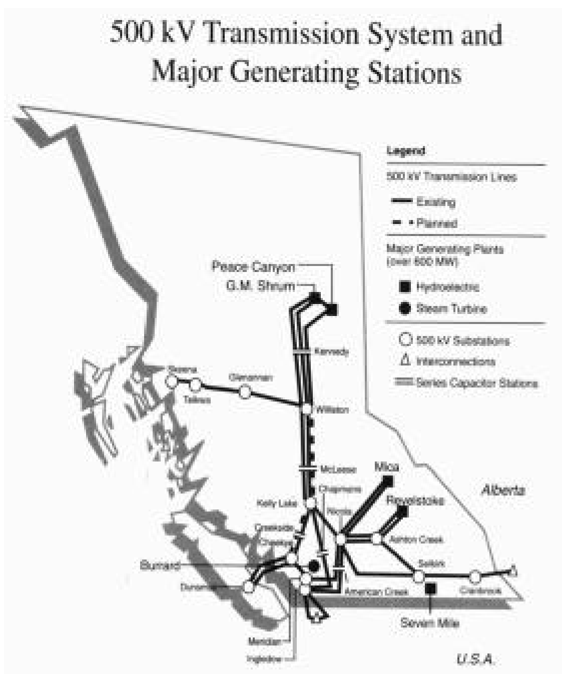
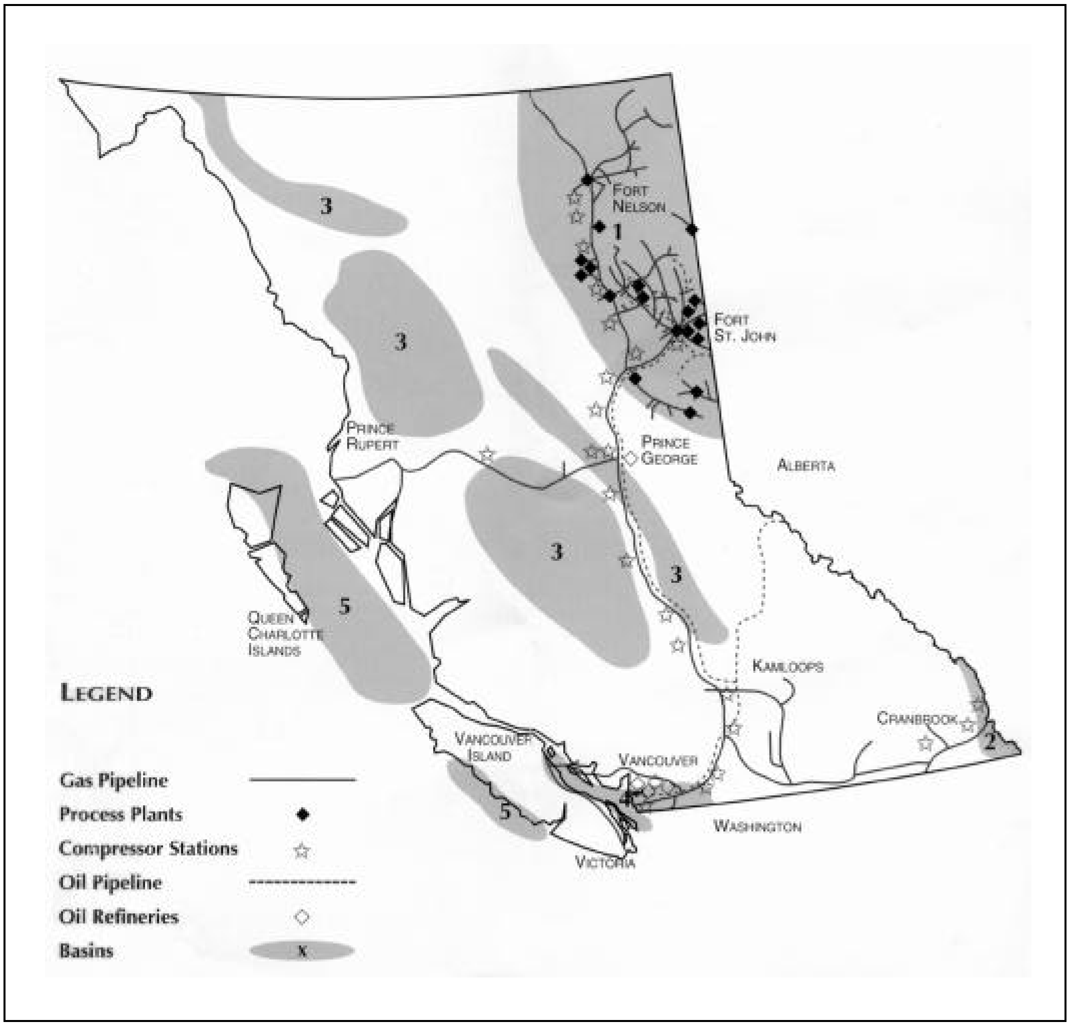


Table 3. Natural gas and crude oil production in B.C. and Yukon (1990-1994)

Energy Sector	1990	1991	1992	1993	1994
B.C.[1]					
Natural Gas Production (1000 cubic metres)	13,964,785	15,929,898	17,654,709	19,547,356	20,304,610
Crude Oil Production (cubic metres)	1,966,000	1,984,000	2,029,000	1,979,000	1,935,000
Yukon[2]					
Natural Gas Production (1000 cubic metres)	0	0	393	388	374

[1] Ministry of Energy, Mines and Petroleum Resources (1996)
[2] Yukon Bureau of Statistics (1996)

Figure 3. Gas and oil production in B.C. (MEMPR, 1994)



Production of Refined Petroleum Products (RPPs)

The production of refined petroleum products is small in B.C. Currently, only two oil refineries are operating in the province. One refinery is located in Prince George, B.C. and the other is situated in the Lower Mainland, in Burnaby, B.C. These refineries produce diesel, gasoline and other refined petroleum products which are primarily used for transportation and heating applications within B.C. (Stephen, 1996)

Coal Production

There are seven surface and one underground coal mining operations in B.C. As shown in Figure 4, the surface operations are located in southeastern and northeastern B.C. along the Alberta border. The underground operation is located on Vancouver Island. While coal reserves do exist in the Yukon, there are currently no coal mines operating in the Yukon (Downing, 1996).

Figure 4. Coal mining operations in B.C. (Coal Association, 1996)

Coal is not used to generate electricity in B.C. and the Yukon. As presented in Table 4, the majority of B.C.'s coal production is exported for metallurgical applications and used in the manufacture of iron and steel. Approximately 10% of B.C.'s exported coal is used for energy production. Within B.C., a small amount of coal is consumed for industrial use.

Table 4. Coal production in B.C. - 1995 (Coal Association, 1996)

Energy Sector	1995
B.C. Production	
Coal Production (tonnes)	24,350,123
- metallurgical	21,585,946
- thermal	2,615,348
B.C. Domestic Consumption	
Coal Consumption (tonnes)	203,729
- steel	0
- electricity	0
- industrial	203,729
B.C. Exports	
Coal Exports (tonnes)	23,980,780
- metallurgical	21,570,188
- thermal	2,419,592

Biomass Production

In this paper, biomass production paper refers to bark, sawdust and other wood residues generated by forestry and forest industry operations. The solid wood product operations (e.g. sawmills, plywood mills, etc...) and pulp and paper mills are the largest producers and consumers of wood residue in B.C. Smaller amounts of biomass are consumed through residential wood burning in rural and small communities in B.C. and the Yukon.

The locations of B.C.'s pulp and paper mill operations, shown in Figure 5, provide a general indication of the location of the biomass production.

The annual production of wood residue in B.C. is estimated to be 9 million bone dry tonnes, about half of which is used in energy, fibre supply and agricultural applications. (Canadian Resourcecon, 1993) In certain regions of the province, particularly in B.C.'s interior, there exist situations of surplus residue. With the phase out of beehive burners and restrictions on open burning and landfilling in B.C., it is expected that more of the biomass production will be consumed for its energy and/or fibre potentials.

It should be noted that increased use of biomass for energy applications is part of the Canadian forest industry's strategy to reduce its net GHG emissions. If the biomass is derived using sustainable practices, the Intergovernmental Panel on Climate Change's guidelines state that the use of biomass for energy should release no net CO_2 to the atmosphere. This provides a great incentive to use more biomass and reduce the consumption of fossil fuels for energy. Consequently the availability of biomass may become a more important issue in the future, particularly in regions of limited supply.

CLIMATE CHANGE SCENARIOS, IMPACTS AND IMPLICATIONS FOR ENERGY PRODUCTION, DISTRIBUTION AND DEMAND

Future climate change has the potential to impact, directly and/or indirectly, the energy sectors in B.C. and the Yukon. The wind and solar energy subsectors are directly dependent on climatic conditions (e.g. wind patterns, storm frequency, solar radiation, etc.) and as such the implications can be readily identified. However,

Figure 5. Pulp and paper mill operations in B.C. (COFI, 1994)

other subsectors, such as the production of hydro-generated electricity, are one or more steps removed from climatic conditions. For example, hydro-power generation depends on reservoir management that depends on streamflow and runoff that depends on the hydrological conditions of the basin. The hydrology is affected by climate variables (e.g. temperature, precipitation, etc.) and other parameters such as vegetation and soil characteristics, the distribution of glaciers, etc. (Loukas, 1996) For these subsectors, impacts must be evaluated on a case by case basis with the support of modeling tools.

Tables 5 through 7 summarize the responses received from interviews with energy experts and several published studies to the questions "What if the (temperature was warmer)?, Could this effect the operation of this subsector? and How so?" While focus was placed on the identification of potentially vulnerable activities of the energy sector, it should be noted that the implications are a mixture of positive, neutral and negative effects.

ENERGY SECTOR RESPONSES TO POSSIBLE RISKS

When energy experts were asked about the sensitivity of their operations to future climate change, most replied that the risks associated with climate change were considered to be very small. In fact, this section would be considerably longer if it were describing the risk of climate change-related policies or regulations to the industry instead of the risk of climate change.

Future Climate Change Perceived as a Small Risk

Interviews with representatives from B.C. utilities and natural gas companies revealed the following:

- the priority for "climate change spending" is on mitigation (GHG emission reduction efforts) and that, at present, no significant funds are being allocated to assess the impact of future climate change on their operations;

- the planning horizons for new facilities or supply purchases generally fall short of the period when significant climate change is expected to occur; and
- the current understanding of the nature and timing of potential impacts leads them to believe they will have enough time and have already (or can develop) the technologies to adapt to the predicted changes.

Planners within all of the energy subsectors stated they are “keeping an eye” on climate trends, but that climate change is not currently a significant factor in their decision-making.

The Intergovernmental Panel on Climate Change has come to a similar conclusion, stating that “the climate sensitivity of most activities [energy, industry, and transportation] is low relative to that of agriculture and natural ecosystems, while the capacity for autonomous adaptation is high, as long as climate change takes place gradually.” (IPCC, 1995)

CONCLUSIONS

The preliminary assessment identified the following areas and/or activities of the energy sector in B.C. and the Yukon to be most vulnerable to climate change.

Energy Production

The hydro-generated electricity energy subsector is believed to be most sensitive to future climate change. In particular, future climate scenarios that will reduce runoff are of greatest concern because they may be very difficult to adapt to. The interviewees felt confident they could adapt to most of the other implications listed in Table 5.

In general, the renewable forms of energy are more sensitive to climate change than the non-renewable forms of energy. Under the renewables category, wind energy and solar energy subsectors are believed to be more sensitive to climate than hydro-generated electricity and biomass energy.

Energy Distribution

Energy sector activities in the distribution category appear to be the most vulnerable to extreme climate events. The dominant implications are system disruption and increased costs. Operations that are currently working on the edge, i.e. encountering difficulties during current extreme events, are likely most sensitive to future change.

Energy Demand

The timing of the energy demand is expected to shift with warmer temperatures, however the net effect on the annual energy demand is not clear. It is expected that the demand for space heating by residential and commercial customers will decrease during the winter months while the demand for air conditioning may increase depending upon other climate variables (e.g. moisture content/humidity).

The demand for transportation fuels, on a per vehicle basis, will likely decrease with warmer temperatures but population growth is likely to mask this reduction. Industrial energy use is not expected to be affected by future climate change.

ACKNOWLEDGEMENTS

The authors acknowledge the input which was generously provided by Eric Taylor (Environment Canada) and energy experts at BC Gas, BC Hydro, BC Ministry of Employment and Investment, Canadian Association of Petroleum Producers, Chevron, Coal Association of Canada and Pacific Northern Gas. It should be noted that the opinions expressed by the professionals are those of the individuals and are not necessarily the opinions of the organizations to which they belong.

Table 5. Climate change impacts and implications for energy production in B.C. and the Yukon

Energy Sector	Climate Change Scenario	Impacts	Implications of Impacts
Hydro-electricity	Warmer temperatures Reduced snow pack and/or receding mountain glaciation; Drier summers (particularly multi-year).	Reduced run-off Increased fire frequency	• Lower reservoir levels • Dam capacity reduced and less hydropower generation; • Need to increase thermal generation to meet demand (increases GHG emissions); • Reservoir management plans & operations require changes; • Increased competition for available water from other users (fisheries, recreation, irrigation, etc) municipalities, etc.); • Fish ladders require upgrading; • Loss of trees resulting in poorer water quality; • Higher water taxes as competing demands place higher premium on water availability.
	Increased precipitation	Increased runoff. Increased erosion	• Increased reservoir levels • Additional hydro generating capacity. • Poorer water quality.
	Extreme increase in precipitation	Increased runoff - Flooding	• Liability for downstream damages • Exceeded design flows; Threatened dam structural integrity.
Thermal electricity (Lower Mainland)	Warmer summers	Increased smog	• Burrard operation curtailed (emissions contribute to smog)
Natural gas/oil (Northeast B.C./ Southeast Yukon)	Warmer winters	Shorter period with frozen ground	• Shorter winter construction window (frozen ground needed for transportation and construction).
	Increased precipitation	Muddier, softer roads	• Difficulties traveling roads • Higher road construction costs
	Decreased precipitation	Increased fire frequency	• Reduced access
RPP (Low Mainland)	Warmer summers	Increased smog	• Refinery operation curtailed

Coal Mining	Decreased precipitation	Drier, dustier conditions (open pit)	• Increased health concerns; • Increased equipment wear
	Increased precipitation	Overflow of tailings ponds Decreased slope stability (open pit)	• Environmental damage; • Increased safety concerns
	Increased electrical storms	Interference with blasting operations	• Increased safety concerns
Biomass Harvesting	Increased precipitation	More road washouts Increased insects & disease	• Reduced access, higher road construction costs; • Less biomass available
	Decreased precipitation	Increased fire frequency Decreased growth (water limited) Increased insects & disease	• Reduced access; • Less biomass available.
Wind	Shifting wind patterns; Changes in wind direction, duration and/or velocity.		• Less reliable energy production • Higher system costs, increased design requirements • Site selection uncertainties
	Severe storms		• Damage equipment
Solar	Less incoming radiation Increased cloud cover		• Less energy production
	More incoming radiation Less cloud cover		• More energy production

Table 6. Climate change impacts and implications for energy distribution in B.C. and the Yukon

Energy Sector	Climate Change Scenario	Impact	Implication of Impact
Electricity transmission lines	Warmer temperatures		• Increased line losses • Decreased efficiency of transmission lines (particular concern where the distribution system is operating at capacity)
	Extreme temperatures Prolonged periods		• Sagging lines • Increased outages • Increased costs for tree trimming • Added hazard to joint utility (CAT, telephone) plant.
	More storms (snow, freezing rain, wind).		• More storm outages • Increased system disruption
	Drier summers	Increased forest fire frequency	
Natural Gas/Oil pipelines	Increased precipitation	Increased flooding Increased washouts Changes in river flow regimes	• Increased scour could expose underwater lines (river crossing) • Increased erosion and flooding could affect valves sited at river crossings. • Increased frequency and severity of washouts could affect pipeline installations. • Increased disruption
Natural Gas/Oil pipeline (Yukon)	Warmer temperatures	Changes to the permafrost regime.	• Local changes in ground conditions (discontinuous permafrost) could complicate pipeline construction and operation.
Coal	Increased precipitation	Increased flooding Increased washouts	• Disruption of rail transport
Biomass	Increased precipitation	Wetter, heavier biomass	• Lower heating value; • Higher transportation costs

Table 7. Climate change impacts and implications for energy demand in B.C. and the Yukon

Energy Sector	Climate Change Scenario	Impact	Implications of Impact
Electricity Use	Warmer summers	Increased demand for air conditioning	• Increased load (res/comm).
	Warmer summers Decreased precipitation	Increased demand for irrigation and water	• Increased demand for pumping (irrigation, water)
	Warmer winters	Reduced demand for heating	• Decreased load (res/comm) • The combination of more air conditioning and milder winters could make electric heat pumps more attractive vis-à-vis gas heating and potentially increase electrical demand from a certain sector of the market.
	Wetter winters	On a per degree day basis, demand for heat higher than if weather dry.	• Potentially a partial offset to warmer winters.
Natural Gas Use	Warmer winters	Reduced heating demand	• Reduced load (res/comm).
	Hotter summers	Increased pool heater and water heater demand	• Increased load
	Hotter summers	Increased thermal generation for air conditioning	• Possible expanded exports to US gas fired plants and gas fired air conditioners.
	Moderate climate (milder winters)		• Possible improved system load factor although decreased total consumption. Note: this result may not occur if climate variability and cold spells increase.
	Extreme weather Increased climate variability including peak cold spells		• Gas Utility Planning & Operations • Changes to gas supply nomination and design day criteria may be required. More conservative peak load design assumptions could increase capacity related investment costs.
RPP	Warmer winters	Vehicles get improved fuel economy at warmer temperatures so demand may decrease.	• Reduced fuel use.
	Warmer winters	Decreased demand for heating oil.	• Reduced fuel use.
Biomass	Warmer winters	Decreased demand for home heating.	• Reduced biomass use (res)

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Chapter 18

THE IMPACTS OF CLIMATE CHANGE ON THE ABBOTSFORD AQUIFER

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OVERVIEW

The unconfined Abbotsford aquifer is comprised of surficial sand and gravel deposits located in southwestern British Columbia and extending across the international boundary into northwestern Washington State. The aquifer is an important source of water for domestic, municipal, agricultural, and other industrial users in both countries.

A climate change will impact the groundwater quantity and quality of the aquifer. Higher precipitation in the winter months will increase the recharge to the aquifer and the peak of the water table seasonal fluctuation may be higher and earlier than March or April of each year. Less precipitation in the summer months will result in declining water table in the fall. In areas of high withdrawal by high capacity wells, the local groundwater flow may be altered as a result of well interference. The contaminant plumes, such as nitrates, which are coupled to the groundwater flow, may be dispersed at altered rates and directions, towards to zone of influence.

INTRODUCTION

Climate change in the Fraser Lowland will intensify the hydrologic cycle and will have impacts on the regional aquifers, like the Abbotsford aquifer (see Figure 1) that use the groundwater resource for drinking, production, irrigation and industry.

In the event of a climate change, the ground water flow mechanism will respond to changes in precipitation, evapotranspiration and soil moisture changes. In an unconfined aquifer where ground water is directly recharged by precipitation, the water table response to a precipitation change may be linear. However the water table response to evapotranspiration and soil moisture will be more complex and non-linear. In the case of a confined aquifer, the ground water flow mechanism will respond to other mechanisms like atmospheric pressure effects and external loading.

AQUIFER RECHARGE AND SEASONAL FLUCTUATION

The Abbotsford aquifer (Liebscher, 1992) is a major unconfined aquifer in Hydrostratigraphic Unit C (Halstead, 1986) of the Quaternary unconsolidated deposits in the Fraser Lowland. Like most unconfined aquifers in the Fraser Lowland, it is recharged mainly by direct precipitation. This recharge occurs in the winter months where precipitation is high and evapotranspiration is low. As a result the water table in the Abbotsford aquifer is highest in March or April. Similarly the water table is lowest in late October because of low precipitation in the summer months and evapotranspiration which may exceed the average seasonal precipitation.

The north-western edge of the aquifer is also recharged by surface water runoffs from the low permeable clays of Hydrostratigraphic Unit B (Halstead, 1986) and from Fishtrap Creek which flows from the clay uplands across the surface of the aquifer southwards into the Nooksack River in Washington State. The lower reaches of Fishtrap Creek lie above the local water table for about six months of the year during which the creek flows into and recharges the aquifer (Liebscher, 1992).

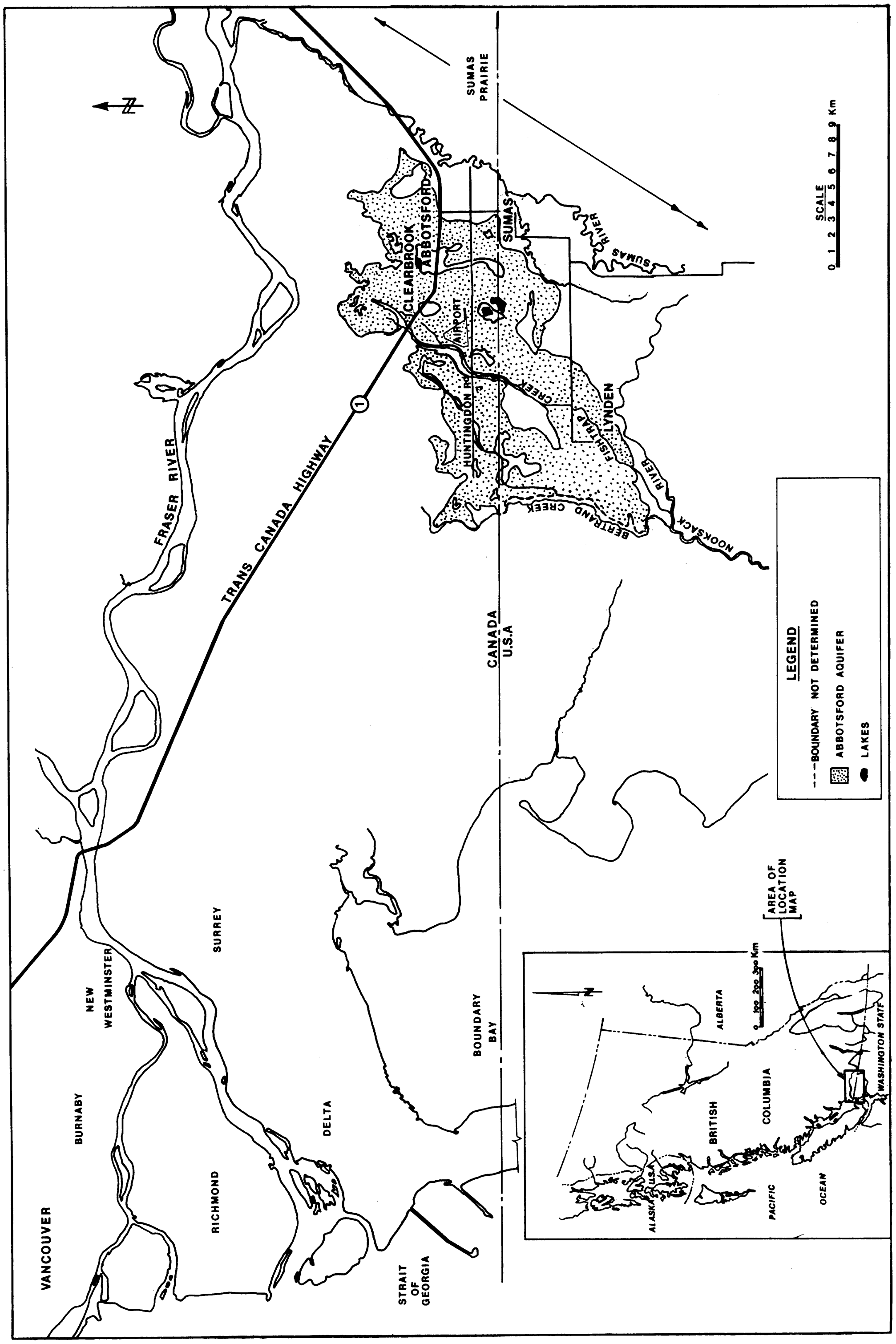
During the growing season, the soil moisture is low and the demand of groundwater for irrigation increases. The extent of groundwater withdrawal for irrigation and other purposes is governed by the number of wells and their capacities. High capacity irrigation wells are mainly located in an area just south of the Abbotsford Airport. High capacity production wells of the Abbotsford Municipality and the Fraser Valley Trout Hatchery (FVTH) are concentrated in the south-east corner of the aquifer where the groundwater flow directions are mainly towards the “radii of influence” of these production wells. Interference effects from high capacity production wells at FVTH, together with below average precipitation recharge between 1976 and 1979, caused a temporary decline in the local water table - approximately 1 metre per year (Zubel, 1979). However historic water table records indicate that the annual groundwater recharge to the aquifer has always been sufficient to balance the withdrawal from wells and natural discharges to the Sumas Prairie, the Nooksack River Drainage Basin and lower reaches of Fishtrap and Bertrand Creeks.

CLIMATE CHANGE IMPACTS ON THE AQUIFER RECHARGES

75% of the annual rainfall of about 1500mm occurs between October and March in the Abbotsford area. Water from direct precipitation and surface runoff recharges the aquifer at a rate of 850 to 1850 l/sec (Kohut, 1987). In response to a winter recharge season which can be considered as one recharge event, the water table peaks in March and April of every year. A change in the magnitude and frequency of precipitation may alter the number of recharge events. According to the Geophysical Fluid Dynamics Laboratory (GFDL) climate change scenarios for British Columbia and Yukon, the Abbotsford aquifer will experience a 2 to 3 degrees Celsius rise in temperature throughout the year with slightly more precipitation in January and spring but much less precipitation (25 to 50%) in July and August.

The GFDL predicted increase in precipitation and the rise in temperature in winter and early spring may cause the water table to peak earlier than usual. In areas where groundwater recharge is also influenced by discharge from creek or surface runoffs such as the lower reaches of Fishtrap Creek, the water table may reach the land surface more often

Figure 1. Outline of the Abbotsford Aquifer in the Lower Fraser Valley of British Columbia and Washington.



because of the increased recharges due to precipitation and surface runoff.

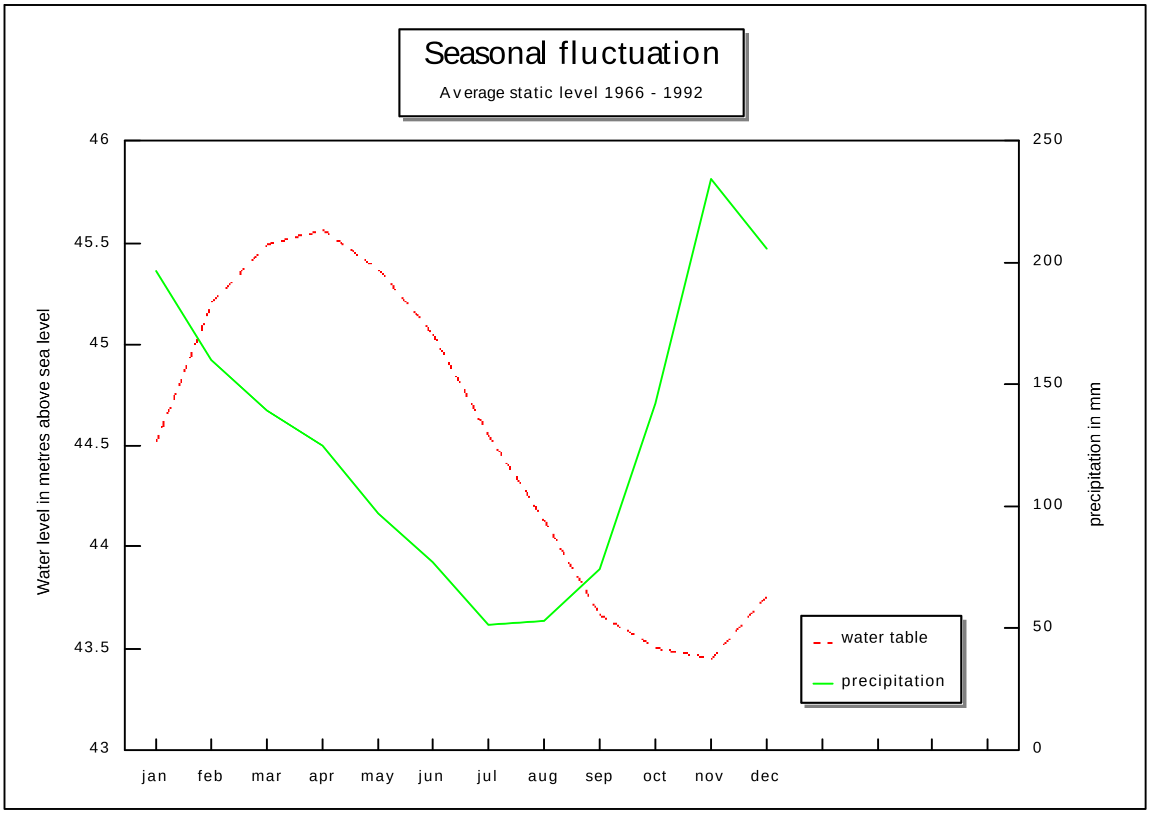
Figure 2 illustrates the relationship between the seasonal fluctuations of precipitation and the water level.

It appears that seasonal water-level fluctuations at observation well # 2 are directly related to the seasonal fluctuation of precipitation with a time lag of a few months. Actually there is more than one mechanism operating simultaneously (Freeze, 1979). In this case it is more natural than man-induced since there are no high capacity wells near the observation well. The man-induced mechanism would be the irrigation withdrawal and return flow for the raspberry fields around the Abbotsford airport during the drier growing season.

The Abbotsford aquifer is probably more sensitive to a drier summer. 50% less precipitation during July and August will cause a proportional drop in the water table in the fall. According to the graphs, such a 50% decline of precipitation in July and August may result in lowering the water table at the airport by almost a metre. However in other areas of high withdrawals by high capacity wells for production, irrigation and other demands, the drop in the water table may be intensified by well interference. The local groundwater flow systems may be altered as a result of this effect.

Ground water flow rates in the aquifer have been estimated using a modified version of Darcy's equation. Depending on the real and assumed values of site-specific variables, they range from 5 to 450 m per year (Liebscher 1992). The regional ground water flow direction in the southern part of the aquifer is primarily southwards, with local variations controlled by subsurface hydraulic conductivities, ground water recharge, water withdrawal and natural discharge zones. A climate change may alter the regional ground water flow rates because of the increase or decrease in the ground water recharge depending on the time of the year.

Figure. 2. Mean monthly height of the water table in the Abbotsford aquifer and the mean monthly precipitation at Abbotsford Airport. Water level in the aquifer lags precipitation by four or five months. If climate change results in lower summer rainfall, a reduction in summer and fall water tables would result.



CLIMATE CHANGE IMPACTS ON WATER QUALITY

Unconfined aquifers in the Fraser Lowlands are highly vulnerable to contamination from numerous sources such as livestock manure and pesticide applications at the surface and septic fields in the sub-surface. Of the 13 identified aquifers in the Fraser Lowlands, 3 aquifers have been classified as **1A** (Kreye, 1994) because they have high quality and quantity concerns. They are Hopington, Abbotsford and Langley/Brookswood in descending order of ranking. A climate change will probably affect these aquifers more severely than others in terms of quality. High concentrations of nitrate have been reported from these 3 aquifers and regional quantity concerns of declining water levels have also been documented in Hopington aquifer. The quality of ground water in local areas of the Abbotsford aquifer has been gradually declining over the past decades. Elevated nitrates and trace of pesticides have been found in samples taken from piezometers and wells throughout the aquifer. Urban development with septic fields for waste disposal is spreading over parts of the aquifer recharge areas. These septic effluent drainage systems are installed below the soil in the permeable sands and gravels and they are the point source of nitrate contamination to ground water. The livestock manure and chemical fertilizers spread in raspberry fields are non-point sources of nitrate contamination to ground water. A climate change-induced increase in precipitation may cause an overall dilution and also a simultaneous increase in the amount of leaching of nitrates from point and non-point sources. In some areas, these nitrates may reach the saturated zone sooner as it will have a shorter distance to travel to the rising water table. The dispersions of the nitrate plumes in the aquifer may also be altered. In the case of increasing precipitation, these dispersions may be accelerated because of higher hydraulic gradients. An increase in water withdrawal by high capacity wells in the drier months may redirect nitrate plumes towards the zone of influence of these high capacity wells.

CONCLUSIONS

The primary impacts of climate change on the Abbotsford aquifer would likely be:

1. a change in the seasonal fluctuation of the water table with a further decline in the water table during the fall as a result of less precipitation in the summer.
2. a change in the local groundwater flow in areas of high withdrawals by high-capacity wells as a result of well interference.
3. a change in the nitrate concentrations with an overall dilution and at the same time, an increase in the leaching of nitrates due to more recharge from high precipitation during the winter.
4. a change in the size and dispersion of nitrate plumes as more nitrates would leach to the water table sooner and be dispersed faster because of higher hydraulic gradients.

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Chapter 19

IMPACTS OF FUTURE CLIMATE CHANGE ON THE LOWER FRASER VALLEY OF BRITISH COLUMBIA

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OVERVIEW

Global climate may be in for a shock as greenhouse gas concentrations rise. However, scientists can only offer an educated guess as to the magnitude and timing of the regional climate changes expected over the coming decades. Accurate predictions of how physical and biological systems will fare in the Lower Fraser Valley or anywhere else in the world if the climate changes as expected are not yet possible. However, it makes sense to estimate the possible range of changes that might take place due to a changed climate, rather than be surprised by them at a later date. These changes range from a rise in sea level that could require reinforcement of the diking systems of the Lower Fraser Valley, to the increased immigration pressure on the Lower Fraser Valley from environmental refugees fleeing climate change-ravaged homelands outside of Canada. Knowledge of the potential changes that might put pressure on the Lower Fraser Valley will be a useful tool in planning the development of the area for the future.

INTRODUCTION

The distribution of all life forms on this planet has always been inextricably linked with the changing climate of the earth. Hot and humid conditions in Alberta hundreds of million years ago nourished vast tropical wetlands which were home to strange reptiles, dinosaurs and mammals. More recently, during the last glacial period, frigid conditions created kilometre-thick ice sheets that scoured much of British Columbia, driving most plant and animal life well south of the 49th parallel. Even today, climate has a dominant influence on human life. Settlement patterns, housing, clothing, agriculture, transportation and culture all reflect the influence wielded by climate.

This section deals with the interaction between climate and both man-made systems and natural ecosystems in the Lower Fraser Valley of British Columbia. Some of the material in this section is based on other portions of this report, and the rest has been found from reviewing literature, consulting with experts, as well as results from the analysis of climate data by Environment Canada.

SCIENCE OF CLIMATE CHANGE

Hengeveld (1997) states in this volume there is a very real possibility that the balance between incoming solar radiation and the outgoing infrared radiation is being disturbed by a continuous rise in atmospheric concentrations of so-called greenhouse gases such as carbon dioxide (CO_2) due to emissions from human activities. This increased concentration is caused mainly by the burning of vast amounts of fossil fuels such as natural gas, petroleum and coal, and also by widespread forestry and agricultural activities. Unchecked, the concentration of the most important of the greenhouse gases, CO_2, will have doubled over pre-industrial times during the next 50-80 years.

Theoretically, such an increased concentration of greenhouse gases should raise the global average temperature. Globally temperatures have risen about 0.3 to 0.6 °C during the last 100 years (IPCC WGI,1995) and along the coast of British Columbia there has been a gradual rise in temperature of 0.4 °C since 1900 (Gullett et al, 1992). The Intergovernmental Panel on Climate Change has stated that the balance of evidence suggests that human activities over the last century have had a discernible influence on global climate (IPCC WGI Summary, 1995).

Environment Canada's Canadian Centre for Climate Modelling and Analysis in Victoria, British Columbia, has performed a climate experiment using a general circulation model to estimate how global climate might change when the concentration of greenhouse gases doubles in the 21st century. The general circulation model results project that average temperatures in the Lower Fraser Valley and much of the south coast of British Columbia will rise by 4 to 5 °C in winter and by 3 to 4 °C in summer by the latter half of the next century (Boer et al, 1992). These results also project that precipitation in the Lower Fraser Valley could increase by 40% in winter while decreasing by 20- 25% in May and June.

In themselves, adaptation to these changes in climate by the people and ecosystems of the Lower Fraser Valley may not be an onerous problem. However, the indirect effects of these changes on the incidence and severity of such things as flooding, summer drought, and decreased water availability and quality may be more problematic.

Though much work has gone into the formulation of General Circulation Models, scientists are still not entirely confident in these climate projections, which therefore must be viewed with caution. This fact is brought home by a comparison between the climate projections of different general circulation models for the latter half of the 21st century due to a doubled carbon dioxide atmosphere. For example, Table 1 shows the percent change in precipitation in the Lower Fraser Valley projected by three different climate models under a doubled carbon dioxide climate. Though all three general circulation models agree on the direction of the change in seasonal temperature and precipitation, there is disagreement on the magnitude of these changes, particularly with respect to precipitation. The reasons for these changes lie in the way that the climate models solve the basic atmospheric equations, and how various climate processes are modelled mathematically. Until scientists can use these and other models to give a more accurate prediction of the future state of the climate in the Lower Fraser Valley and elsewhere, society must plan for a wide range of possible changes.

Table 1. Projections by three separate general circulation models for the change in temperature and precipitation in the Lower Fraser Valley due to a doubled CO_2 climate. These projections disagree due to the way the models formulate and solve the atmospheric equations and to differences in the way climate processes are mathematically described.

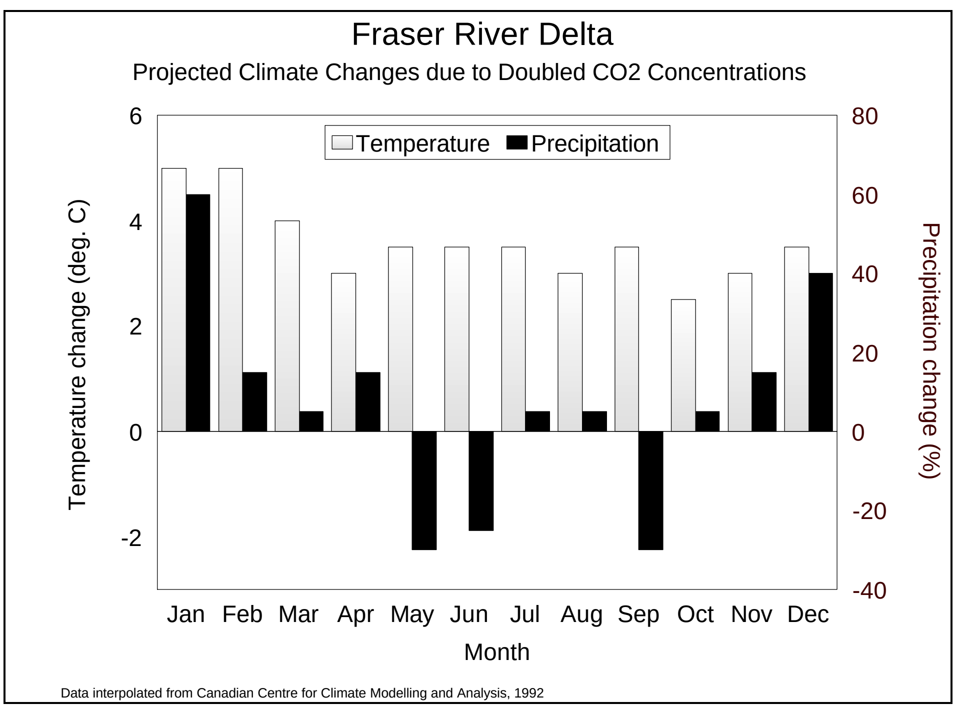
GENERAL CIRCULATION MODEL	TEMPERATURE CHANGE (°C)		PRECIPITATION CHANGE (%)	
	Summer	Winter	Summer	Winter
Canadian Centre for Climate Modelling and Analysis (1992)	+3.3	+4.4	-7%	+40%
Goddard Institute for Space Studies (1995)	+1.5	+2.2	-5%	+5%
Geophysical Fluid Dynamics Laboratory. (1991)	+2.7	+2.3	-25%	+7%

PROJECTED CLIMATE OF THE 21ST CENTURY DUE TO INCREASED GREENHOUSE GAS CONCENTRATIONS

Figure 1 shows the monthly temperature and precipitation changes in the Lower Fraser Valley projected by the Canadian Centre for Climate Modelling and Analysis general circulation model for a doubled CO_2 atmosphere. These changes could occur gradually over the next 80 to 100 years, or they could occur over a shorter time span if global climate modes were to shift suddenly. Atmospheric CO_2 concentrations are expected to double by the latter half of the 21st century.

As shown in Figure 1, the model projects that the mean temperature will be warmer throughout the year with a doubled CO_2

Figure 1. Average temperature and precipitation changes projected by a Canadian Centre for Climate Modelling and Analysis general circulation model for the Lower Fraser Valley for an atmosphere with a carbon dioxide concentration double that of pre-industrial times.



atmosphere. Winters are expected to be wetter, while summers (May through September) should be drier. As measured at Vancouver Airport, this means a winter (November through February) precipitation increase of 200 millimetres (rising from 600 to 800 millimetres) and a summer (May through September) precipitation decrease of 40 millimetres (falling from 240 to 200 millimetres).

The model results in Figure 1 also suggest that the fraction of winter precipitation falling as snow will be sharply reduced due to a changed climate. Assuming a standard atmospheric temperature decrease of 6.5 °C per kilometre of altitude (Hess, 1959), the mean freezing level, which generally corresponds to the mountain snowline, in the Lower Fraser Valley area could rise 500-800 metres during the winter. This would cause much of the precipitation over the delta and the surrounding coastal mountains to fall as rain rather than snow. Sea level snow events, now averaging about 15 days per year, could become relatively rare. Snow accumulation on the coastal mountains could be much reduced, with implications for summer water availability, hydrology, and winter recreation.

PROJECTED CLIMATE IMPACTS ON THE LOWER FRASER VALLEY

If climate change occurs in the Lower Fraser Valley as projected by general circulation models, there will be many local consequences. These include changes in water quantity and quality, stream and river flow, agriculture, human population health, sea level rise, fisheries, recreation and tourism, and extreme climatic events. Figure 2 summarizes some of these expected changes. They are discussed in detail below.

Water Quantity and Quality

Climate change may have significant impacts on water availability and quality for domestic and industrial use in the Lower Fraser Valley. At the same time, population growth over the next 80 to 100 years will put increasing demand on the water supply system.

The Lower Fraser Valley is one of the fastest growing regions in North America. Since the late 1980's an average of 40,000 people have moved into the region annually. In 1995 the Greater Vancouver Regional District's population was 1.98 million. This population is expected to double to 3 million by 2021 (Greater Vancouver Regional District, 1993; Fraser Basin Management Board, 1996). A continuation of this growth pattern would result in a population of 6 million by the latter half of the 21st century. Meanwhile, daily water consumption from the Greater Vancouver Water District has risen from 100 million gallons per day (MGD) in the 1960s to about 230 MGD in the 1990s (Figure 3). Assuming current per capita water consumption, the projected population growth alone would result in a quadrupling of the demand of water for domestic and industrial use by the latter half of the 21st century.

Reservoirs that are dependent on local rainfall and snowmelt are the main water suppliers to people and industry in the Lower Fraser Valley. If there are changes to the amount and timing of precipitation and snowmelt, the operation of these reservoirs may be impacted. Three reservoirs currently provide water to the Greater Vancouver Regional District; the Capilano, Seymour and Coquitlam. Three alpine lakes are used as supplemental reservoirs in the Seymour and Capilano watersheds. The Capilano and Seymour reservoirs currently each provide about 40% of the Regional District's water demand. The reservoirs and alpine lakes are generally full to capacity in the spring so that additional rain and snowmelt is normally spilled over the dams until June or July (Morse, 1993). Reservoirs are drawn down due to water demand in the summer, usually reaching their lowest level in late September. They fill again to capacity during the winter and early spring. If climate changes as projected by the graphs in Figure 1, the reservoirs will likely fill sooner than at present since total winter precipitation is expected to significantly increase. The average snowpack in the reservoir watershed may be much lower, or nonexistent, by May 1 due to an increased fraction of mountainous winter precipitation falling as rain and a higher winter snowline. This could lead to the draw down of the reservoirs beginning earlier in the year, since there will be little replenishment due to snow melt and May precipitation is expected to be 25% lower than at present. Due to increased temperatures after May 1, higher evapotranspiration and thus an increase in monthly water demand could occur until September if current per capita water

Figure 2. Summary of possible impacts of changes in temperature and precipitation due to future climatic change in the lower Fraser Valley of British Columbia.

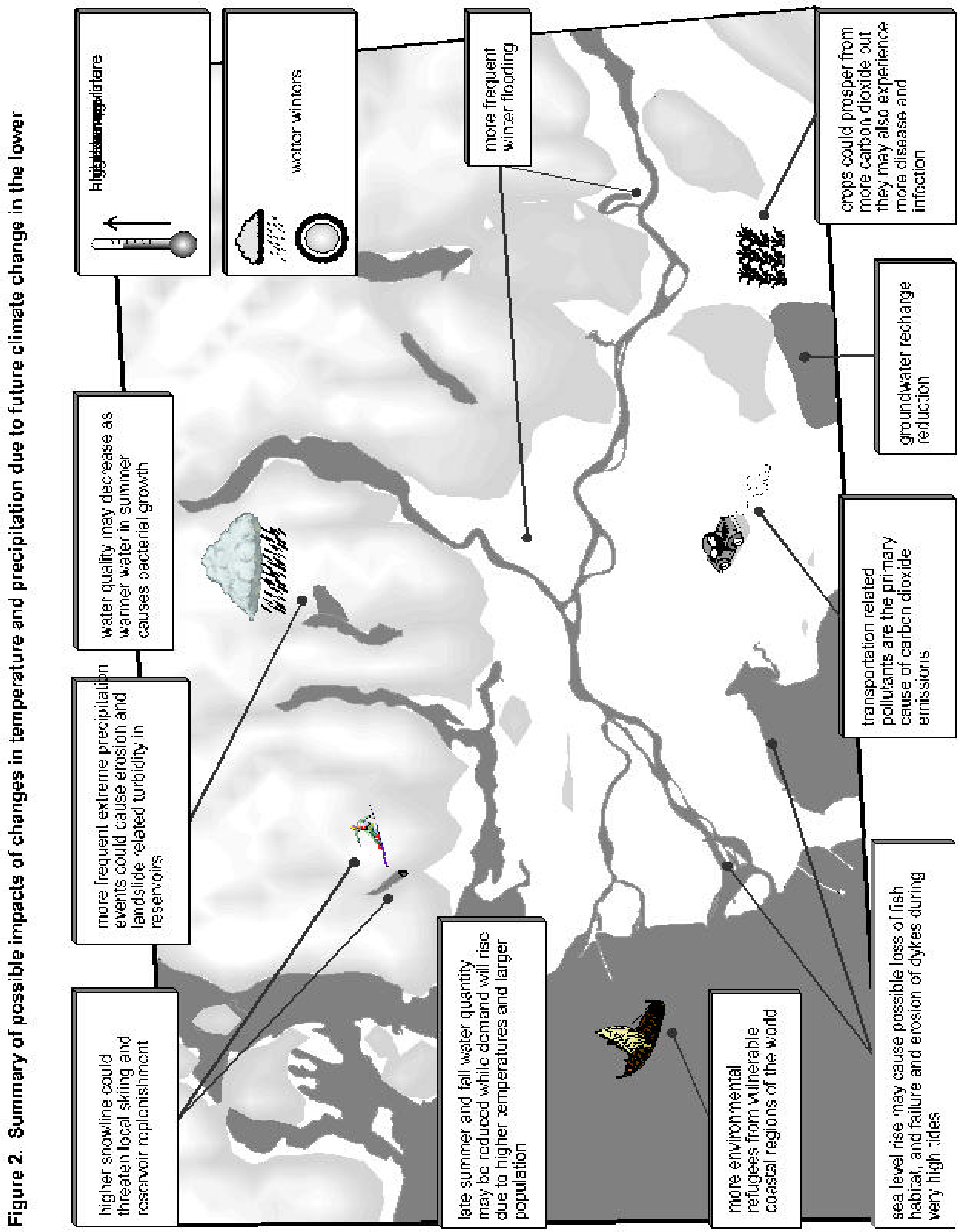


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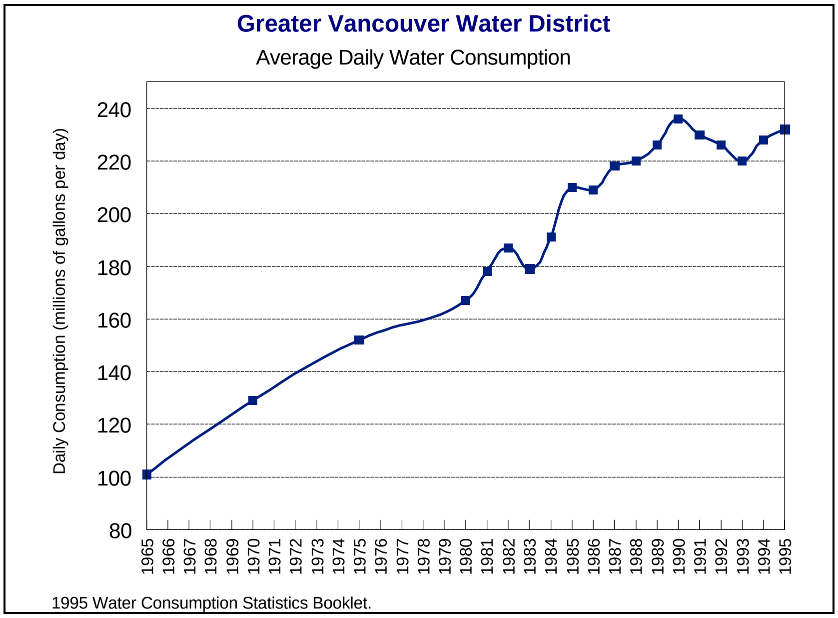
Figure 3. Average total daily flow from Greater Vancouver reservoirs from 1965 to 1995.



consumption remains the same. Since the reserves of the Capilano and Seymour reservoirs sometimes already fall to 50% of their capacity, as happened in 1992 (Elsie, 1993), water resources in these reservoirs could fall to precariously low levels more frequently due to climate change. New water storage in the Coquitlam Reservoir is expected to be added over the next decade to help alleviate this problem. Some of the Capilano water storage is presently being used by B.C. Hydro to generate power. Transfer of this water to the Greater Vancouver Water District will require the utility to purchase the lost power elsewhere.

More investigation is needed to estimate how the reservoirs will be affected in the latter half of the 21st century by the combination of an earlier draw down of the reservoir, a higher summer water demand and a quadrupled population in the Lower Fraser Valley region. Elsewhere in the province, climate change-induced reservoir level modifications could also have an impact on the production of hydroelectric power used by residents of the Lower Fraser Valley.

The quality of the water supplied to the population of the Lower Fraser Valley from mountain reservoirs may also be impacted by climate change. Temperatures are generally higher in shallow lakes than in deeper lakes in late summer. If the frequency of very low reservoir levels in late summer increases due to climate change, this would lead to increased average water temperature in the reservoir. Bacteria density in chlorinated tap water generally increases due to warmer water. The expected reservoir warming, in addition to the increased warming of the 500 kilometres of supply mains and concrete storage reservoirs in the lower Fraser valley due to increased ambient temperatures, could lead to a potential increase in the incidence of dangerous bacterial density in the water distribution system of the valley. Planning is now underway to design rechlorination stations to deal with the current growth of bacteria in the water system (Morse, 1996). More study would likely be needed to assess whether these rechlorination stations are capable of adding sufficient chlorine disinfectant to the water to keep the bacterial regrowth in check in a warmer climate.

Water quality may also be adversely affected in fall and winter due to climate change. The turbidity of the water rises when naturally occurring landslides and soil erosion occurs in the watersheds. This turbidity causes problems with the both the appearance and quality of the water. This problem is aggravated when heavy rain falls on snow in the alpine areas. Heavy rainfall causes rapid melting and instability of the snowpack. Avalanches and intense runoff result in severe soil erosion on mountainsides, stream and river banks, logging roads and the shores of the reservoirs. An example of this occurred on November 23, 1990, when 30 centimetres of rain fell over a

24-hour period, causing torrential run-off, the erosion of stream banks, and landslides. In the month of November 1990, 145 centimetres of rain and snow fell in the watersheds, compared to only 25 centimetres of rain at the Vancouver International Airport. Massive amounts of rain arriving at one time disturbs the exposed reservoir banks and stream beds and often causes much of the early winter water turbidity problems (Greater Vancouver Regional District, 1994). If climate change causes the increase in winter precipitation as shown in Figure 1, these kinds of turbidity and associated water quality problems could be expected to increase in both frequency and intensity.

Climate Change Impacts on Local Streams in the Lower Fraser Valley

The hydrological system is potentially very sensitive to changes in climate. Changes in precipitation and temperature can change the timing of runoff and the frequency, duration and intensity of droughts. However, due to the many uncertainties associated with the accuracy of the GCM projections as well as the lack of understanding of many hydrological processes, estimates of the effects of climate change on hydrology are very uncertain.

GCMs are the basis for most experiments dealing with the impacts of climate change on hydrology. There is mounting evidence after analysis of many GCM experiments that a warmer climate will be one in which the hydrological cycle will in general be more intense (IPCC, WGI, 1995). One analysis of daily precipitation from five general circulation models simulating a doubled carbon dioxide climate found that there were more frequent extreme precipitation events and an increased intensity of rainfall (Henderson-Sellers 1995). Also, there is moderate confidence that, in general, the variability of river flows will increase with climate change and the frequency of both high and low flows would increase.

All general circulation models project that average global precipitation will increase as temperatures rise. However, regional responses may vary considerably, with some areas likely to experience reduced precipitation.

The flow of low elevation rivers and streams in the Fraser Valley are controlled mainly by high winter precipitation rather than snow melt. A recent investigation of the impacts of climate change on low elevation streams in the Lower Fraser Valley utilized the temperature and precipitation projections from the three separate GCMs in Figure 1 for a doubled CO_2 climate (Taylor, 1996). Historical streamflow data from unregulated Kanaka Creek was used to develop a mathematical streamflow model. Monthly flows in Kanaka Creek are small, averaging from 0.5 to 5 cubic metres per second through the year. This compares to the Fraser River which averages from 900 to 5000 cubic metres per second. The results of the investigation were:

- Flows in small streams like Kanaka Creek in the Lower Fraser Valley area are much more sensitive to changes in monthly precipitation than monthly mean temperature. For example, a moderate increase in precipitation will have more of an effect on the flow of streams than a moderate increase in temperature.
- All three climate model projections of a doubled CO_2 climate resulted in increased winter flow in small streams.
- Two of the three climate model projections of a doubled CO_2 climate resulted in lower summer flows in small Lower Fraser Valley area streams. Since low water flows generally lead to increased water temperatures, this would imply also that summer water temperatures in Lower Fraser Valley area creeks and streams would likely be greater.
- The modelled flow in these small streams in a doubled CO_2 climate revealed that the frequency of both very high flow events and very low flow events increased substantially under a changed climate.

The following implications could be drawn from these results. In unregulated creeks near or in the Lower Fraser Valley that are fed predominantly by rainfall rather than snow melt:

- Climate change may result in more winter flooding in and around the Lower Fraser Valley and the adjacent slopes. Areas where forest cover and other vegetation has been removed may be more vulnerable.
- Lower summer streamflows in small streams under a changed climate could hamper migrating fish stocks in the Fraser Valley due to both lower water levels and higher water temperatures.

Salmon stocks migrating up the Fraser River in the fall will also be affected as the river and its tributaries will likely experience lower flows and higher water temperatures (Levy, 1992). Also, since the fraction of winter precipitation falling as rain is expected to increase in the mountains surrounding the Lower Fraser Valley, those creeks and streams that rely for a major portion of their flow on snowmelt will likely have a spring runnoff that occurs a month or so earlier. (IPCC WGII, 1995). The major runoff peak of the Fraser River may also shift to an earlier time due to similar temperature rises in the watersheds of its tributaries in the British Columbia interior.

Warmer temperatures and the changing precipitation regime may also result in lower groundwater levels in the Lower Fraser Valley in summer and higher groundwater levels in winter.

Agriculture

Zebarth et al. (1997) note elsewhere in this report that climate change will likely have both good and bad effects on agriculture in the Lower Fraser Valley. Among favorable effects, a large number of experiments have shown that increased concentrations of CO_2 have a fertilization effect on agricultural crops, increasing yields by an average of 30% on average (IPCC WGII, 1995). CO_2 increases have also been shown to improve water use efficiency of crops. However, there is some evidence that plants adapt to increasing levels of CO_2 and become less efficient at using the gas.

The growth of some crops such as perennials would benefit from a longer growing season, since the average frost-free season could begin up to 5 weeks earlier in the spring and extend for up to 4 weeks in the fall. Annual crops may not benefit from this lengthened growing season if spring and fall months are wetter than at present, since this would inhibit planting and harvesting operations. The primary benefit of the extended growing season may be the possible introduction of a wider variety of crops into the Lower Fraser Valley and surrounding area (Zebarth et al., 1997).

There could be a number of detrimental effects on agriculture by climate change in the Lower Fraser Valley:

- Most crops in the area are currently not irrigated. Higher temperatures and lower May through September rainfall would increase evapotranspiration and lower soil moisture. This could lead to substantial increases in both the area of land irrigated and the quantity of water used. If the spring freshet is reduced or occurs substantially earlier than at present, the subsequent lowering of the summer water table would also increase irrigation requirements (Zebarth et al., 1997).
- Weeds would also benefit from the beneficial effects of increased concentrations of CO_2.
- Due to increased temperatures in the Lower Fraser Valley, more insect pests could migrate from the United States, more insect species could overwinter in the delta and adjacent areas, insects growth rates could increase, and pests that currently can only manage one life cycle per season could increase that to two (IPCC WGII, 1996). This could dramatically increase pest numbers in the Lower Fraser Valley in late summer and also in the spring if overwintering occurred due to milder winters (Vernon, 1994).
- Some crop diseases currently migrate to the Lower Fraser Valley annually from the southern United States. A warmer climate would mean that the distance that these diseases need to travel is shorter and that they would arrive earlier, thereby having a greater impact. (Zebarth et al., 1997).

Human Population Health

Human population health worldwide is anticipated to be affected by climate change. These changes would mostly be adverse (IPCC WGII, 1995). Some of these worldwide impacts will be from increased frequency and intensity of heat waves. Extensive research has shown that heat waves cause excess deaths (Weihe, 1986). Extreme maximum temperatures of 37.5 °C (Port Coquitlam, August 8, 1978) have been recorded in the urbanized area of the Lower Fraser Valley (Environment Canada, 1981). Assuming that the maximum temperature will rise by the same amount as that expected of the mean temperature in summer (3.5 °C), this would suggest that extreme maximum temperatures could reach 41.0 °C in the Lower Fraser Valley by the latter half of the century. This extreme temperature could be higher due to the urban heat island effect of a more densely populated region by the latter half of the next century. This suggests that excess heat-related deaths could occur in summer in the Lower Fraser Valley due to increases in either the extreme maximum temperature of a summer or the length of heat waves.

Some vector-borne diseases such as malaria and vector-borne viral infections such as dengue may increase their range as climate changes. Dengue is a severe influenza-like disease which in parts of Asia is transmitted by the *Aedes aegypti* mosquito, now colonizing North America (IPCC WGII, 1995). Further investigation is needed to develop credible projections of the vulnerability of populations in the Lower Fraser Valley to these kinds of diseases under climate change.

Air pollution is a public health issue in the Lower Fraser Valley. Thomson (1997) notes in this volume, that the airshed in the Lower Fraser Valley is physically bounded on the north, east and south by mountains. Under stagnant, stable meteorological situations of several days where vertical mixing of the atmosphere is minimal, air pollutant concentrations near ground level gradually increase. This occasionally leads to advisories to the general public concerning deteriorating air quality, particularly in summer during hot, relatively calm days. Air pollutants of concern include ground level ozone in the summer and fine particulate matter all year round. Ground level ozone and fine particulates are largely the result of air emissions from the transportation sector - particularly the automobile. Ozone and fine particulates have been shown to exacerbate asthma, impair lung function and produce excess deaths in other jurisdictions (Beckett, 1991; Schwartz, 1994; Dockery et al, 1993). Annual health costs associated with air pollution in the Lower Fraser Valley area were estimated at $830 million in 1990 and are projected to increase to $1.5 billion in 2005 (Fraser Basin Management Board,1996; BOVAR-CONCORD, 1994). Since temperatures are expected to be higher in the Lower Fraser Valley in a changed climate, this suggests that the warm stable atmospheric conditions that accompany very high temperatures could also be more frequent. These warm stable conditions are also a critical component of elevated levels of ground level ozone, since this pollutant is formed photochemically by the interaction of precursor chemicals and ultraviolet solar radiation under warm conditions. Stable atmospheric conditions also favour elevated concentrations of fine particulates. With the burgeoning population of the area, the supply of precursor pollutants and fine particulates, primarily from automobiles, will likely increase in the next fifty to eighty years. This suggests the frequency of summer days with elevated concentrations of both ground level ozone and fine particulates will increase and negatively impair human health in the Lower Fraser Valley by the end of the next century. Combined with an aging population, this could cause the annual health costs associated with poor air quality to rise well beyond $1.5 billion during the latter half of the next century.

In winter, fine particulate concentrations increase during clear, calm, and cold conditions in the Lower Fraser Valley. This meteorological situation usually occurs as a ridge of high pressure builds over the British Columbia interior and pushes cold, dry air westward over the valley. The pollutant concentrations increase due to a combination of increased burning of fuels for space heating during cold days and the stable atmosphere near the ground under high pressure areas and during cold, clear conditions. If climate change results in milder and wetter conditions in the Lower Fraser Valley, as is projected by the Canadian Centre for Climate Modelling and Analysis GCM, the frequency of these cold, clear conditions may decrease, resulting in fewer episodes of elevated concentrations of fine particulates in winter. This beneficial aspect of climate change could be offset, however, by the increasing emission rates from the transportation sector.

Sea Level Rise

Beckman et al. (1997) and Thomson and Crawford (1997) discuss elsewhere in this report the expected sea level changes and impacts along the coast of British Columbia. The lowlands of the Lower Fraser Valley are one of only two sites in British Columbia that have been identified as coastlines that are highly vulnerable to sea level rise (Marko, 1994). The Lower Fraser Valley has been subsiding approximately 1 to 2 cm. per decade this century relative to sea level (McLaren et al, 1983). The best current estimate for the expected rise in global sea levels generated by climate change is 38-55 centimetres by the year 2100 (IPCC WGI,1995). Thomson and Crawford (1997) estimate that all sea level change processes in the inner south coast will cause a relative rise in sea level of up to 20 centimetres by 2100 in the Lower Fraser Valley.

Lowlands of the Lower Fraser Valley, including large parts of the municipalities of Richmond and Delta, are protected from the invading sea and from the Fraser River by an extensive system of dikes. These dikes may have to be reinforced due to sea level rise. However, climate change will also cause changes in the intensity and timing of the peak flow of the Fraser River in the spring. If the height of the peak flow decreases, this could offset some of the need for dike reinforcements in the estuary. If the height of the peak flow increases, this could increase the need for dike reinforcement.

Tidal wetlands and estuarine areas that would normally migrate inland as sea level rose will be unable to do so in many areas of the Lower Fraser Valley because of dike barriers. As Beckmann et al. (1997) note, these wetlands represent critical waterfowl wintering and fish rearing habitats, and the reduction of their already limited area or productive capacity would be detrimental to these species.

Sea level rise in less developed countries could have an indirect impact on many developed areas of the world, including the Lower Fraser Valley area. Forty million people in the developing world are now estimated to annually experience flooding due to storm surges under present climate and sea level conditions. Anticipated sea level changes due to climate change could increase this number to between 80 and 120 million (IPCC WGII, 1995). This could lead to increasing pressure on developed countries to admit vast numbers of environmental refugees from around the globe.

Fisheries

The commercial and sports fishery is an important resource for the human population of the Lower Fraser Valley. Climate change may have a marked influence on this resource as fish production could be significantly altered as temperatures rise. Fraser River salmon, an important commercial and sports species, would be generally negatively affected by climate change, particularly those species which rely on freshwater habitats for juvenile rearing that are near the southern margin of their geographical range (Levy, 1992). This would be due to both changes in river flow caused by precipitation shifts in the interior and by rising water temperatures, which adversely affect salmon in both early and late stages of their life cycle.

All salmon species spend the majority of their life in ocean environments. Experiments with general circulation models project that northeast Pacific Ocean sea surface temperatures may rise 2 to 4 °C and that average wind speeds in the area will diminish. Lower winds would lead to decreases in nutrient-rich ocean upwelling of cold waters from the ocean bottom. These nutrients maintain the population of zooplankton, a key element of the food change for salmon in the ocean. Warmer sea surface temperatures would mean a significant loss of thermal habitat area for at least one species important to the Fraser River, sockeye. This would lead to lower salmon survival (Cox et al, 1995). Thermal habitat area is the ocean area that is cool enough for fish to both survive and thrive.

Since the mid-1970s, warmer sea surface temperatures along the west coast of North America and changes in near-shore currents associated with more frequent El Niño events appear to have contributed to remarkable increases in the productivity of Alaskan salmon stocks and to declining runs of some salmon that spawn in Washington, Oregon, and California. In 1994, these trends culminated in an all-time record Alaskan salmon harvest and the complete closure of the once-thriving Coho and Chinook fisheries in Washington and Oregon (Environmental and Societal Impacts Group, 1996). If climate change leads, as some scientists predict, to more frequent El Nino - type conditions, these types of closures of southern rivers, including the Fraser River, to salmon harvesting could become more common.

Recreation And Tourism

Climate change may both benefit and damage recreation and tourism in the Lower Fraser Valley. Warmer, longer and dryer summers would likely provide more recreational opportunities in summer and favour increases in tourism. However, recreational activities could be curtailed in winter due to increased rainfall in the delta area. Also, milder temperatures could

Table 2. Height of main ski mountains near the Lower Fraser Valley. The average snowline for the current climate in January is estimated at 900 metres currently, and 1300 metres in a changed climate.

Mountain	Height (m)	Elevation above snowline in January in today's climate (m)	Elevation above snowline in January in changed climate (m)
Seymour	1468	568	168
Fromm (Grouse)	1182	282	0
Hollyburn	1344	444	44
Stron (Cyprus)	1476	576	176

lead to an increasing proportion of precipitation in the surrounding ski hills falling as rain rather than snow, resulting in shortened ski seasons.

Table 2 gives the approximate height above sea level of ski hills bordering North and West Vancouver. If the mean freezing level in the Lower Fraser Valley were to rise in winter by an average of 500 to 800 m due to climate change, the mean snow line could, by inference, also rise by this amount. The mean snow line in the present climate averages about 800-900 metres above sea level in January and February (Grouse Mountain Resorts, 1996, personal communication.). Climate change could increase this average snow line to between 1300 to 1700 metres. A January snow line of this altitude is effectively above all the ski runs of the north shore mountains, and would result in the elimination of a viable skiing industry from this area.

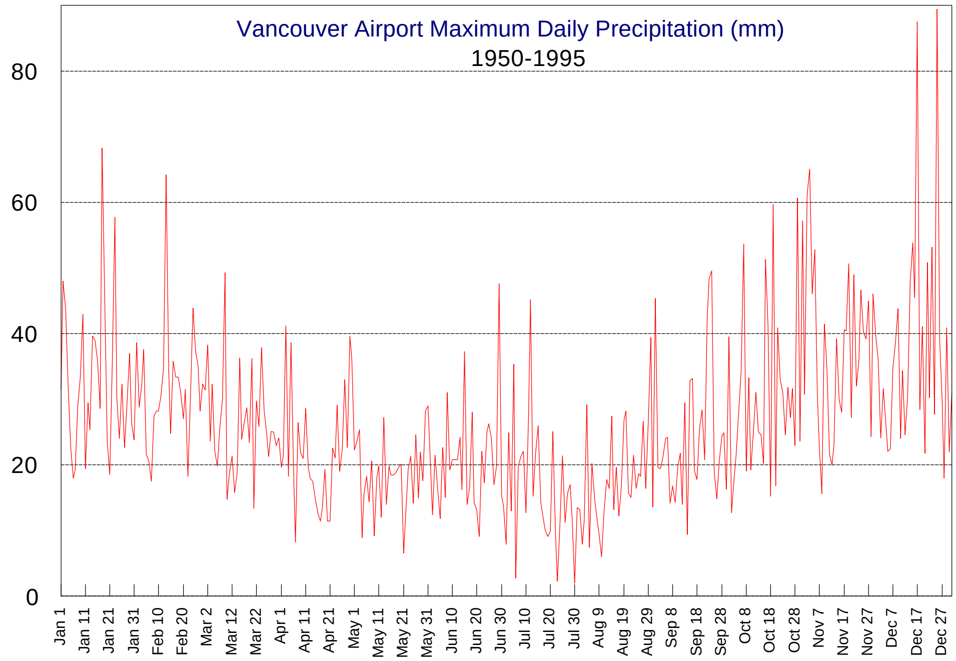
Extreme climatic events

Climate change may change the frequency and severity of extreme climatic events such as heavy rain episodes (Henderson-Sellers A. , 1995). In the period 1950-1995, heavy rain episodes in the Lower Fraser Valley, as characterized by a daily precipitation of more than 50 millimetres, occurred from October to early February (Figure 4). The highest frequency of these events occurred from late October to early November. The three general circulation models all project increasing precipitation in the Lower Fraser Valley in winter. If, as projected by the Canadian Centre for Climate Modelling and Analysis experiment, the majority of this increase occurs in December and January, by inference the frequency of heavy rain episodes in December and January may also increase. This would result in an increase in flooding in low lying areas of the Lower Fraser Valley, to increases in flow in small streams in the surrounding mountains, a resultant increase in streambank erosion. As noted earlier, increased incidence of erosion around reservoirs would also lead to an increase in high turbidity events in late fall and winter.

CONFRONTING FUTURE CLIMATE CHANGE IN THE LOWER FRASER VALLEY

The issue of climate change can be tackled in a number of ways. The global atmospheric concentrations of greenhouse gases could be reduced or stabilized by improved industrial processes, better land use practices and a reduction in the burning of fossil fuels. The Framework Convention on Climate Change is an international effort attempting to achieve stabilization of greenhouse gas concentrations early in the 21st century. Canada is a signatory to this Convention and domestic programs are now in place to support the Convention. Municipalities in the Lower Fraser Valley area could take meaningful steps to support Canada's contribution to responding to the climate change issue, including joining other metropolitan areas across the country in becoming a member of the "20% Club". This group of cities each has a goal of reducing their greenhouse gas emissions by 20% by the year 2005 . In the Lower Fraser Valley, burning fossil fuels, specifically in the transportation sector, has been linked to other environmental problems such as air pollution. Therefore, a reduction in burning fossil fuels will contribute to the improvement of other environmental and health problems as well as reducing greenhouse gas emissions. Continuation of the implementation of improved forestry and agricultural practices in the areas surrounding

Figure 4. Maximum one day precipitation at Vancouver Airport, in the western section of the Lower Fraser Valley, between 1950 and 1995.



the Lower Fraser Valley could both decrease the stress on a number of environmental sectors as well as reduce net atmospheric greenhouse gas emissions.

Due to the significant increase in greenhouse gas concentrations that have already taken place since pre-industrial times and the continuing anthropogenic emissions of these gases, some degree of climate change is likely inevitable. Because of this, it may be wise for the population of the Lower Fraser Valley to consider adapting to a climate that may cause some significant changes. Some sectors such as agriculture that are capable of responding relatively quickly to changes will be better able to adapt to a changed climate. However, some sectors, such as infrastructure construction and maintenance that require long term planning and investment, would benefit from the inclusion of climate change adaptation measures into the planning process. An example in the Lower Fraser Valley is water storage and distribution. If climate change threatens to disrupt water quantity and quality over the next 80-100 years, it may be beneficial to consider measures to cope with such threats. This could include:

- controlling water use and land use
- devising incentives to conserve water and reduce per capita consumption
- improvement and expansion of water storage, distribution and management systems
- increase the availability of supplies of water, perhaps by the incorporation of the Coquitlam Reservoir in the Lower Fraser Valley water supply.
- improve the efficient use of water by better technology.

Work on the last four of these measures is currently being planned in the Greater Vancouver Water District (Morse, 1996).

Other major projects that should include the issue of climate change in long term planning are systems such as dikes, sewers, roadways and railways that may be at risk due to climate change-induced sea level rise or winter flooding. Improvements or replacement of these structures, which have a lifespan of 50-100 years, could be expensive. For instance, Kitajima (1993) estimated that the cost of protecting Japanese ports, harbours, and adjacent coastal areas against sea level rise would total $92 billion.

Another activity that could be considered as indirectly adapting to climate change in the Lower Fraser Valley is the support of foreign aid by residents of the area. If climate change produces millions of refugees from undeveloped countries under present economic conditions, the Intergovernmental Panel on Climate Change has noted that it may be beneficial for the developed world to deliver economic services and opportunities to the refugees' countries of origin over the next 50 years in order to prevent population migration (IPCC WGII, 1995.).

CONCLUSION

The Intergovernmental Panel on Climate Change has stated that there is a general consensus among scientists that there is "a discernible human influence on global climate" (IPCC WGI Summary, 1995). Climate scientists using general circulation models project that the changes now being seen in the global climate will continue through the 21st century. All regions of the world, including the Lower Fraser Valley, are expected to experience these changes, some to a greater extent than others.

The specific magnitude and timing of how climate will change in the Lower Fraser Valley and the extent that these changes will impact human activities and environmental health cannot be accurately predicted. However, climate scientists can give some approximate projections. These include a milder and wetter winter on average for the region, and a warmer, dryer and longer summer season. These kinds of changes would affect a number of human activities and environmental sectors important to the residents of the Lower Fraser Valley. Water for domestic and industrial use could be in shorter supply if additional storage is not provided to capture high winter runoff. Air quality may deteriorate due to more frequent atmospheric stagnation episodes. Sea level rise and winter flooding could threaten dikes and other infrastructure. Critical waterfowl wintering and fish rearing habitats in the estuary could be threatened by sea level rise. The salmon fishery, relied upon by a large number of citizens of the Lower Fraser Valley, could be at risk. Winter recreation in the local mountains could disappear. Population could soar due to increased immigration from climate change-impacted nations.

By participating in national and international efforts to curtail greenhouse gas emissions, citizens of the Lower Fraser Valley can do their part in reducing the climate change threat. Another benefit to these efforts is that measures to curtail greenhouse gas emissions often lead to improvements in other environmental areas, such as improvements in local air quality. Planning to adapt to some level of climate change in the Lower Fraser Valley will be a prudent approach, since most climate scientists believe some change is inevitable. Projects that have long lifetimes will benefit most from the inclusion of the climate change issue in their planning process. Acknowledging the very real possibility of future gradual or rapid climate change and responding to it by including it in long term planning decisions will better prepare us for its effects and proactively prevent undue large expenditures to repair or compensate for problems when they occur.

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Chapter 20

INTEGRATION OF CLIMATE CHANGE IMPACTS ON BRITISH COLUMBIA AND YUKON

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OVERVIEW

This is a “scenario” describing the various direct and indirect ways a changing climate could affect British Columbia and the Yukon. It is based on assessments provided for ecosystems and economic sectors which appear elsewhere in this document. It is not based on a formal integration model which would link various components by a series of mathematical equations. By reviewing all sectoral assessments together, the perspective becomes a regional one. What may appear to be an adverse impact on one sector may provide an opportunity for another at specific locations. On the other hand, such changes need to be considered within the context of stakeholders’ preferences for resource development and management, including conservation and sustainability.

THE "WHAT IF" QUESTION

If the world's climate warms because of air pollution and land use change (primarily deforestation), what would happen to land, water and marine resources, and to the communities that depend on them? This central question is at the heart of the debate about responding to climate change. The Intergovernmental Panel on Climate Change (IPCC) has concluded that 1) atmospheric concentrations of greenhouse gases (carbon dioxide, methane, etc.) are increasing, 2) there has already been some warming and a rise in sea level, 3) some of this warming (and associated sea level rise) may be due to greenhouse gas emissions and other human activities, and 4) this trend will continue if these concentrations continue to rise (Houghton et al., 1996). As a consequence, 5) ecosystems, food production, coastal communities and national economies would be at risk from climate warming, and 6) emission reduction and adaptation would be needed to avert these effects (Watson et al., 1996).

Current knowledge of the costs and risks associated with climate warming is largely confined to a few key sectors, particularly agriculture. There is also a good inventory for coastal zones vulnerable to sea level rise, and there is a growing data base on potential effects on ecosystems, water resources and human health. For developed countries, current estimates from the IPCC indicate a loss of 1-1.5% GDP. For developing countries, the range is 2-9% (Bruce et al., 1996).

Determination of impacts on places rather than sectors (agriculture) or ecosystems is a more complex challenge because units of land and water are used for many purposes, not just one. This multi-purpose aspect of resource use is a fundamental part of how regions develop. Each region has many stakeholders, and their varying objectives may or may not be met in a scenario of climate warming. Some of these objectives, including social and cultural ones, are difficult to measure in terms of GDP. It might appear to be foolish to extend the discussion this far away from "climate" but the scenario being described is a climate (not just weather) unlike any we have experienced in British Columbia and the Yukon this century. Warmer climates exist elsewhere of course, and landscapes and lifestyles have adapted to these over time, but what would happen if such conditions were to be superimposed here within a few decades? Would it make a difference to this region's ecosystems and communities? Would the economy be affected?

Regional Impacts Issues

Regions are integrators of landscapes and human activities. If climate warming changes the landscape, and indirectly affects human demands for resources, could these affect stakeholders' visions of the future? Could they lead to alterations of land use patterns? Would this make sustainable development more difficult to achieve?

The following discussion will focus on three themes:

a. renewable resources
b. economic development, and
c. communities

Reference is made to authors of other reports in this document. Additional sources are also cited.

Renewable Resources

Ecosystems and renewable resource production is expected to be altered by climate warming:

- southern British Columbia watersheds would experience increased winter flooding as a higher percentage of winter precipitation would fall as rain rather than snow; longer summers and reduced precipitation would reduce summer streamflow and increased water temperatures (Taylor); northern British Columbia watersheds may experience similar effects while Yukon watersheds may become wetter (Coulson); coastal and southern interior BC would experience increases in peak flows while the north would see higher minimum flows (Coulson)
- fisheries are being affected by current climate variability as well as fishing pressures (Beamish);
- in northeast British Columbia, forest growth will be improved for hardwood species, but declines in softwood growth are expected due to warmer temperatures and expansion of pests; yield would decline, particularly

due to increased fire frequency (Hartley and Marshall, 1997); elsewhere, the expected trend is for movement of ranges of species to migrate northward and to higher elevations (Hebda)
- some biogeoclimatic zones would be replaced by zones with no modern analogue, suggesting that there are no examples of such zones that can be found under current conditions (Hebda)
- agriculture may benefit from the longer growing season, but this will depend on availability of irrigation (Zebarth et al.); given the water resources scenario described by Coulson for the southern interior and coastal regions, would this require additional reservoir storage?
- coastal zone resources would be affected in complex ways, and these effects would be site specific; some Pacific coast areas would experience wetland loss while plant production along the Yukon coast would benefit from warmer sea surface temperatures (Beckmann et al.)
- projected increases in wind speed would lead to decreases in bird migration between breeding grounds in British Columbia and winter habitats in the southern USA and tropical regions (Butler et al.)

Economic Development

Production of climate sensitive commodities, including timber, food, fish, and hydro-electricity, would be affected by this scenario. Changing climate would also create new challenges for infrastructure, transportation, tourism and trade:

- hydroelectricity production may be reduced by lower summer streamflow while increased winter precipitation could lead to winter/spring flooding downstream from reservoirs (Wellisch)
- per capita space heating demand would decline (Wellisch)
- the energy industry expects to be able to adapt to this scenario; current priorities are on reducing emissions as part of the international commitment to the United Nations Framework Convention on Climate Change (Wellisch)
- closures of fisheries in the Fraser and other southern rivers could become more frequent (Taylor, Beamish)
- winter recreation in the Fraser Delta region would not be as viable due to reduction in reliable snow cover and increases in rainfall; summer recreation would benefit from warmer conditions (Taylor)
- forest management is experienced in responding to fire, disease, pests and reforestation failure, but it is the extent and location of these problems that will change (Spittlehouse);

Communities

Direct impacts of climate warming would be felt by resource-based and aboriginal communities. Forestry impacts could result in changes for forest-based communities if there are changes in harvesting methods, seasonal activities and annual allowable cut. Proactive management strategies will lead to costs to forest management, but they are likely to be less than those that result from doing nothing (Spittlehouse). Similar impacts could be experienced in fishing communities if there are changes in management strategies. Aboriginal communities dependent on wildlife for subsistence would be concerned about the long term viability of traditional lifestyles, and their responses would depend on the status of land claims agreements and availability of jobs in the wage economy (Lonergan et al., 1997; Pinter, 1997). Larger service centres (e.g. Vancouver, Prince George, Whitehorse) would experience indirect effects depending on how fishers, foresters and other affected groups adapt to these scenarios.

How well a community responds to a change in climate will also depend on the area's previous experience with severe weather and long term variations in climate, and on its geographic, economic and social situation. A recent study of remote Northern communities in the Northwest Territories and northern Ontario suggests that differences in experiences can affect levels of preparation and vulnerability to floods, droughts and other atmospheric events, as well as their dependence on other levels of government for assistance (Newton, 1995).

If the extent and location of problems and opportunities change, these changes could cross borders and jurisdictions. For communities, provincial/territorial and federal agencies, this presents a new challenge in coordinating responsibilities for managing resources and preparing for the future.

Is there a Bottom Line?

At the outset, a number of questions were asked about the implications of climate change for regional land use patterns, economic development, community stability and sustainability. These questions are difficult to answer. Ultimately, regional and national responses to a "global" stress like climate change will be influenced by

- observations of regional changes (e.g. Are there more fires? Have wildlife patterns changed?)
- responses of other governments (e.g. What will the USA and other major trading partners do about climate change? Can existing interjurisdictional water agreements provide the framework to respond to changes in water resources?)
- availability of new technologies that can reduce emissions (e.g. hydrogen powered vehicles) or increase resilience of climate sensitive activities (e.g. use of trees that can tolerate a wider range of moisture conditions), and
- visions of resource managers and other stakeholders, and whether these visions might be affected by the prospects of a changing climate (e.g. Does the scenario of impacts make a difference to their visions of the short or long term future?).

This inventory of current information and judgment on potential regional impacts of climate change includes significant changes to renewable resources and ecosystems, and their management. It does not include a damage assessment in dollars or jobs, nor does it provide clear choices about the most appropriate adaptation responses to reduce these costs. This assessment has not yet been done for this region.

Even if British Columbia and the Yukon successfully stabilize or even reduce greenhouse gas emissions, this may not be enough to prevent global greenhouse gas concentrations from increasing, thereby resulting in the above suite of impacts (in this scenario). This means that along with strategies to reduce greenhouse gas emissions, adaptation has to be considered in all its dimensions, including the need to

- reduce vulnerabilities to extreme events (e.g. coastal flooding, forest fires),
- respond to changes in renewable resources (e.g. forest products, fish, freshwater resources),
- reassess land use choices (e.g. preservation of agricultural land, establishment of new parks and tourism facilities, granting of timber licenses, calculation of annual allowable cut and other quotas),
- review the design and maintenance of infrastructure (e.g. coastal dykes, electric transmission lines),
- translate such impacts into potential changes in risk (e.g. insurance), and
- lengthen some planning horizons (e.g. beyond a generation, up to a forest rotation or the expected life of a dam or other major capital infrastructure).

These considerations require consultation with a broad range of expertise and stakeholder interests. This needs to happen in governments, professional societies and the private sector as well as the research community. Because of the broad dimensions of the climate change issue, we are all stakeholders.

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Part 6

HUMAN RESPONSE TO CLIMATE CHANGE IN BRITISH COLUMBIA AND YUKON

Chapter 21

GREENHOUSE GAS EMISSION REDUCTIONS: THE FRAMEWORK CONVENTION ON CLIMATE CHANGE AND THE CANADIAN FEDERAL RESPONSE

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OVERVIEW

The Framework Convention on Climate Change is the first international treaty that specifically addresses the cause, effects and mitigation of climate change. This chapter describes the development and commitments of the treaty and the Canadian federal response to its main obligations under the treaty. The current Canadian response is inadequate to achieve stabilization of our national greenhouse gas emissions and additional measures will be necessary in order for Canada to meet our climate change commitments.

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

International Conventions, Treaties and Protocols

United Nations (U.N.) conventions, or treaties, are drafted and adopted through a negotiating process among member states. Adoption of an U.N. convention only implies that the duly empowered representatives of the negotiating states expressed their collective consent to the draft text in the convention. Once adopted, an U.N. convention can be opened for signing by the member states. An U.N. convention can only become a legal binding agreement (i.e., entered into force) when a certain specified number of the signatories have deposited their ratification at the U.N. A member state that ratifies a convention is called a Party to the convention. After the ratification of a convention, future negotiations and implementation of a convention are the responsibilities of the Conference of Parties (COP) which generally holds annual meetings of the Parties.

A Framework Convention does not normally have very specific legal obligations but rather, it sets out ultimate objective(s), important principles and general commitments of the Parties. More specific legal obligations or commitments can be agreed upon later and such future agreements (generally called Protocols) are negotiated through a process similar to the development of a convention.

Framework Convention on Climate Change (FCCC)

The need for a global treaty to address the climate change problem arose from a series international conferences during the late 1980's. The United Nations Environmental Programme and the World Meteorological Organization responded by forming a working group to prepare for treaty negotiation. Acting on a proposal from the working group, the United Nations General Assembly set up an International Negotiating Committee (INC) for a Framework Convention on Climate Change (FCCC) in 1990.

The INC's mandate was to negotiate and draft the FCCC, which excluded those greenhouse gases (e.g. CFCs) already controlled under the Montreal Protocol. The INC consisted mainly of government representatives/negotiators from over 150 nations but it was open to accredited observers as well. After five negotiation sessions over a 15-month period, the FCCC was drafted and adopted by the INC in May 1992. The INC continued to function until the treaty entered into force.

Article 2 of the FCCC incorporated the ultimate objective of the Convention which is "to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic [man-made] interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Article 3 of the FCCC incorporated the two most important principles in the framework convention: precautionary approach and sustainable development. Implementing a precautionary approach means "the Parties should take precautionary measures to anticipate, prevent, or minimize the causes of climate change and mitigate its adverse effects", and the industrialized Parties (i.e., developed countries) are assigned the lead to combat climate change. Application of the precautionary principle means potentially dangerous activities that threaten serious or irreversible damage should be restricted, or even prohibited, before there is absolute scientific certainty about their impacts. In addition, "the Parties have a right to, and should, promote sustainable development taking into account that economic development is essential for adopting measures to address climate change." Like most international environmental treaties, the FCCC provides specific differences in commitments between developed and developing country Parties.

Article 4 of the FCCC incorporated some very general commitments for the Parties, including:

- All Parties are to "develop, periodically update, publish and make available to Conference of Parties....national inventories of anthropogenic [man-made] emissions....of all greenhouse gases...." (from paragraph 1(a) of Article 4);

- All Parties are to "formulate, implement, publish and regularly update national....programmes containing measures to mitigate climate change...." (from paragraph 1(b) of Article 4); and

- Developed country Parties "shall adopt national polices and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic [man-made] emissions of greenhouse gases....by the end of the present decade...." and shall communicate "....detailed information on its policies and measures....with the aim of returning....to their 1990 levels these anthropogenic [man-made] emissions of carbon dioxide and other greenhouse gases." (from paragraph 2(a) and (b) of Article 4). Legal examination of this commitment concluded that this commitment is merely a call toward an aim to greenhouse gas stabilization but it does not bind the Parties to it.

Earth Summit at Rio de Janeiro - June 3-14, 1992

The UN Conference on Environment and Development was held in Rio de Janeiro in June 1992 and this conference is generally referred to as the Earth Summit. The FCCC received signatures from over 162 governments during and soon after the Earth Summit.

Ratification of the FCCC

Article 24 of the FCCC requires ratification by 50 member states for it to enter into force (i.e., a legally binding agreement). The INC was dissolved after the FCCC entered into force on March 21, 1994. The Conference of Parties (COP) then took over the responsibility for future negotiations and in the implementation of the FCCC. This date marks the first time that an international law specifically addresses the causes and effects of climate change. 159 countries have ratified the FCCC as of June 6, 1996.

First Session of the Conference of Parties (COP1) - April 5-7, 1995

The COP met during the March 28 to April 7, 1995 FCCC meeting in Berlin, Germany. This first session of the COP is generally referred to as COP1. At this session, the COP reviewed the adequacy of paragraph 2(a) and (b) of Article 4 (i.e., the aim to reduce greenhouse gas emissions to 1990 levels by the year 2000) in the FCCC against the current scientific facts on climate change and concluded that these paragraphs are not adequate in meeting the ultimate objective of the framework convention.

Therefore, the COP adopted an agreement to begin a process to enable it to take appropriate action for the period beyond 2000, including the strengthening of the commitments of the Parties through the adoption of a Protocol or another legal instrument. This agreement is generally referred to as the **Berlin Mandate** and it called on the developed country Parties "to set quantified limitation and reduction objectives within specified time-frames, such as 2005, 2010, and 2020, for their anthropogenic [man-made] emissions....of greenhouse gases...." To initiate the process of establishing this Protocol, the COP established the Ad Hoc Group on the Berlin Mandate (AGBM) with the objective of working toward the adoption of a Protocol at the third session of the COP.

Second Session of the Conference of Parties (COP2) - July 18-19, 1996

The COP met during the July 8-19, 1996 FCCC meeting in Geneva, Switzerland. This second session of the COP is generally referred to as COP2. At this session, the COP noted that although the developed country Parties are fulfilling their commitments to implement national policies and measures on the mitigation of climate change, additional efforts are needed to achieve the aim of returning their emissions of man-made greenhouse gases to 1990 levels by the end of the present decade. Table 1 and 2 show the compilation of greenhouse gas emission inventories submitted to the COP by the Parties, including Canada's, for the period 1990-1994 and on the projected inventory for the year 2000, respectively.

At this meeting, the AGBM reported its progress to the COP. Parties were invited to submit concrete proposals on polices and measures for a Protocol (or another legal instrument) to the AGBM by October 15, 1996.

Table 1. 1990-1994 inventory of man-made greenhouse gas emissions (CO_2 equivalent, excluding land-use change and forestry)

	(kilo-tonnes)	(percentage relative to 1990)			
PARTIES	**1990**	**1991**	**1992**	**1993**	**1994**
Australia	465,305	---	---	---	---
Austria	75,286	---	---	---	---
Bulgaria	123,755	---	---	---	---
Canada	577,954	99	102	103	106
Czech Rep.	196,551	---	---	---	---
Denmark	71,770	104	103	103	103
Estonia	46,479	96	73	55	57
Finland	67,114	100	91	92	102
France	494,032	104	101	99	---
Germany	1,241,509	94	90	90	---
Greece	94,888	---	---	---	---
Hungary	104,082	---	---	---	---
Iceland	3,227	95	92	94	---
Ireland	63,757	---	---	---	---
Italy	563,117	---	---	---	---
Japan	1,206,523	102	103	101	---
Latvia	27,640	---	---	---	---
Liechtenstein	265	---	---	---	---
Luxembourg	12,123	---	---	---	---
Monaco	71	---	---	---	---
Netherlands	220,346	102	102	101	103
New Zealand	80,266	99	101	99	100
Norway	52,235	96	92	96	100
Poland	614,300		73		
Portugal	51,045	---	---	---	---
Romania	253,152	84	72	75	---
Russian Fed.	3,078,892	---	---	---	---
Slovakia	71,900	---	---	---	---
Spain	310,070	---	---	---	---
Sweden	75,573	---	91	---	95
Switzerland	58,196	103	100	98	97
U.K.	724,754	101	97	94	94
U.S.A.	5,842,371	99	101	102	103

(*data from UNEP-IUCC web site - October 1996*)

Notes: 1990 data based on inventory previously reported by the Parties to the COP.
Some Parties (e.g. Bulgaria, Hungary, and Poland) has chosen different base year than 1990. Some figures are adjusted from temperature and electricity trade (e.g. Denmark, and Netherlands.).

Table 2. Projected man-made greenhouse gas emissions (kilo-tonnes as CO_2 equivalent, excluding land-use change and forestry) in 2000 and as percentage variation from 1990 base level.

	(kilo-tonnes)		Variations
PARTIES	**1990**	**2000**	**% from 1990**
Australia	465,275	512,811	+10.2
Austria	75,944	81,844	+7.8
Bulgaria	112,213	101,011	-10.0
Canada	547,324	607,085	+10.9
Czech Republic	178,848	148,056	-17.1
Denmark	71,660	66,106	-7.8
Estonia	37,800	17,500-23,000	-53.7 to -39.2
Finland	67,734	84,158	+24.2
France	510,857	498,643	-2.4
Germany	1,220,884	1,057,343	-13.4
Greece	94,888	107,288	+13.1
Hungary	83,506	77,536	-7.1
Iceland	3,227	3,094	-4.1
Ireland	63,757	70,968	+10.6
Italy	557,640	597,200	+7.1
Japan	1,221,850	1,244,815	+1.9
Latvia	27,640	20,197	-26.9
Liechtenstein	208	245	+18.1
Luxembourg	12,081	8,471	-30.3
Monaco	---	---	---
Netherlands	219,214	206,761	-5.7
New Zealand	76,480	77,560-77,950	+0.9 to +1.9
Norway	52,322	54,627	+4.4
Poland	---	401,386-518,386	---
Portugal	38,689	54,274	+40.3
Romania	---	---	---
Russian Federation	2,330,000	1,930,000-2,026,000	-17.2 to -13.0
Slovakia	70,891	60,330	-14.9
Spain	222,908	276,523	+24.1
Sweden	75,625	79,310	+4.9
Switzerland	52,401	50,552	-3.5
United Kingdom	746,520	704,220	-5.7
United States	5,944,684	5,975,064	+0.5

(*data from UNEP-IUCC web site - October 1996)*

Notes: 1990 Projection data are different from Inventory data in Table 1 because:
-projections for all gases were not reported by some Parties.
-some Parties (e.g. Bulgaria, Hungary, and Poland) has chosen different base year than 1990.
-some figures are adjusted from temperature and electricity trade (e.g. Denmark, and Netherlands.).
-all data are subject to revision at the next reporting period

Next Step

Negotiations took place during the December 1996 meeting of the AGBM on the draft text for the legal instrument. The AGBM is continuing with further substantive negotiations on the draft text with a scheduled completion of the text for adoption at the third session of the COP at Kyoto, Japan during December 1-12, 1997. The legal instrument is expected to contain quantified objectives for emission limitations and significant overall reductions of man-made greenhouse gases within certain specified time-frames, such as 2005, 2010 and/or 2020.

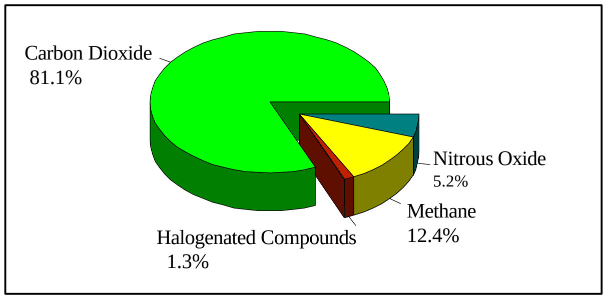
CANADIAN FEDERAL RESPONSE TO THE FCCC

Current Trends on Canadian Emissions of Greenhouse Gases

Canada has about 0.56% of the world's population but contributed to just over 2% of the global emission of man-made greenhouse gases. In 1995, about 77.3% of Canada's man-made greenhouse gas emissions (as carbon dioxide equivalent) were energy related (i.e., burning of fossil fuels) with stationary and mobile (e.g. transportation) sources accounting for 50.7% and 26.6% of this total respectively. This large percentage points to an energy strategy as an essential element of any action plan. Another 15% of man-made greenhouse gases emitted in 1995 was from industrial processes.

The quantities of greenhouse gases emitted in British Columbia, Yukon Territory and Canada from 1990 to 1995 are shown in Table 3. The quantity of greenhouse gas emissions in the 1990 base-year was relatively low primarily because of the mild winter and the recession at that time. It is estimated that Canada emitted about 9.4% more greenhouse gases in 1995 than the 1990 level. Figure 1 illustrates the different types of greenhouse gases that were emitted in 1995 in Canada. The 1995 data and any modification to the previous years' data will be submitted to the COP in April 1997.

Figure 1. 1995 Canadian inventory of greenhouse gas (as CO_2 equivalent) emissions in Canada.



(*based on 619,000 kilo-tonnes of total emissions, data from Environment Canada*)

NOTE: Halogenated Compounds (exclude those controlled under the Montreal Protocol) include: CF_4, C_2F_6, SF_6 and HFCs.

Table 3. 1990 to 1995 Greenhouse Gas Emissions* (kilo-tonnes of CO_2 equivalent) in British Columbia, Yukon Territory and Canada.

	Year	1990	1991	1992	1993	1994	1995
BRITISH COLUMBIA	Stationary Combustion	20,000	19,300	18,100	20,500	20,200	22,400
	Mobile Combustion	19,400	19,800	20,700	21,100	22,500	23,900
	Industrial Processes	4,640	4,740	4,840	5,220	5,680	5,760
	Agricultural Sources	1,170	1,160	1,270	1,260	1,250	1,330
	MSW Incineration	257	161	166	170	174	179
	Other Sources	3,980	3980	3,680	3,650	3,060	3,060
	Total	49,447	49,141	48,756	51,900	52,864	56,629
YUKON		NA	NA	557	465	468	565
CANADA		566,000	559,000	575,000	581,000	598,000	619,000

*CO_2 emissions from combustion of biomass are not included; *data from Environment Canada*)

NOTES: MSW = municipal solid waste. 1995 data are preliminary. Finalized 1995 data (+ adjustment to prior years') data will be submitted to the COP in April '97. All data are subject to correction, contact Environment Canada for latest version.

Canada's International Commitments

To maintain the momentum at the Earth Summit until a sufficient number of countries have ratified the FCCC, Canada outlined its Quick Start Agenda to challenge other countries to take immediate action on ratification of the FCCC; submission of national action reports and other activities. Canada provided its signature to the FCCC during the Earth Summit on June 12, 1992. The Council of (Canadian) Energy Ministers and the Council of Canadian Ministers of the Environment (CCME) gave support for early ratification of the FCCC in September and November 1992 respectively. The Prime Minister signed the ratification to the FCCC on December 4, 1992 in Delta, B.C.
Under Article 4 and 12 of the FCCC, Canada is required to prepare a national communication on our implementation of the Convention. A draft of the original national communication titled the *"Canada's National Report on Actions to Meet Commitments Under the United Nations FCCC*" was released for public comment in September 1993. This draft document was finalized as the *"Canada's National Report on Climate Change*" (CNRCC) and it was approved by the federal Cabinet and submitted to the COP in February 1994. Following changes to the FCCC guidelines for preparation of national communications, Canada tabled a second national communication titled: "*Canada's National Action Program on Climate Change*" (NAPCC) at the COP1. The NAPCC was reviewed by a subsidiary body of the COP and a report on the in-depth review of the national communication of Canada was published by the COP Review Team on February 21, 1996. Some of the findings of the Review Team are:

- "Canada is making a considerable contribution to the scientific understanding of climate change";
- "45% of Canada is covered by forest...., it seems that it shifted from being a large net sink to becoming a lesser net source of emissions around 1990. Pests and forest fires are contributors to loss of carbon from this reservoir";
- Among OECD (Organization for Economic Cooperation and Development) countries, Canada has relatively high intensity of energy use per capita (eight tons of oil equivalents in 1990 in Canada vs. 4.8 tons as the OECD average) and high carbon dioxide emission per person (17 tons per person in 1990 vs. 12 tons as the OECD average). Furthermore, "Canada's population growth rate of 1.5% per annum is highest among OECD member countries and this is an important factor behind historical and expected growth in the economy and emissions" of greenhouse gases in Canada.
- Although Canada has committed itself to stabilizing greenhouse gas emissions at 1990 levels by the year 2000, the NAPCC projects a 13% growth in greenhouse gas emissions from 1990 to 2000 unless new initiatives, including those identified in the NAPCC are implemented. "....In order to close the stabilization gap, further options need to be developed", and "if the Government at that time finds that Canada is unlikely to reach its target without more aggressive action, there will be limited time to implement and see the full effects of new initiatives by 2000, even if the NAPCC is seen as a flexible instrument allowing for prompt action."

Canada has reaffirmed that the COP must accelerate work toward a post-2000 Protocol or other legally binding instrument at COP3.

Canada's Domestic Commitments

Aside from the commitments under the FCCC, Canada has stated an aim of lowering carbon dioxide emissions by 20% from 1988 level by the year 2005. This additional commitment was originally stated in the Green Plan (1990) and later restated in the Liberal Party Red Book (1993) and by the federal Minister of Environment's speech at the COP1 in 1995.

Canada's Domestic Actions Plan

Canada first established a Canadian Climate Program in 1979, following the first World Climate Change Conference. In 1990, the federal Green Plan outlined federal government's actions as part of the National Action Strategy on Global Warming. The CCME approved the Comprehensive Air Quality

Framework for Canada in 1993 and established a Climate Change Task Group which reports to the National Air Issues Coordinating Committee. In May 1994, the federal Cabinet directed the Ministers of Environment and Natural Resources to develop the NAPCC with a mix of voluntary, regulatory and market-based instruments and with associated costs and sources of funding. The NAPCC is to provide a strategic national framework for action. The NAPCC released in April 1995.

The NAPCC is intended to provide all jurisdictions with the opportunity to describe what steps they are taking to deal with climate change. The plan outlines Canada's strategic directions in pursuing the national goal of stabilization and also highlights on-going activities and achievements; new measures (e.g. energy efficiency standards and labeling) that can be implemented immediately; measures that are committed to be undertaken; and those under active consideration for potential future implementation.

One of the new measures is the national Climate Change Voluntary Challenge and Registry (VCR) program which is a joint initiative of federal, provincial and territorial energy and environment departments in consultation with other public and private Canadian organizations. The VCR began in September 1994 and the first annual progress report was released in November 1995. Memorandums of Understanding and letters of cooperation between Natural Resources Canada have been signed with those sectors representing over 50% of Canada's total greenhouse gas emissions. Over 600 industrial companies and associations have signed on to the VCR as of November 1996.

A meeting of the federal, provincial and territorial energy and environment ministers was convened on December 12, 1996 to chart the course ahead. New initiatives announced to strengthen and expand the NAPCC include:

- enhancing the VCR by having higher level commitments and to include more participants from the transportation and commercial sectors;

- implementing energy efficiency regulatory measures in the commercial sector and working toward fuel efficiency in the transportation sector. The Canadian Home Energy Efficiency Rating Systems will also be released;

- promoting the use of alternative energy (e.g. from renewable sources);

- educating and engaging all Canadians by developing a national climate change educational/outreach program to meet the challenge ahead; and

- completing the Canada Country Study by including an integrated assessment of social, biological and economic impacts of climate variability and change in Canada.

Governments to Lead by Example

At the November 1995 meeting of the Joint Environment and Energy Ministers' meeting, each provincial/territorial government tabled its climate change action plan outlining the activities in their jurisdiction. Since provinces hold considerable constitutional authority related to energy production, energy use and transportation, significant reductions in greenhouse gas emissions can only be achieved with their direct cooperation. The B.C. Greenhouse Gas Action Plan was published in November 1995. On December 13, 1996, the B.C. government announced a decision to extend, for an additional three years, the motor fuel tax exemption for natural gas and high-level alcohol blended gasoline. The Federation of Canadian Municipalities 20% Club membership requires a commitment to 20% reduction of 1990 greenhouse gas emission levels by the year 2005. Delta, Kamloops, Port Moody, Saanich, Surrey, and Vancouver are the British Columbia members of the 20% Club.

The NAPCC calls for the governments at all levels to lead by example. In early 1996, the federal Cabinet approved the Federal Action Program on Climate Change (FAPCC) which provides guidance to the federal government on the federal climate change policies for federal government operations. A commitment to purchase 'Green Power' from utilities in Ontario and Alberta was recently announced by the federal government. The FAPCC has some of the same elements in the NAPCC and it is intended to show the federal leadership in living up to its commitments to stabilize greenhouse gas emissions from federal facilities to 1990 levels by 2000 and to reduce emissions by 20% by 2005.

Will Canada meets its Commitment on Emission Stabilization?

At the COP2, the federal Minister of the Environment stated that "like most developed countries, Canada is experiencing difficulty in closing the gap on greenhouse gas stabilization to 1990 levels by the year 2000. Despite efforts to date, current analysis indicates that without further measures, Canada's greenhouse gas emissions at the turn of the century could be about 13% higher than 1990 levels." Excluding land-use changes and forestry, the data in Table 2 show that Canada's greenhouse gas emission in the year 2000 is projected to be about 10.9% higher than the 1990 level.

Much of the projected emission increase results from increased energy usage. This is mainly due to an improved economy and population growth which may offset the benefits from increased energy efficiency. The federal government acknowledged that the stabilization target will not be met even with the implementation of the new initiatives announced on December 12, 1996.

Future Actions

Canada is experiencing difficulties in meeting our commitment on greenhouse gas stabilization and has proposed a number of plans to correct this deficiency. Over this year, the federal government will work with the stakeholders to identify new options and approaches for action. The NAPCC will continue to evolve to ensure Canada meets our climate change commitments. Canada is due to provide an update of its national communication report to the COP in April 1997.

Chapter 22

GREENHOUSE GAS EMISSIONS IN BRITISH COLUMBIA

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OVERVIEW

Most scientists believe that human induced greenhouse gas (GHG) emissions are discernibly influencing our climate. In British Columbia the primary GHG emissions playing significant roles in the "enhanced greenhouse effect" are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), CFC-substitutes and perfluorocarbons (PFCs).

- **Carbon Dioxide -** In the 1990 revised GHG inventory, British Columbia emitted 41 megatonnes (MT) of CO_2; 46.8% from transportation, 23.0% from industrial energy use and processes, 16.6% from residential and commercial uses and 13.6% from fuels for other stationary sources.
- **Methane -** Methane sources are predominantly from landfills {134 kilotonnes (KT)}, upstream and downstream oil and gas operations (58 KT), and the rest from coal mines, prescribed fires, domestic animals and manure. Total CH_4 emission for 1990 was 304 KT (6,384 KT of CO_2-equivalent). *(Inventory methods have improved since the earlier inventory. The earlier 1990 - inventory overestimated the total emissions by 5.5 MT of CO_2 - equivalent mainly due to CH_4 - overestimation. This accounts for the difference between the old 1990-inventory and this revised version presented in this paper.)*
- **Nitrous Oxide -** N_2O amounts to only 7 KT (2170 KT of CO2-equivalent) accounts for 4% of British Columbia's GHG emissions. It primarily comes from transportation, stationary fuel combustion, prescribed fires and very little from fuel wood and fireplaces.
- **Perfluorocarbons** - PFC (i.e. CF_4 and C_2F_6) from aluminum smelting was estimated to be 807 KT of CO_2-equivalent (2% of British Columbia total GHG emissions).

An Environment Canada unpublished report on emission trends in Canada indicates that the British Columbia GHG emissions are over 8% higher in 1994 than the 1990 revised estimate. Preliminary estimates of the 1995 energy related CO_2 emissions are 15% higher than 1990. This is largely due to the rate of population and economic growth and a reduction in the 1990 baseline inventory. This increasing trend is giving a signal that without intensifying and accelerating the implementation of the planned measures, and implementing additional aggressive and collective actions by the federal, provincial and local governments, industries and the public, emissions will continue to increase in the next four years and stabilization will be beyond reach in the near term.

GASES PLAYING SIGNIFICANT ROLES

Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) are the gases playing significant roles in this thermal and radiative phenomenon called “enhanced greenhouse effect” and the resulting global climate change. Scientists believe that increasing emissions and concentrations of these gases in our atmosphere due to human activities cause a discernible influence in our climate.

Chlorofluorocarbons (CFCs) are being used in refrigeration and air conditioning, as aerosols, fire extinguishers, etc. They have long lifetimes and very high global warming potential (GWP). Since the control of manufacture and phase out of CFCs are covered under the Montreal Protocol, and the United Nation Framework Convention on Climate Change (UN-FCCC) only covers the non-Montreal Protocol gases, this paper will not address CFCs.

Although water vapour is the most important radiative gas in preventing heat from escaping the earth’s surface, human beings have no control to change its balance and role in the natural greenhouse effect.

Gases of minor significance include ground level ozone (O_3), perfluorocarbons (PFC), sulfur hexafluoride (SF_6) and many others whose direct and indirect radiative forcing are known to be very small.

PRIMARY GHG AND SOURCES OF EMISSIONS IN BRITISH COLUMBIA

Greenhouse gases (GHG) come from natural and anthropogenic (human-caused) sources. The natural sources are numerous and include wetlands, wild animals, lightning charges, soils, and lakes and rivers.

Contributions and Effectiveness of Greenhouse Gases

The importance of greenhouse gases depends on their concentration in the atmosphere and the strength of the absorption of infrared radiation during their lifetimes.

Radiative Forcing

Radiative forcing (IPCC, 1994) is defined as a change in the average net radiation at the top of the atmosphere due to change in either solar or infrared radiation. It is the overall effect due to each gas on the thermal radiation stream. The total radiative forcing of all greenhouse gases has been determined to be equal to 2.45 Wm^{-2}. Of this total the radiative contribution of CO_2 has been estimated to be 1.56 Wm^{-2}; Methane(CH_4), 0.47 Wm^{-2}; Nitrous oxide (N_2O), 0.14 Wm^{-2}; and CFCs and hydrochlorofluorocarbons (HCFCs), 0.25 Wm^{-2}. Hydrofluorocarbons (HFCs), PFCs and SF_6 contribute very little radiative forcing, but could have impacts in the future due to increasing use of HFCs as substitute to CFCs, increased aluminum production and increased use of SF_6 as a tracer gas.

Global Warming Potential (GWP)

The Global Warming Potential (Table 1) is used to compare the relative effectiveness of greenhouse gases. GWP is defined as the cumulative radiative forcing between the present and late time horizon caused by a unit mass of gas relative to CO_2 as the reference gas. IPCC has recommended a 100-year time horizon for carbon dioxide equivalent calculations and recently a set of revised GWPs as a result of improvements in their determination (IPCC, 1996), particularly the value for methane.

Table 1. Revised Lifetimes and GWPs for 100-year time horizon (IPCC, 1996) of the Primary GHG relevant to British Columbia

Gas	Lifetime (yrs)	GWP
CO2	variable	1.0
CH4	12	21
N2O	120	310
CF4 (PFC)	50,000	6500
C2F6 (PFC)	10,000	9200

Carbon dioxide (CO_2):

Although it is the least effective of the greenhouse gases in terms of its GWP, much more CO_2 is being released globally than any other GHG. Hence, it plays the most powerful role and contributes very significantly to the greenhouse effect. It is primarily a product of combustion of fossil fuels (oil, gas, and coal) used to run motor vehicles, heat homes and produce power.

Deforestation of the world's forests to make way for farmland and provide wood also contributes a significant release of carbon dioxide to the atmosphere. Forests are extremely valuable storehouse of carbon. When logged areas are not reforested, the process of photosynthesis will no longer be available to reabsorb the CO_2 released to the atmosphere. Planting trees is an effective way of sequestering CO_2 and can provide a significant "sink" for CO_2. *(The international community has agreed that CO_2 released from the burning of biomass that has been derived from sustainable forestry will not be counted for the country's emission inventory.)*

Industrial processes (e.g., cement and lime production and natural gas stripping) also release CO_2 to the atmosphere. Since the industrial revolution, global CO_2 concentrations have increased by over 28% from 280 ppm to almost 360 ppm by volume in the 1990s. Concentrations have been increasing at a rate about 0.5% per year and at faster rates in recent years. This rate of increase closely follows the rate of increase in human-induced emissions due to fossil fuel use. British Columbians emit 16.9 tonnes/person of CO_2. This per capita emission is lower than the Canadian average emission of 20.8 tonnes/person due primarily to the province's major electricity source being based on hydropower. Due to Canada's resource based economy, climate and size of the country, its per capita emission ranks as one of the highest in the world. Canadians emit about 2% of the global emission.

Methane(CH_4)

Methane is also called "marsh" gas since it has been seen bubbling from decomposing organic material in marshes. Its major sources are wetlands, natural gas, oil drilling and production, coal mining operation, rice paddies, landfills and from wood and peat burning. Although its concentration is low in the atmosphere, its effect is far from negligible because of its strong radiative effect. Since 1800, its concentration has more than doubled and is increasing at a rate of about 1% per year to the present (about 1720 ppbv).

Nitrous oxide (N_2O)

Nitrous oxide, also known as "laughing gas", is used as an anesthetic. It is emitted as a result of fossil fuel combustion, agricultural operations, and the burning of biomass. Power lines and lightning discharges also create this gas. Its present atmospheric concentration of about 311 ppbv is 8% higher than the pre-industrial level and it is increasing at a global rate of 0.25% per year.

Although its atmospheric concentration is low, it has a long lifetime and a global warming potential more than 300 times more powerful than CO_2.

Other Gases

In British Columbia, aluminum smelting is the only source of perfluorocarbons (PFCs) emissions, such as perfluoromethane (CF_4) and perfluoroethane (C_2F_6).

REVISED 1990 BRITISH COLUMBIA EMISSION INVENTORY

The development of emission inventories is a constantly changing process. Methodologies will change with improved techniques and with additional measured data. These data are Environment Canada's best estimate from currently available information. The emissions are presented in CO_2 equivalent, that is the absolute emission multiplied by the GWP. The nature of inventory analysis is such that there will always be some degree of uncertainty in the data and the information is constantly updated as improved information becomes available.

British Columbia emits about 9% of Canada's total emissions (Figure 1). Ontario and Alberta together account for more than 70% of the national total. In 1990, British Columbia (Figure 2) emitted 41 MT of CO_2; 46.8% from transportation, 23.0% from industrial energy use and processes, 16.6% from residential and commercial uses, 13.6% from fuels for other stationary sources.

CH_4 sources (Figure 3) are predominantly from landfills (134 KT), upstream and downstream oil and gas operation (58 KT), and the rest from coal mines, prescribed fires, domestic animals and manure. Total CH_4 emission for 1990 was 304 KT or 6,384 KT of

CO_2 equivalent. (These data differ from inventory information published in 1990 and reflect changes in the model and accounting methodology.)

In British Columbia N_2O accounts for only 7 KT or 2,170 KT CO_2 equivalent. Major sources of this gas are derived from transportation, stationary fuel combustion, prescribed fires and with minor contribution from fuel wood and fireplaces.

PFC (i.e. CF_4 and C_2F_6) from aluminum smelting was estimated to be 807 KT of CO_2 equivalent.

In 1990 the total GHG emissions were 51,675 KT of CO_2 -equivalent, 80% of which are CO_2, 14% from CH_4 and 6% from N_2O and PFCs (Figure 4).

Figure 1. Provincial CO2 Emissions (1990)

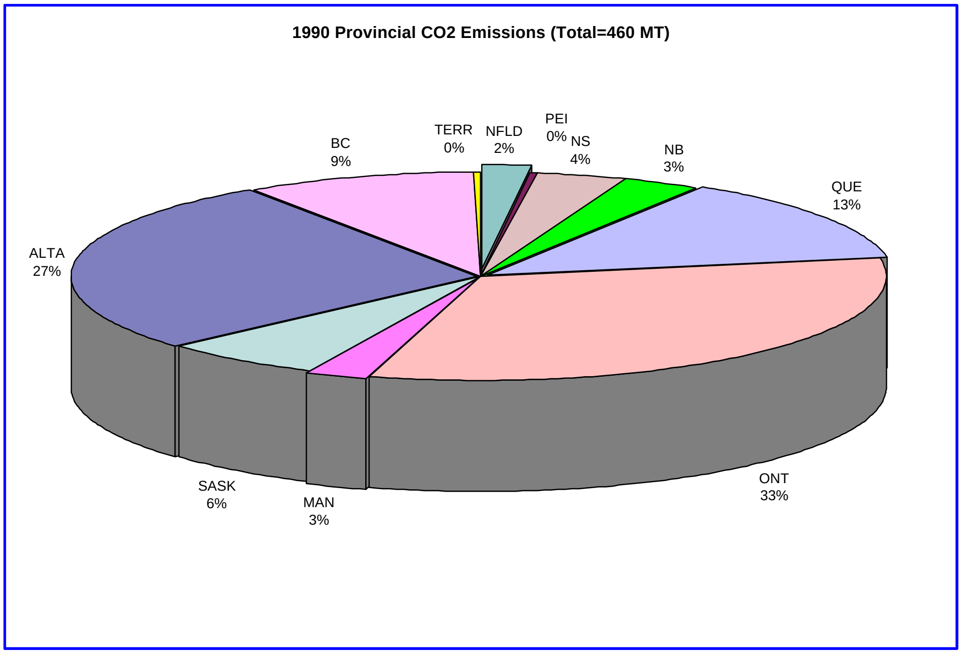


Figure 2. CO2 Sources in British Columbia

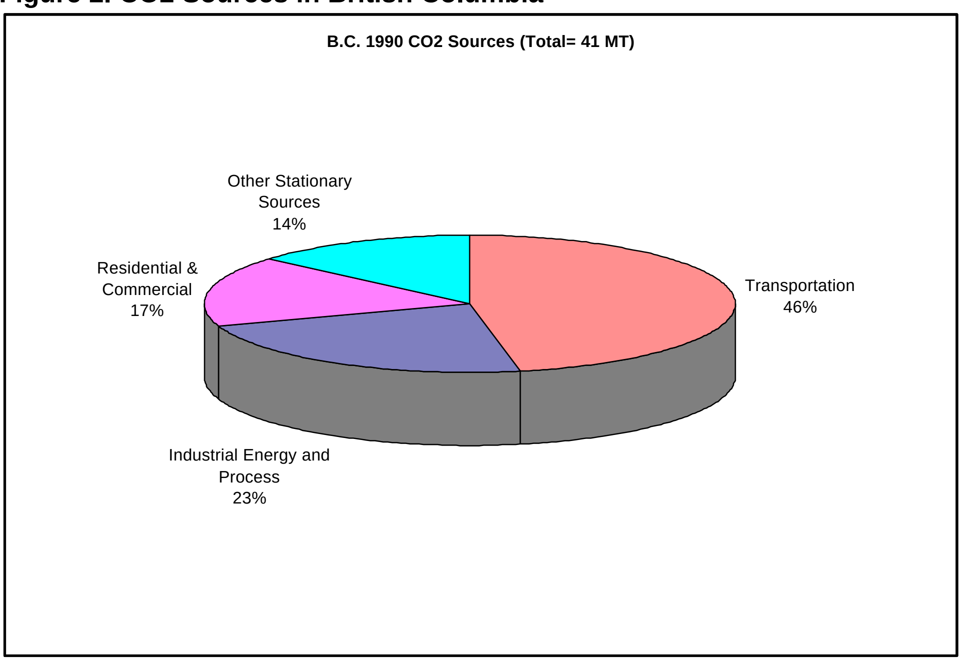


Figure 3. CH4 Sources in British Columbia

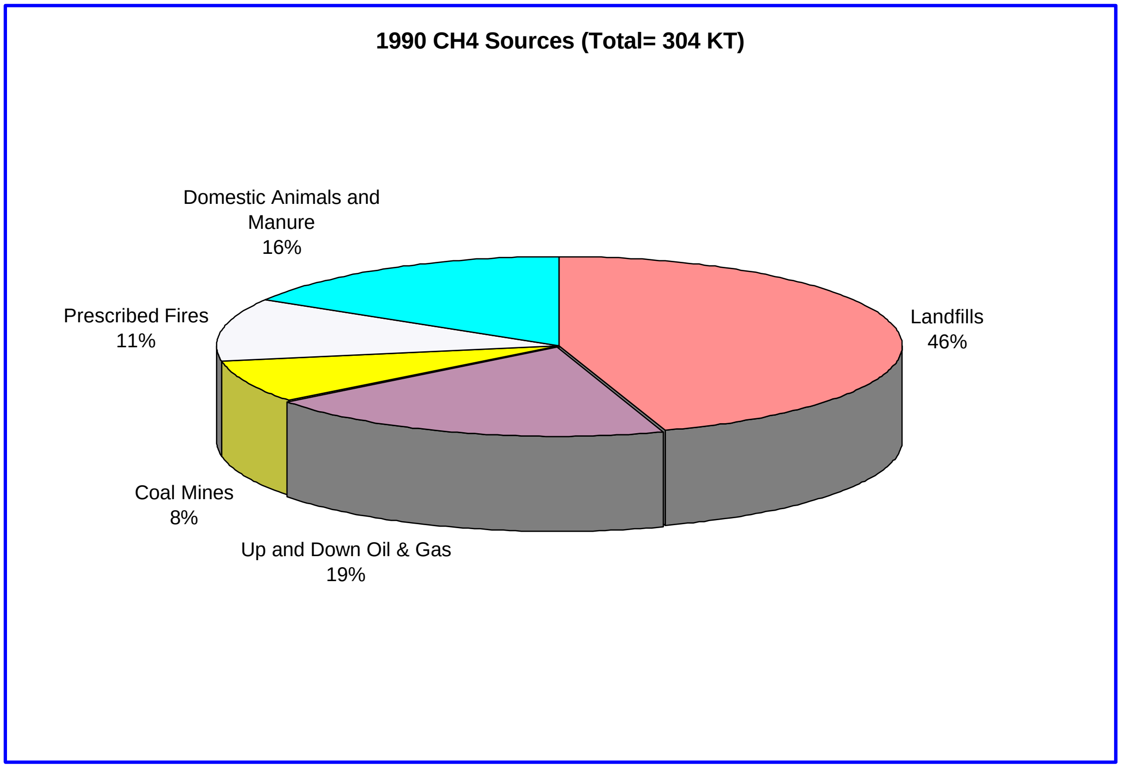
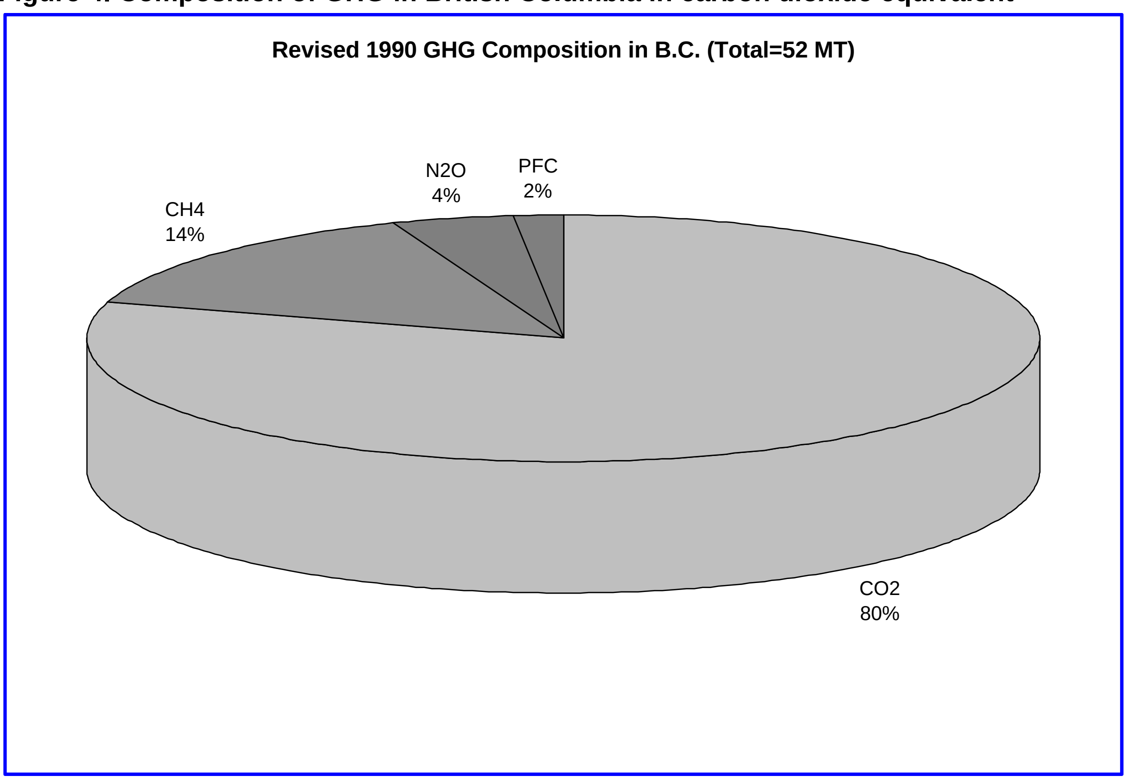


Figure 4. Composition of GHG in British Columbia in carbon dioxide equivalent



TRENDS TO 1994 AND LATER

Canada's total GHG emissions are 8% higher in 1994 than they were in 1990 (Environment Canada, 1996). The World Energy Council reported that there has been a 12% increase in global CO_2 emissions resulting from fossil fuel burning during the period of 1990 and 1995. In British Columbia, emissions from transportation have been consistently increasing since 1990 (Figure 5). The emissions from stationary sources and industrial processes both decreased in 1991 and 1992 but showed increases in 1993 and 1994.

As a result of this increasing trend, the British Columbia GHG emissions are over 8% higher in 1994 than the 1990 revised estimate (Figure 6). Preliminary estimates suggest that the 1995 energy related CO_2 emissions are 15% higher than 1990. This is largely due to the rate of population (Figure 7) and economic growth and a reduction in the 1990 baseline inventory.

Figure 5. Sector emission trends from 1990-1994

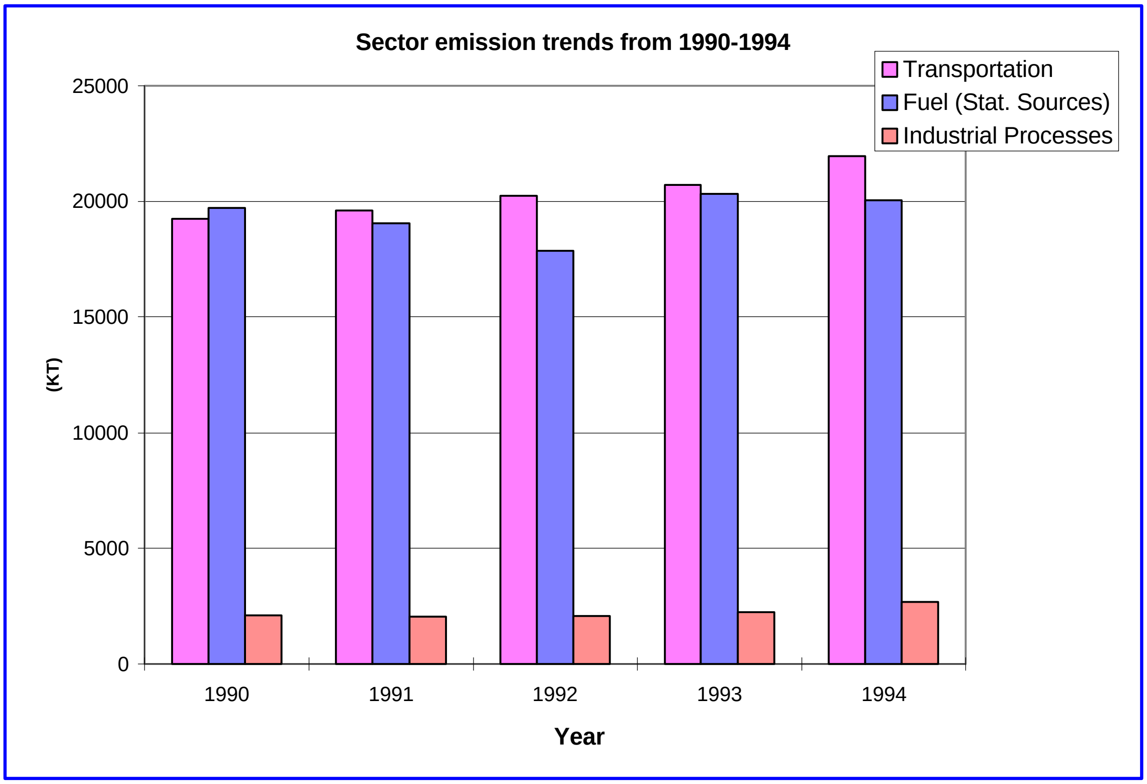


Figure 6. Total CO_2-equivalent difference from 1990.

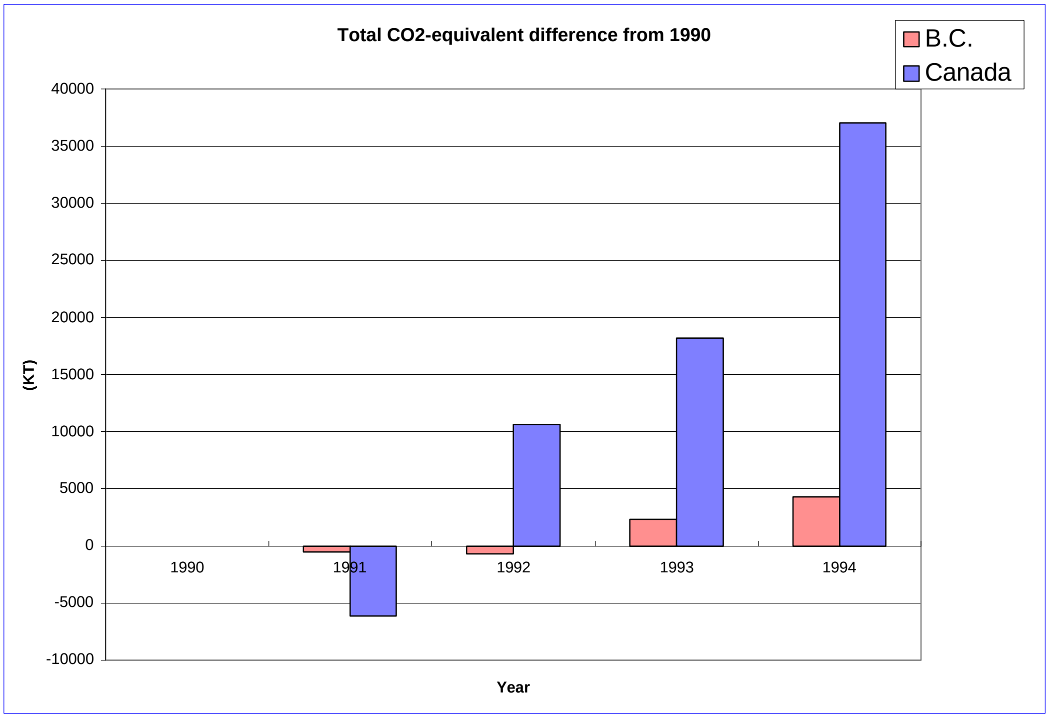
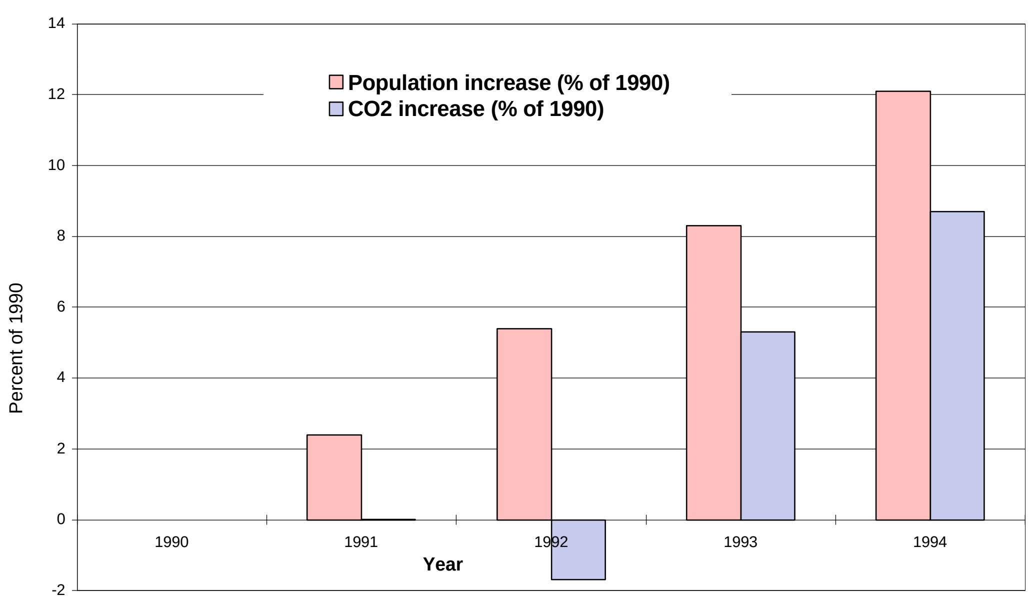


Fig. 7. British Columbia Population and CO_2 emissions from 1990-1994.



BRITISH COLUMBIA REDUCTION STRATEGIES AND ACTIONS

History of Provincial Activities

Some of the earlier provincial GHG activities are:

- Clean Air Strategy Development beginning in 1991
- Greenhouse Gas Workshop held in 1992
- Completed a British Columbia GHG Inventory (First province to complete a provincial GHG emission inventory, 1992)
- The development of the British Columbia Energy Council's Energy Strategy for British Columbia in 1993 and released in 1994.
- A Climate Change Outreach in Vancouver in late 1994, as a part of the development of the National Action Plan on Climate Change.
- Greenhouse Gases Consultation on the development of British Columbia Greenhouse Gases Action Plan in August-September, 1995. This process consisted of Focus Group Meetings of GHG emitters and submissions from a wider general interest group from industries, NGOs, local governments, Crown Corporations and the general public.
- Released the BC GHG Action Plan at the Ministers' Meeting on November 20, 1995.

Strategies and Actions

British Columbia has worked at addressing the issue of greenhouse gases and global climate change since the significance of the potential threat became obvious to many scientists in the Toronto Conference on *The Changing Atmosphere* in 1988. A GHG Inventory for British Columbia and evaluation of GHG reduction measures were completed and published in 1992. In addition, workshops and consultations with stakeholders have been conducted on this important issue since 1991.

British Columbia supports the federal government's commitment and has been leading the way among the provinces and territories in stating its commitment to the goal of stabilizing emissions at 1990 level by the year 2000. All these activities culminated in the development and release of the *British Columbia Greenhouse Gases Action Plan-Meeting the Challenge of Climate Change* at the Environment and Energy Ministers Meeting in November 1995.

BRITISH COLUMBIA GREENHOUSE ACTION PLAN

The BC GHG Action Plan was submitted to Canada's Energy and Environment Ministers at the November 20, 1995 Meeting.The plan is a "living" document in that many actions are already underway and will continue to evolve as benefits and cost of reduction options become clear.

In the plan, it is necessary to find the right mix of actions and players to achieve the provincial goal of stabilization. But because GHGs are emitted primarily from the burning of fossil fuels, many of the measures in the plan are energy related that involve:

- using energy more efficiently
- switching to less GHG intensive fuels
- choosing low- or zero-emission transportation mode.

The plan contains more than 50 actions that the province has implemented, will implement or will evaluate further for the next 2 to 3 years. It addresses all major sources, sectors and potential sinks for greenhouse gases.

To summarize, the plan consists of 8 actions by the Provincial government demonstrating its leadership, 10 actions on energy conservation and efficiency, 9 actions involving transportation, 5 on the energy supply industry, 4 actions on forestry and agricultural GHG sinks, 2 on solid waste management, 6 actions involving cross-sectoral elements, 3 on science, education and awareness, 3 on local government and 4 actions relevant to national activities. (Please refer to the action plan for a complete list.)

In general, the impetus for the early programs and actions taken by British Columbia was not to reduce GHGs, yet the actions have positive implications to GHG management.

Potential Future Measures

The plan includes options for further development that demand more study and extensive consultation, but could ultimately be needed if sufficient progress is not made through planned initiatives, and the public and private sector voluntary actions. Emission trading, offsets, and GHG regulations are examples of possible future measures.

NEXT STEPS

In spite of the controversy underlying the IPCC conclusion of a “discernible human influence on climate change”, the Canadian, U.S. and many national governments support and accept this conclusion.

FCCC objective of stabilization is being perceived by many as likely to fail. Current indication is that very few countries are on-target. Canada’s Environment Minister, the Honourable Sergio Marchi, in a recent speech to the National Press Club, stated “Canada is not doing as well as it should. Period. No excuses. Full stop.” Reaching stabilization is going to be a difficult task. The National Action Program on Climate Change relies mainly on voluntary action and current forecasts suggest that Canada will fall at least 8% short of the goal of stabilizing greenhouse gas emissions at 1990 levels by 2000.

In July 1996 the U.S. Government indicated a change in its position, suggesting they will now support binding international targets. Voluntary initiatives on the part of industry are proving to be ineffective. The new U.S. proposal will likely be put forward at the next series of international negotiations in December 1997. Scenarios could include “quantitatively legally binding objective for emission limitations and significant overall reductions within specified time-frames." Many of the specific details of this proposal are not yet known.

British Columbia is similarly facing a significant challenge to attain the emission stabilization goal in the next four years. Coordinated action with other governments and the private sector is required and must be put forward in a global context. Following the Joint Ministers Meeting in December 1996, British Columbia has initiated a multi-stakeholder GHG forum to prepare the necessary framework and action plans to allow British Columbia to do its part.

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Chapter 23

THE STRATEGIES OF BRITISH COLUMBIA'S FOREST INDUSTRY TO REDUCE NET EMISSIONS OF GREENHOUSE GASES

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OVERVIEW

The Canadian forest industry is actively participating in the voluntary approach to meeting greenhouse gas emission stabilization adopted in the National Action Program on Climate Change. In total eleven companies have filed greenhouse gas (GHG) action plans which include B.C. operations. The plans focus on the sector's largest emitters - the pulp and paper mills - and the dominant source of emissions - the combustion of fossil fuels for energy. Over the period 1990-1995 the industry implemented a number of energy, forestry and environmental initiatives which collectively have reduced the industry's net contribution of GHG emissions to *below* its 1990 level. All of GHG inventories reviewed show a decline in emissions both on an absolute (tonnes CO_2/yr) and on a per unit of production (tonnes CO_2/tonne) basis. The main factor which contributed to these reductions was the industry's decreased consumption of fossil fuels. Since 1990, more fossil fuel energy has been replaced with energy from biomass, processes have become more energy efficient (backing out fossil fuels) and less GHG-intensive fuels (e.g. natural gas) have replaced Bunker C oil. B.C.'s forest industry has reduced its GHG emissions below 1990 levels largely because the industry's energy supply has become less GHG-intensive.

INTRODUCTION

The Forest Industry in B.C. and the Yukon

Canada's forest industry is defined as a combination of industry groups including the forest management industries (e.g. logging, silviculture), solid-wood industries (e.g. lumber, plywood and panelboard manufacturers) and paper and allied industries (pulp mills, newsprint mills and producers of paperboard and fine paper products).

In B.C., the forest industry is one of the province's dominant industries and vital contributor to the economy. In 1994, 75.1 million cubic metres (m^3) were harvested from an area of 190,244 hectares. At this time the industry was comprised of 3,297 logging operations, 607 solid wood operations and 66 paper and allied operations which together produced $14 billion in exports. (NRCan, 1996)

The forest industry in the Yukon is considerably smaller than in B.C. In 1994, approximately 390,000 m^3 were harvested from 2,056 hectares. Logging and lumber manufacturing are the dominant types of forest industry in the territory. The value of exports from the Yukon was $3 million in 1994 (NRCan, 1996).

Different governments manage forest industry activities in B.C. and the Yukon. The provincial government regulates most of the industry activities in B.C., whereas the federal government directs the industry in the territory.

The Forest Industry's Greenhouse Gas (GHG) Emissions

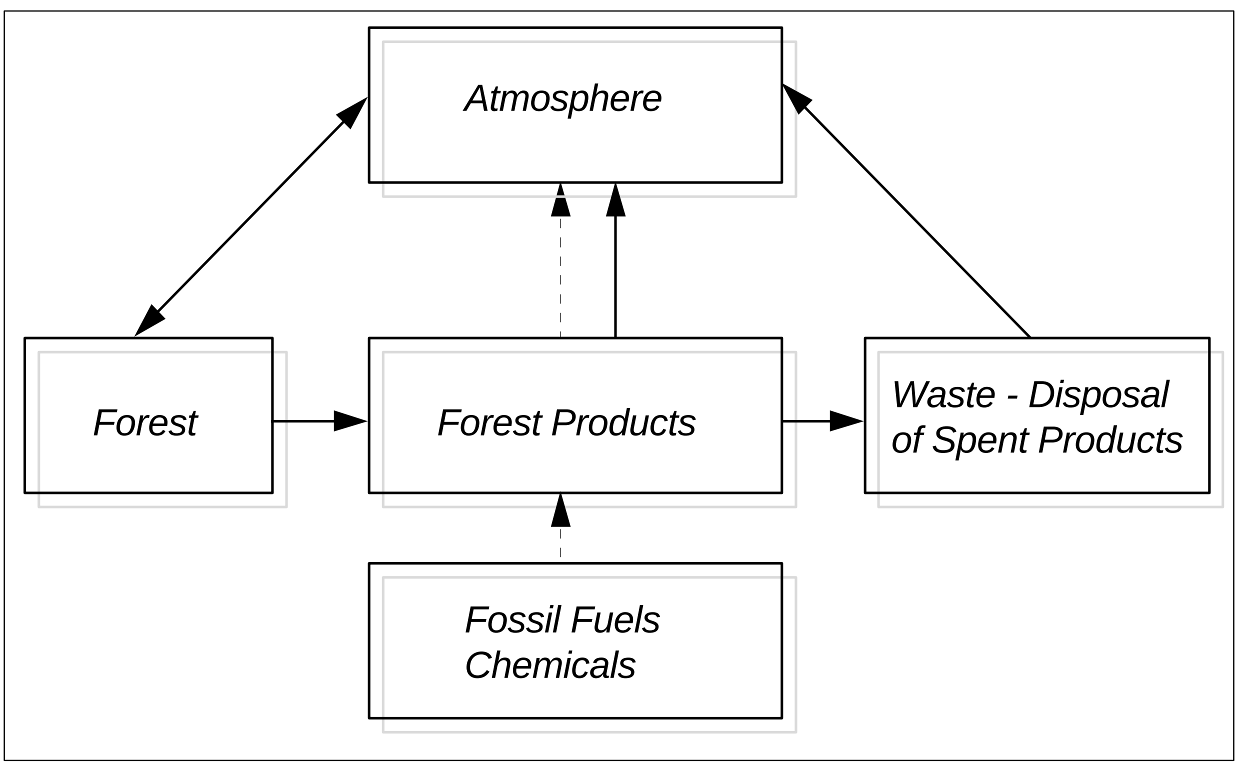
Of the three GHGs (carbon dioxide, methane and nitrous oxide), carbon dioxide is by far the dominant form of GHG emitted by the forest industry.

The forest industry's contribution to anthropogenic emissions of GHGs differs from most other industries because it involves:

- both non-biomass and biomass sources of GHG emissions; and
- sinks, stores and sources of biomass GHGs (part of the terrestrial carbon cycle)

Figure 1 shows the pathways which correspond to the non-biomass and biomass emissions of GHGs.

Figure 1. Schematic of Non-Biomass (dashed line) and Biomass (solid line) Flows



Most of the industry's non-biomass emissions relate to the industry's energy consumption. The majority of these emissions result from the combustion of fossil fuels and use of purchased electricity, a portion of which is generally fossil fuel-derived. A small percentage of non-biomass emissions comes from the industry's use of chemicals and other materials which release GHGs during their consumption. One example is purchased limerock used as a "make-up" chemical in Kraft pulp mills.

In general, the non-biomass emissions are the direct result of a combustion or other chemical reaction. The release of these emissions is estimated (and inventoried) by multiplying the amount of purchased fuel or chemical by a conversion factor.

Emissions from biomass sources are shown in Figure 1 to be both 'taken up from' and 'released into' the atmosphere. Of the three GHGs, only carbon dioxide (CO_2) is believed to be taken up by any significant amount by the forest ecosystem. Consequently, the IPCC Guidelines treat methane (CH_4) and nitrous oxide (N_2O) emissions from biomass sources in the same manner as if derived from non-biomass sources.

The solid line in the schematic describes the terrestrial carbon cycle. Carbon dioxide is taken up by the forest ecosystem, stored as carbon in both the forest and forest products, then released to the atmosphere, primarily in the forms of CO_2 and CH_4. A portion of biomass carbon is released from decaying slash and prescribed burning, from combustion in beehive burners and from combustion for steam and electrical energy at the mill-site. The majority of the carbon is converted into a variety of short and long-lived products ranging from newsprint to structural lumber to antique furniture. Eventually, the paper and wood products are either incinerated or landfilled, and the biomass carbon is returned to the atmosphere.

It is not difficult to see that CO_2 emissions from biomass sources follow a very different path than CO_2 from non-biomass sources. IPCC guidelines state that if the biomass is derived using sustainable forestry practices then there should be no net CO_2 released to the atmosphere. Canada's national and provincial inventories assume sustainable forestry is practiced and do not include CO_2 from biomass as part of Canada's total GHG emissions. Forest companies have also adopted this guideline in the preparation of their corporate inventories.

FOREST INDUSTRY ACTION RELATED TO GLOBAL CLIMATE CHANGE

Forest Industry Position

The Canadian forest industry supports the _voluntary_ approach to meeting the stabilization target which was adopted in the National Action Program on Climate Change.

While this paper focuses on the B.C.-Yukon region, the forest industry's approach to the climate change/greenhouse gas issue has been developed at a national level. The Canadian Pulp and Paper Association, through its Forest Practices Task Force, prepared its first statement on climate change in 1991 and updated the statement in 1995. The pulp and paper industry supports a mitigative strategy which incorporates "voluntary programs, energy conservation, use of renewable biomass fuels, sound stewardship of the renewable forest resource, efficient use of harvested wood and long-term use of paper and solid wood products". In addition the industry "attaches high priority to reducing the existing scientific uncertainties associated with global climate change". (CPPA, 1995)

Industry Activities Related to Climate Change

While the Association completed a number of activities between 1990 and 1995 (CPPA, 1996b), it would be fair to say that the climate change issue was not of top priority for most of the industry. The environmental sustainability of Canada's forestry practices and products was the subject of intense international scrutiny during this period. Consequently, most of the industry's energies were directed to the improvement of forest management practices and modification of its manufacturing processes, in particular, chemical pulp bleaching.

In the early part of the decade several forest companies started to include the climate change issue on their corporate environmental agenda. In 1990, MacMillan Bloedel Ltd. became a founding member of the B.C. Carbon Study which was chaired by Dr. Patrick Moore. As a participant, MacMillan Bloedel Research conducted a carbon life-cycle assessment of its operations in the Alberni Region of Vancouver Island. E.B.Eddy Forest Products Ltd., one of the first companies to produce sustainability reports, demonstrated vision with its discussion of climate change as a sustainability issue. In 1995, the first year of the Voluntary Challenge & Registry (VCR) program, four companies (Avenor Inc., Canadian Forest Products Ltd., E.B. Eddy Forest Products Ltd., Kruger Inc.) submitted greenhouse gas action plans.

Industry Response to the National Challenge

The real jump in forest industry action came in 1996. The CPPA's Global Climate Change Task Force actively encouraged all forest companies to participate in the VCR and Canadian Industry Program for Energy Conservation (CIPEC) programs. The Association developed guidelines to "facilitate preparation of action plans by forest companies and provide a consistent, comparable and transparent reporting system". (CPPA, 1996a) As a result, 24 parent companies, representing 68 % of Canada's total production of pulp and paper, have registered with at least one of these programs. What has been most impressive is the number of companies which have prepared GHG action plans: 21 out of 24 registered companies.

Listed in Table 1 are the eleven forest company plans filed with the VCR which include facilities and operations located in B.C. (Note: No forest company plans include operations located in the Yukon.) The plans account for over half of the pulp mills in B.C. Several companies have included their solid wood product operations (i.e. sawmills, plywood mills, oriented strand board mills). MacMillan Bloedel Ltd. included the GHG emissions associated with its woodlands and raw materials divisions operating in B.C.

B.C. GREENHOUSE GAS ACTION PLANS

Company Commitments

Overall, the forest companies have not made very strong commitments to address the climate challenge. All companies have stated that they will investigate opportunities for greenhouse gas emission reduction within their operation. Having said this, all forest companies that have submitted GHG action plans to the VCR indicate they have either stabilized or reduced their GHG emission relative to 1990.

Three companies have gone a step further and made the commitment to voluntarily reduce and/or stabilize their company's GHG emissions at 1990 levels by the year 2000. These companies are: Avenor Inc., E.B. Eddy Forest Products Ltd. and Weyerhaeuser Canada Ltd.

Table 1. Pulp and paper companies with GHG action plans (CPPA, 1996b)

Parent Company/Company	B.C. Facilities Included in Action Plan
Avenor Inc.	Gold River
Canadian Forest Products Ltd.	Howe Sound; Prince George; Sawmills
Crestbrook Forest Industries Ltd.	Skookumchuck Pulp; Sawmills
E.B. Eddy Forest Products Ltd.	Island Paper
Eurocan Pulp & Paper Co.	Eurocan Pulp
Fletcher Challenge Canada Ltd.	Crofton Pulp & Paper; Elk Falls Pulp & Paper; Mackenzie Pulp
MacMillan Bloedel Ltd.	Alberni Specialties; Powell River Paper; k3 Specialties; Solid Wood (Lumber, Woodlands, Raw Materials)
Northwood Pulp and Timber Inc. (Noranda Forest Inc.)	Northwood Pulp and Timber Inc., Prince George Mill; Sawmills; wood preserving plant
Repap Enterprises Inc.	Repap British Columbia
Weldwood of Canada Ltd.	Cariboo Pulp and Paper; Quesnel Plywood mill
Weyerhaeuser Canada Ltd.	Kamloops; Sawmills

Corporate GHG Inventories

With one exception, the GHG action plans, including inventories, were prepared at a corporate level. Over half of the inventories are segregated by province and/or facility.

Shown in Table 2 is the change in CO_2 emissions for B.C. facilities and operations over the period 1990-1995. The data were compiled from the individual plans which do not all report GHG emissions in the same units.

The focus in virtually all of the GHG inventories is on the companies' pulp and paper mills - the largest consumers of energy and largest sources of GHG emissions. (It is estimated that the solid wood industries consume approximately one tenth of the energy used by the pulp mills.) The data in the right hand column of the table represent CO_2 emissions associated with the combustion of fossil fuel. Secondary or indirect emissions associate with purchased electricity are not included.

The trends in GHG emissions are encouraging. All inventories show a decline in GHG emissions over the period 1990-1995 both on an absolute (tonnes CO_2/yr) and on a per unit of production (tonnes CO_2/tonne) basis. Similar results are observed at the national level.

The main contributor to this reduction in emissions is the industry's decreased reliance on fossil fuels. Over the past five years, more fossil fuel energy has been replaced with energy from biomass, processes have become more energy efficient (backing out fossil fuels) and less GHG-intensive fuels (e.g. natural gas) have replaced Bunker C oil. The industry's energy supply has become less GHG-intensive.

Table 2. Change in GHG emissions (1990-1995)

B.C. Facilities With GHG Action Plans	**Change in GHG Emissions from 1990 Levels**
Avenor Inc. (B.C.): Gold River	Reduced Emissions: 226 to 75 kt CO_2/yr 1.51 to 0.33 t CO_2/tonne
Canadian Forest Products Ltd. (B.C.): Howe Sound; Prince George; Sawmills	Reduced Emissions: 530 to 498 kt CO_2eq/yr (Howe Sound) 1.28 to 0.31 t CO_2eq/tonne (Prince George) 0.52 to 0.39 t CO_2eq/tonne (Sawmills) 47 to 39 t CO_2eq/10^6 bdft
Crestbrook Forest Industries Ltd. (B.C.) Skookumchuck Pulp; Sawmills	Reduced Emissions: 124 to 120 kt CO_2/yr
E.B. Eddy Forest Products (B.C.): Island Paper	Reduced Emissions: 67 to 64 kt CO_2/yr
Eurocan Pulp	Reduced Emissions: 149 to 150 kt CO_2/yr 0.44 to 0.37 t CO_2/tonne
Fletcher Challenge (B.C.): Crofton Pulp & Paper; Elk Falls Pulp & Paper; Mackenzie Pulp	Reduced Emissions: 997 to 523 kt CO_2eq/yr (3 mills) 0.65 to 0.36 t CO_2eq/tonne
MacMillan Bloedel Ltd. (total Canada)	Emissions not broken out by province; Reduced Total Company Emissions: 646 to 401 kt CO_2/yr
Noranda Forest Inc. (total Canada)	Emissions not broken out by province; Reduced Total Company Emissions: 823 to 770 kt CO_2/yr
Repap British Columbia*	Reduced Emissions: 6.18 to 5.26 t CO_2/adtonne
Weldwood (B.C.) Cariboo Pulp and Paper; Quesnel Plywood mill	Reduced Emissions: 175 to 126 kt CO_2/yr (Cariboo Pulp) 0.62 to 0.40 t CO_2/adtonne
Weyerhaeuser Canada Ltd. (total Canada)	Emissions not broken out by province; Reduced Total Company Emissions: 607 to 530 kt CO_2/yr

* It is suspected that biomass CO_2 is included in these numbers.

GHG Management Measures

Most of the forest companies list the management measures which have contributed to the reduction in GHG emissions. However only a few report the associated GHG reduction potentials.

The management measures, as with inventories, concentrate on opportunities to reduce energy consumption and/or use less GHG-intensive energy. As the GHG savings incurred with the switching from fossil fuel to biomass depend on whether or not the biomass has been sustainably harvested, several companies have included descriptions of their forest management projects.

Energy-Related Measures

The main types of energy-related measures that have been implemented and/or are planned for B.C. facilities include:

- Increased use of biomass fuels for energy which displaces fossil fuels and purchased electricity reducing both direct and indirect GHG emissions.
  Examples of applications are: changes to the hogfuel (wood residue) boiler which allow more hogfuel to be burned; changes to the recovery boiler which allow more black liquor to be burned; upgrading the turbogenerator so the mill can self-generate more electrical energy; fuel conditioning to improve the energy value of hogfuel and sludges; converting a fossil fuel system to burn biomass (e.g. tall oil).

- Reducing total mill energy demand which reduces the demand for fossil fuels and purchased electricity.
  Applications range from BC Hydro's Powersmart initiatives, to process changes, to major mill modernization projects. Examples include: improved process efficiency (e.g. paper machines), low grade heat recovery, installation of more energy efficient equipment (e.g. variable frequency drives, adjustable speed fans), preventative maintenance programs.

  Note: While the majority of projects have improved the energy efficiency of a certain segment of the process, additional pollution control requirements (e.g. secondary treatment) have in some cases increased the mill's total energy demand.

- Increased substitution of GHG-intensive fossil fuel (e.g. heavy fuel oil) with less GHG-intensive fuel (e.g. natural gas).
  The construction of the natural gas pipeline to Vancouver Island provided a "new" opportunity for facilities on the Island to use natural gas. Additional, albeit smaller, opportunities for conversion also exist.

Forestry-Related Measures

As stated at the beginning of this section, in order for companies to claim the benefits of switching from fossil fuels to biomass, the biomass must be derived using sustainable practices. In other words the emissions from biomass must be balanced with the uptake by biomass to release 'zero net CO_2'.

Ways of maintaining this balance include "ensuring rapid regeneration of harvested sites; protecting forests from fire, insects and disease; reducing carbon loss from the forest floor and soil; making efficient use of harvested fibre; producing products with long lifespans from harvested wood; and promoting long term use of forest products through recovery, recycling and reuse". (CPPA, 1996b)

Several of the policies enacted in B.C. over the last years were not intentionally brought into balance with the carbon budget but they are in fact helping maintain this balance. The reduced use of prescribed burning and open burning, the phase-out of woodresidue incineration in teepee burners, the use of diverted woodresidue for energy and fibre (e.g. sawdust pulping, medium-density fibreboard), and the implementation of more sustainable forestry practices are having positive benefits with respect to the carbon cycle.

Note: Those who believe human-induced climate change has already begun, or will soon manifest itself warn, that forest ecosystems including the carbon cycle will be affected. The rate and form of such climate change will define the level of impact on ecological cycles. Consequently, the requirements for maintaining the carbon balance may need to be adjusted.

In the terrestrial carbon cycle, ultimately all of the biomass carbon taken up by forest growth is returned to the atmosphere. While in theory there is no net loss or gain of carbon over time, it is believed that the rate of carbon cycling, the rates of 'uptake from' and 'release to' the atmosphere, can be changed. As the forest carbon cycle can store carbon for many decades and even centuries, it is thought by some that there are management strategies which have the potential to "buy us time" while permanent ways to reduce GHGs are found.

The proposed strategies to increase the amount of carbon taken up from the atmosphere and the length of time carbon is stored (sequestration) fall into three categories:

- Forest management; Different types of forest management can affect the rate of CO_2 uptake from the atmosphere and the length of time carbon is stored in forest ecosystems. A certain portion of the forest resource could be managed intensively to increase carbon storage.

- Harvest and conversion of harvested fibre; the types of forest harvest and harvesting method, and what product the harvest fibre is converted into can affect the length of time carbon is stored.

- Consumer use and disposal of forest products; How long the consumer uses the purchased products and how the spent product is ultimately disposed of can effect both the rate and type of emissions (CO_2 or CH_4) returned to the atmosphere. Product recycling increases the size of the product pools whereas disposal in landfills releases the product as CO_2 and CH_4 over several decades.

As many countries are preparing to negotiate legally binding agreements, the interest in such strategies is increasing. Strategies to increase 'temporary storage' of carbon are being explored as potential offsets to rising GHG emissions.

ISSUES FACING THE FOREST INDUSTRY

As we approach the start of a new millennium, the forest industry is facing a number of policy issues which could have significant consequences for industry operations in Canada.

International Challenge of Legally Binding Agreements

The climate change issue is driven by agreements made at international levels. In preparation for the Third Conference of the Parties to be held in late 1997, countries are evaluating the implications of possible legally binding protocols that establish GHG emission commitments for the post-2000 period.

As Canada's land mass encompasses approximately 10 % of world's forests and the country is a major exporter of forest products, international agreements are certain to impact this sector. Through its participation in a non-government advisory committee, the industry is keeping involved with international discussions, particularly those with the U.S. - a major trading partner and chief player in these negotiations. Some of the topics which are expected to be deliberated over the next months are: GHG emissions trading, GHG emissions accounting (including forestry and land use) and formal credits for joint implementation projects.

'B.C. Specific' Issues

In addition to meeting the requirements of international climate change agreements, B.C.'s forest industry is facing several specific challenges.

The implementation of the numerous environmental and forestry policies in B.C. over the past five years have come with a substantial price tag. Speakers at a recent conference hosted by The Fraser Institute warned that the full costs of these initiatives have not yet been felt (Fraser Institute, 1996). In addition, the Government of B.C. is committed to the settlement of land claims. While the majority of people would like to see these negotiations completed they are expected to be both lengthy and costly.

From an environmental perspective, there remains an unanswered question as to what are the GHG implications of harvesting old growth forests with long natural rotations. The issue, raised several years ago by Dr. Mark Harmon, continues to be asked by the environmental community.

As these issues are not simple in nature, both government and industry in B.C. will have to wisely allocate the resources needed to develop effective solutions. There are a number of important issues on the table including the forest industry's competitiveness in the global market.

CONCLUSIONS: NEXT STEPS

On an industry level, the forest industry will need to provide input to the international climate change negotiations. In particular, the industry will need to assess the potential implications of proposed commitments and to communicate its findings to Canada's negotiating team.

As large energy users, the forest industry has an opportunity to play leadership role by demonstrating that the industry can use energy more efficiently, increase the use of biomass to meet its and others' energy needs and reduce its consumption of fossil fuels and purchased electricity. As co-stewards of the forest resource, the industry also has an opportunity to minimize impacts of its forest management activities on the carbon cycle.

In terms of future planning, it is in the industry's best interest to keep abreast of latest predictions of future climate and to examine what effects climate changes could have on the health and productivity of forest ecosystems.

At company level, forest companies should implement the measures specified in their action plans, with the expected release of government guidelines for "Tier 2" level action plans in the Spring of 1997, companies will likely have to set stronger goals and objectives, and more vigorously explore opportunities to reduce net emissions of GHGs.

EXTERNAL REVIEW

This paper was reviewed by Brian McCloy, Vice-President, Environment and Energy, Council of Forest Industries (COFI). Mr. McCloy is a member of the Canadian Pulp and Paper Association's Global Climate Change Task Force and serves as a forest industry representative on the Non-Government Advisory Committee on Climate Change. Revisions which result from Mr. McCloy's review will be included as an addendum in the final publication.

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Chapter 24

FOREST MANAGEMENT AND CLIMATE CHANGE

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OVERVIEW

Forest management decisions made now will effect forests many decades into the future. Thus it is important for managers to take account of how forests may respond to future climatic conditions. Unfortunately, the picture of what the climate will be at specific locations and times in the future is not clear. Even less clear is the picture of how organisms will respond. Consequently, management actions to address climate change must be flexible and such that they do not compromise the health of the forest should the climate not change as predicted. Actions will further be complicated by differing values placed on forests by society, disagreement on whether impacts of climate change are positive or negative, and the priority of governments for addressing other impacts. Also, there will be increased pressure to manage forests to offset emissions from the burning of fossil fuel and to moderate the effects of climate change on non-timber resources.

This task of planning for the unknown is not as daunting as it may seem. The first step requires policy makers and resource managers to accept that change is probable and that responses can be developed. Incorporating responses into forest management planning requires:

- A clear definition the problem, that is, the level of change at which action is needed.
- The determination of the sensitivity of forest organisms to changing climate.
- The development of management responses to be implemented when the changes occur, and implementation of actions needed now.
- Monitoring of forests to assess if and when changes are occurring.

Disturbances of forests, such as harvesting and forest fires, provide opportunities for forests to adjust to the changing climate. The success of adjustment will depend on factors such as the sensitivity of species to climate change and the availability of alternate species. We may be capable of aiding managed forest and commercial tree species to adjust to a changing climate; however, in parks and wilderness areas we will probably have to 'let nature take its course'. Forest management already addresses many of the problems, such as fire, disease, insects and reforestation failures, that will occur under a changed climate; it is the location and extent of the problems that will change. New species cannot be planted in anticipation of future climatic conditions because the current conditions would not be suitable. It may be possible to plant new ecotypes that grow well under a range of conditions and thus produce forests that can tolerate a changing climate.

We need to improve our knowledge of the sensitivity of species and ecosystems to climate, to continue provenance trials in different climatic regimes, and to develop adaptive management strategies. Physiologically based models of plant and animal response to weather should be linked to ecosystem level models to predict impacts. Current initiatives to ensure healthy forests, maintain biodiversity and minimize fragmentation of habitat will help buffer the effects of climate change. Some impacts of climate change will be easier to deal with than others, and there will be surprises ahead. However, established forests are resilient, and there should be time to adapt to many potentially negative impacts. Social changes will be significant. Society will need to revise its expectations of, and demands on, forests, and there may be adjustments required by groups whose livelihood is based on the use of forests.

INTRODUCTION

Can we manage forests to help them adapt to future climate changes? We have only a hazy picture of what climate changes may occur and an even less clear understanding of their impacts on forests (Waterstone, 1993; Houghton et al., 1996; Michaels, 1996; Loehle and LeBlanc, 1996). This uncertainty probably discourages most forest managers from even considering the issue, even though the decisions they make now will have repercussions many decades in the future. A previous symposium on Forest Management and Climate Change (Wall, 1992) concluded that forest managers can and must respond to possible future changes in climate. The delegates recommended that managers:

- Accept that climate change is probable, and that actions have benefits now.
- Maintain healthy, diverse forest ecosystems, and develop adaptive management techniques.

What would pro-active responses by forest mangers involve? I describe a framework for response (based on that in Spittlehouse, 1996) and give some examples. These thoughts are preceded by a section describing the environment under which responses would be developed.

FACTS & ASSUMPTIONS

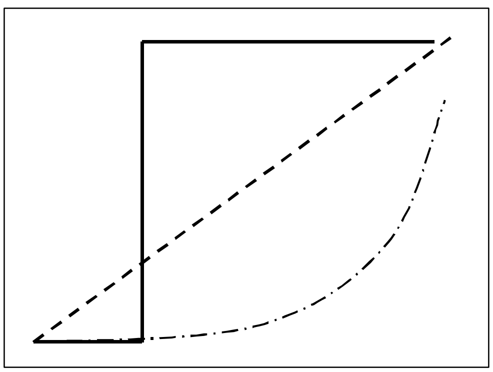
I believe that we will see the equivalent doubling of the atmospheric carbon dioxide concentration in the next 50 to 100 years. The importance of fossil fuel use to the global economy means that we are unlikely to see significant reductions in emissions in the near future (Waterstone, 1993). The Inter-governmental Panel on Climate Change (Houghton et al., 1996) concluded that a 2 to 4° C warming of British Columbia and the Yukon's climate and accompanying changes in precipitation and weather patterns are likely to occur by the end of the next century. However, we are uncertain of the timing, magnitude, spatial distribution and variability of the changes. Some people believe that we are already experiencing human induced changes in climate.

Public policy has to consider more than just climate impacts. Population changes, economic growth, health, education and safety have the highest priority. Society has a large financial and social investment in the status quo and may view the cost of doing nothing as less than the cost of responding. Whether changes are positive or negative depends on society's values (Watson et al., 1992; Waterstone, 1993). An important time frame for forest management is the rotation age of the stand. However, forestry activities are driven by current economics, and a five-to-ten year time horizon may be the major factor in decision making (Sandenburg et al., 1987). Thus, support will be limited for forest management actions targeted to adapting to climate changes that may occur 50 years from now.

Information on past climates and associated vegetation communities (paleoclimatology and paleobotany) and computer simulations have been used to predict impacts of future climate change on forests. The paleo-studies are useful for showing the kind and magnitude of changes that could occur. However, different variables are driving future climate change, and there is a much different landscape (e.g., disturbance regime) than existed centuries ago. Much of the work modelling the response of vegetation to climate change is inadequate. A major concern is that most models are not physically or physiologically based. Henderson-Sellers (1994) shows that although simple vegetation/climate models agree on present vegetation regimes, they produce widely different responses to the same climate change scenario. Loehle and LeBlanc (1996) believe that ecologically based models are, among other concerns, programmed to make forests overly sensitive to climate change. Eamus and Jarvis (1989), de Bruin and Jacobs (1993) and Friend and Cox (1995) show the need to consider physiological responses of the vegetation over short time steps and interactions between variables. For example, increasing atmospheric carbon dioxide induces partial closure of stomata, thus reducing transpiration and increasing water use efficiency. Spittlehouse (1996) showed how, over a few kilometres, site factors could produce quite different responses of tree growth to reduced rainfall. Most simulations of vegetation response are driven by a specific climate scenario. Therefore, they are of limited use for forest management if this climate scenario does not occur, or, if significant response is likely to occur before the new climate is achieved. Bonan et al. (1990), Clark (1991), Clark and Reid (1993), Working Group II (1995) and

Spittlehouse (1996) note the need to assess sensitivity to changes in climate. Sensitivity will vary with species, ecosystem and climate variable. For example, Figure 1 indicates that different management actions would be required depending on the sensitivity to climate change (shape of curve) and the degree of climate change (distance along the x-axis).

Figure 1. Hypothetical responses of organisms and ecosystems to climate change. The dashed line shows a linear response to climate. The dotted and dashed line describes a non-linear response, with sensitivity increasing as the change in climate increases. The solid line describes a catastrophic response to climate change.



Despite their limitations, paleobotany and the computer models can be used to get a broad view of the impacts of climate change on British Columbia's forests (Leverenz and Lev, 1987; Pollard, 1991; Working Group II, 1995; Hebda, 1997). The rate of climate change will be one of the most important criteria in determining how well organisms adjust. There will be changes in the frequency of weather induced disturbances, e.g., fires and pests. There will be shifts in ranges of organisms northward, and upward in elevation. Forests at the edge of their range are likely to be affected first, giving us an opportunity to assess changes and responses before more productive forests are negatively affected. Because species rather than ecosystems move, we could see new mixes of species (Leverenz and Lev, 1987; Bonan et al., 1990; Clark, 1991; Working Group II, 1995; Hebda, 1997). There could also be significant impacts on forest based communities in terms of changes in access time to sites for harvesting, appropriate harvesting methods, species to be harvested, and allowable annual cuts (Pollard 1991; Working Group II, 1995; Rothman and Herbert, 1997).

Disturbance, 'natural' or anthropogenic, provides an opportunity to adjust to a changing climate (Franklin et al., 1992; Veblen and Alaback, 1996). Non-commercial forests, such as parks and wilderness areas, will be extremely difficult to manage for change to meet society's expectations because intervention is not usually part of the management strategy (Pollard, 1991; Peters and Lovejoy, 1992). In this case, society may have to 'let nature take its course'. This will also be the case for non-commercial species in managed forests. Most tree species occupy a wide climatic range, and, although the reforestation stage can be extremely sensitive to climate, established forest trees are resilient and already withstand large interannual variations in weather conditions. Site conditions, e.g., soil depth and topography, moderate the above-ground climate thus extending plant ranges. A patchwork of age classes and ecosystems over the landscape will aid adaptation. Competition by species more suitable to the new climate will not be immediate because it will take many years for them to migrate to new areas. The lighter seeds of many hardwood and non-woody species are likely to disperse further and faster than the heavier conifer seeds. In some situations, there will be an improvement over existing conditions. For example, a gain in productivity through warmer temperatures in presently cold areas may more than offset increased losses to disease and fire. The increased carbon dioxide concentration may result in an increase in water use efficiency and growth of plants (Eamus and Jarvis, 1989; Bonan et al., 1990, Spittlehouse, 1996: Loehle and LeBlanc, 1996).

The importance of moderating the rate of increase in the atmospheric carbon dioxide concentration has implications for forest management (Pollard, 1991). There will be increased pressure to manage forests to offset emissions from the burning of fossil fuel, and forestry will be required to minimize net losses of carbon dioxide and other greenhouse gases to the atmosphere through harvesting and wood processing. Unlike the rest of the developed world, most of British Columbia's harvest is in old-growth forests with the potential for a net loss of carbon dioxide from these sites over the next rotation. British Columbia's forested estate is presently a sink for carbon, but the rate of gain in carbon is decreasing as a result of natural and anthropogenic disturbances, and the aging of the forests (Kurz et al., 1996). Management options may be further complicated by the need to manage forests to moderate the effects of climate change on non-timber resources such as fish habitat and domestic water supplies.

MANAGEMENT RESPONSE FRAMEWORK

Do we just react to changes when they occur, or prepare now to respond to these changes? We are planning for the unknown - we do not know when changes will occur but have some general idea of what to expect. Policy makers and forest managers must accept that climate change is probable and that it can be addressed. Policy makers can create an environment to manage for change and direct research towards aiding adaptive management. Forest managers have to develop and apply plans for responding to climate change. Assessments will be important and aid targeting of limited resources (Sandenburg et al., 1987).

Development of a response plan requires a framework for the analysis (Spittlehouse 1996):

- Identify the issue of concern and the degree of change in forests that would be considered a serious problem.
- Determine the sensitivity of forests to changes in climate, and the impacts of potential future climate changes.
- Develop management responses which include actions to be taken in the future, and actions required now to facilitate future response.
- Monitor forests to determine if changes are taking place, and if thresholds for intervention have been reached.

Global climate model simulations can be used as a guide when defining the problem, e.g., what will happen if the future climate is warmer and drier. Given such a scenario, the management concern is what to do after disturbances such as harvesting, fire, disease, or a drastic reduction in productivity have occurred. These disturbances provide an opportunity for adapting the forest to the new climate. Decisions must be made as to which changes can be managed and which must be left to work themselves out. It is probable that the latter situation will be the case in much of British Columbia.

Forest management already addresses problems such as fire, disease, insects, and reforestation failures that are likely to occur under a changing climate. It is the location and extent of the problems that will change. Consequently, many of the forest research and management activities required to address climate change are useful now and are part of current actions. Management prescriptions must be flexible and not compromise the health of the forest if the climate does not change as predicted (Pollard 1991). Greater emphasis may be placed on managing so as not to limit the options for the non-timber resources. Alternate tree species cannot be planted now in anticipation of future climatic conditions because the current conditions are not suitable. However, it may be possible to plant ecotypes that grow well under a range of conditions and thus produce forests that can tolerate a changing climate. Human adaptations to climate change include changing our expectations and demands on forests. Leaving migration corridors and reserve areas may be the only way to address unmanaged ecosystems and wildlife within a managed landscape. Existing forest health, tree growth and biodiversity monitoring programs may need to be modified so as to be able to discern the impacts of climate change (Sandenburg et al., 1987; Peters and Lovejoy, 1992; Working Group II, 1995; Spittlehouse, 1996).

We must ensure that research provides information that will help in managing for climate change. Genetic variability of tree species needs to be evaluated in terms of the climate of the seed source and the climate of provenance trials (e.g., Rehfeldt, 1995; Carter, 1996). The ecological limits of species in managed (limited competition) and unmanaged situations needs to be determined. Process-based models should be used to assess ecosystem sensitivity to changes in climate, and they should be linked to ecological models that account for such factors as inter-species competition and tree death. The models should be based on short time steps because plants and animals respond to day-to-day weather conditions not average annual conditions. We should be assessing impacts of changes in intensity and frequency of extreme events, e.g., repeated years with summer drought (Spittlehouse, 1996).

EXAMPLES OF USING THE FRAMEWORK

The following are four brief examples of possible responses to the many questions that can be asked about managing for climate change. I address only a change to warmer and drier conditions.

Changes in fire frequency

Problem: Warmer and drier conditions may increase the frequency of fires, resulting in more areas with a high fire hazard.

Responses: High quality fire monitoring and attack capabilities. Increased salvage logging of burnt areas, though the volume of wood per hectare may decrease because the increased fire frequency would reduce the average age of the forest (Rothman and Herbert, 1997).

Actions now: We already have an extensive fire monitoring network. We should increase fire-safety consciousness and fire-proofing of buildings in rural areas. There may be opportunities to improve the utilization of wood salvaged after fires. Changing stand structure and species mix may make the forest less vulnerable to extensive fires (Franklin et al., 1992).

Changes in growth and yield of forests

Problem: Warmer and drier conditions may result in reduced growth rates of existing forests in some areas and increased rates of growth in other areas (Working Group II, 1995; Hebda, 1997). This will affect timber availability, and may also affect international sales through greater competition from countries were tree growth has increased.

Responses: Harvest trees earlier in the rotation where growth is declining, and prepare to use small diameter logs (Working Group II, 1995; Rothman and Herbert, 1997). After harvest, sites would be replanted with alternate ecotypes or species. Increased growth rates in some areas may mean an increase in the allowable annual cut and employment, offsetting reductions elsewhere in the province, but requiring relocation of the labour force.

Actions now: Determine climatic regimes of various ecotypes and compare growth capabilities under a range of climates, e.g., provenance testing program. Develop growth and yield models that explicitly assess the effect of climate on tree growth.

Reforestation problems

Problem: Warmer and drier conditions may result in poor survival and growth of seedlings in certain areas.

Responses: Plant drought tolerant stock. Utilize harvesting and site preparation techniques already developed for existing dry environments to improve the regeneration microclimate. Consider planting alternate species.

Actions now: Development of drought tolerant stock (Farnum, 1992). Review provenance trials for drought tolerance of ecotypes. It may be prudent to plant an ecotype that grows well under a range of conditions, or plant stock from a range of genetic sources at a site (Ledig and Kitzmiller, 1992).

Wildlife, non-commercial plant species, wilderness areas and parks

Problem: Forest habitats will change as the forests adjust to the new climate. We cannot expect to have the knowledge and resources to readily establish noncommercial species of organisms in areas where the climate may be more suitable. Intervention through intentional disturbance and reforestation is not a normal activity in wilderness areas and parks.

Responses: Maintain conditions that allow forest organisms the opportunity to respond as best they can (Peters and Lovejoy, 1992). Seed areas with non-commercial species in areas where the climate has become suitable (Working Group II, 1995).

Actions now: Leave migration corridors in managed areas. Maintain healthy and diverse managed forest ecosystems (Pollard, 1991). We should not rely on only protected areas to maintain biodiversity (Franklin et al., 1992).

CONCLUSIONS

I believe that it is possible to develop forest management responses to future unknown climates. This does not mean that we will be able to manage for all negative impacts, or take full advantage of any positive impacts. It is likely that we will have to allow most of British Columbia's forests to adjust to climate change as best they can, and it is only on the more productive, harvestable sites that intervention will be feasible. It will be important to ensure that management activities do not compromise the ability of unmanaged areas to adjust. Managers must accept that climate change is probable and that actions have benefits now. Responses include deciding the degree of change in the forest that constitutes a problem, determining possible solutions, and initiating monitoring programs to determine when intervention is required. Research is needed to identify species and forest ecosystems at greatest risk, and to better quantify the eco-climatic limits and sensitivity of commercial species. Impact analyses should be done using physiologically based models with short time steps, and should determine the impact of changes in intensity and frequency of extreme events. Many actions for responding to climate change are part of current forest management. Provenance trials where trees are grown 100's of kilometres from their source provide information on a species ability to grow under a wide range of conditions. Management to ensure sustainable forestry, maintain biodiversity, reduce fragmentation and preserve habitat also aids adaptation for climate change. The most difficult adjustment will be society's need to revise expectations of, and demands on, forests.

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CHAPTER 25

CLIMATE CHANGE IS EVERYBODY'S BUSINESS

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OVERVIEW

Responding to global climate change must go beyond international agreements and national programs to reduce greenhouse gases. At the local and regional level, adaptation to a changing climate

Adaptation must be done in a way that recognizes the sensitivity and vulnerability of a particular region to climate change and variability. It also requires an understanding of how the various social, economic

stakeholders will be affected. Individual harvesters and managers of renewable resources, conservation areas, and parks, governments, aboriginal communities, land use and transportation planners, and

how to respond to the impacts of climate change. Communities can simply react to climate change when it occurs or they can prepare for the future by lengthening their planning horizons. The challenge will be

REGIONAL IMPACTS ISSUES

Throughout this report on impacts in British Columbia and Yukon, researchers have provided their assessment on a wide range of concerns:

- renewable resources: water resources, fisheries (freshwater, marine), vegetation growth, wildlife, agriculture, wetlands.
- economic development: hydroelectricity, flood risk, energy demand, tourism and recreation, forest management, transportation.
- communities: resource-based (forest, fishery, non-renewables); service (government, corporate, tourism); aboriginal (traditional, wage-based, mixed).

This list could apply, with some variation, to other regions in Canada. These have often been considered as separate components of this issue, but if they are considered together in the context of a *place*, other dimensions of climate change impacts become more visible, and more important.

CONTEXT FOR ACTION

A piece of land fulfills many goals. It can provide food, wood products, transportation corridors, recreation space, energy, shelter, and spiritual value. Since this piece of land can have so many attributes, it also has many stakeholders (residents, land owners, resource harvesters, resource managers, tourists, etc.). These stakeholders may come from a wide range of jurisdictions (local, regional, provincial/territorial, federal, private sector, aboriginal, international).

Climate change will not occur in a vacuum. Other changes will take place at the same time, and these will affect the relationship between climate and this piece of land, or place. These include:

- observations of regional changes in climate and climate-sensitive resources
- current trends in regional population and economic development (regional, national, international),
- changing institutional arrangements
- responses of other governments to climate change
- availability of new technologies to reduce emissions
- current visions (planning horizons) of governments, business leaders, resource managers and other stakeholders.

All of these can influence the region's sensitivities and vulnerabilities to climate variability and climate change. They will also influence how regions, and countries, respond to the prospects of a global scale phenomenon that could affect their climate no matter what they do on their own.

CHOICES FOR A WARMER FUTURE

The Intergovernmental Panel on Climate Change (IPCC) has clearly stated that increasing concentrations of greenhouse gases (carbon dioxide, methane, etc.) will warm our climate. The most direct response to this challenge is the stabilization or reduction of greenhouse gas emissions. The mechanisms for accomplishing this are the subject of considerable technical and political debate, including the international negotiations among the 160 countries (including Canada) that have signed the United Nations Framework Convention on Climate Change.

The other response option, or suite of options, is adaptation. There are many dimensions to this, including the choice of merely reacting to whatever comes. There are opportunities to be proactive, however, and these could provide benefits in reducing vulnerabilities to current climate variations:

- reduce vulnerabilities to extreme events
- respond to changes in renewable resources
- reassess land use choices
- review design and maintenance of infrastructure
- determine potential changes in risk
- lengthen some planning horizons.

The latter is perhaps the most difficult, since this would buck the current trend towards shorter planning horizons and pay back periods which seem to be so prevalent. The climate change issue requires a long term view, whether it be in a government mandate, a forest rotation or the life of a pipeline. Throughout our history, long term decisions have been made, with investments and risks taken on the basis of uncertain information. Is climate change any different?

WHOSE BUSINESS IS IT?

Since there are many stakeholders in the piece of land, or place, all of these can be part of the solution. There is a tendency to assume that national governments are the only actors on climate change, but they are only one of many. Others include:

- major emitters of greenhouse gases
- individual managers/harvesters of renewable resources, conservation areas, parks
- governments, private sector (fisheries, forestry, etc.) & aboriginal communities as partners in co-management
- land use and transportation planners
- designers and operators of engineered structures such as roads (all-season, winter), pipelines, tailings ponds, transmission lines, houses and other buildings

Climate change is more than just an emission control challenge. Others have a stake as well. Climate change really is everybody's business.

QUESTIONS FOR BC/YUKON STAKEHOLDERS

As a result of research already completed in Canada and other countries, including the reports provided in this document, important questions have been identified. Here are a few:

1. Is the climate change impacts scenario a new vision of the future?
2. Could this new vision make a difference to long term planning?
3. Is it possible to adapt proactively, or should we react to whatever comes?
4. Where is it appropriate to intervene?

- professions (e.g. forestry? energy industry?)
- governments at other levels (local? Provincial/territorial? national? international?)

In addressing the need for stronger measures to control greenhouse gas emissions, and whether such measures are worth doing (which is a complex issue dependent on value judgments of many different stakeholders), it is important to know as much as we can about the

Since there are many stakeholders in costs of doing nothing about emissions. Therefore, we must consider another important question:

5. Is adaptation enough….

- if climate becomes less stable (e.g. season length, ice and snow conditions, extreme event frequencies)?
- if wildlife habitats change (e.g. water temperatures, water levels, tree species)?
- if domestic land capabilities change (e.g. agricultural potential improves while spruce production potential declines)?
- if traditional (aboriginal) lifestyles become more difficult to pursue while wage employment becomes available away from home?

CONCLUSIONS

Climate change is a long term issue requiring long term planning. Legal frameworks, development plans, infrastructure and lifestyles have generally been created on the implicit assumption that climate would not change during the lifetime of such creations. If the IPCC conclusion is correct, and so far, no one has successfully challenged this, future climate stability cannot be taken for granted.

A warmer climate is not necessarily a gloom-and-doom scenario, but the reports elsewhere in this document, and in other studies around the world, suggest that if greenhouse gas concentrations continue to increase and the world warms, there will be impacts, and most of them will be negative. Where new vulnerabilities or opportunities are identified, major land use or infrastructure changes would be needed (e.g. coastal zone protection, expanded irrigation networks). Although there have been opinions expressed on the effects of emission control strategies (e.g. new taxes on fossil fuels), the impacts of land use and other changes associated with adaptation are not known. For example, would stakeholders really support expanded wheat farming and associated irrigation networks on land that currently supports a forest or aboriginal wildlife harvesting?

Long term visions are needed to address the climate change issue in a holistic way. There are new questions not only about adaptation to climate variations and extremes, but also about the broader relationship between "global warming", global environmental change (population growth, biodiversity) and sustainability. This is indeed a challenge for all of us.

Post script: I would like to thank the organizers of this workshop for the opportunity to provide some reflections on the climate change issue, especially as it relates to its human dimensions. For the last 7 years, I have served as Project Leader for the Mackenzie Basin Impact Study (MBIS), a broad collaborative research effort to describe the regional implications of climate change for northeast British Columbia and other areas in the Mackenzie River watershed. The research itself was important, but MBIS also included collaboration with various stakeholders in governments, aboriginal organizations and the private sector. I believe that there are some lessons to be learned from this, which apply to the climate change issue throughout Canada.

Chapter 26

GLOBAL CHANGE AND POLICY

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OVERVIEW

Climate change is a complex topic. Its potential ramifications on the planet range from advantageous to disastrous. Scientists have the knowledge to help influence government and industry policy in reducing greenhouse gas emissions or adapting to the coming changes. However, when it comes to communicating this knowledge to the non-academic community, scientists too often are vague about their climate change predictions and couch them in terms of scientific uncertainty and long time horizons. This is of little use to policymakers who rely upon concrete answers and short term results to base their decisions.

Scientists must consciously learn a new language that is understandable and clear for communication with non-scientists. We are all contributing to the climate change problem, either as individuals, regions or countries. It is up to scientists to build an ever clearer picture of the nature of climate change so that policymakers will act with confidence to confront this important challenge.

INTRODUCTION

During the past decade it has been almost impossible to attend a scientific conference without repeatedly hearing comments such as: "We must engage the policy makers", or "Policy makers must pay attention to our science", or even "Why can't those policy makers listen to and understand our science?". You can hear these statements in such diverse meetings as an International Geosphere Biosphere conference in Beijing, or an ICSU Council session in Paris or an Earth Day anniversary celebration in Washington. And we heard it in at least four talks yesterday. In almost all cases there is some measure of disappointment, frustration, or even anger built into the comment. Obviously, something is not working.

Today I would like to take a few moments to look at this interaction and to share with you some thoughts on why things seem to go so well sometimes and so poorly at other times. At the CGCP we have focused considerable effort on this topic.

WHAT IS POLICY?

We think of policy as a set of rules which govern the way we do things – our actions and our behaviour. These rules or the 'policy' hopefully will make things 'better' for the community that has the policy. Better can mean more efficient, more profitable, less dangerous, or in effect something contributory to the well-being of that community. The community itself can be as small as one individual or as large as the population of the Earth. So here we have an immediate challenge: Policy operates effectively under consensus and a consensus of one is much easier to achieve than a consensus of five billion.

Policy is made and administered by selected small groups of people who have been given authority and power, or who have seized it on behalf of a larger community. Their time span is limited, frequently measured in just one or a few years and they are generally expected to make black or white decisions. The policies will obviously set out to favour the 'host' constituency and can be strongly or even violently opposed to some other community. This often contributes to the 'glass house' syndrome, where groups point fingers and lay blame for their own shortcomings at their neighbour's feet. There is extensive communication between the larger community and its leaders and representatives. Sometimes it is a true dialogue, but often things get lost or misunderstood along the way.

SCIENCE AND POLICY

Science is the body of knowledge. We most often think of this in the sense of physical science, in other words measurement and understanding of the physical aspects of our world. We should not forget, though, that there is an equally important body of knowledge in the social science arena. Because social science deals with and stems from people, it is often more compelling and relevant to policy makers than physical science. Historically, the dialogue between the world of physical science and that of social science has been inconsistent at best. This is demonstrated for example by the fact that many nations who adhere to the International Geosphere Biosphere Program of research do not include social scientists in their committees and working groups. This is unfortunate. I am pleased to say that in Canada groups such as the CGCP have been amongst the world's leaders in bringing both groups to the same table. The results have been intriguing and often startling.

Scientists tend to operate within a long time frame. They have substantial intellectual inertia and are frequently reluctant to confirm a position or proof until the evidence is totally overwhelming. Even they will often confuse a non-scientific audience by excessive language designed to display scientific honesty, open-mindedness and integrity. As an example of this, let me remind you that there were overhead view-graphs yesterday which said: …'POSSIBLE GLOBAL WARMING'. If we use this language, is it any wonder that our less initiated listeners get confused?

Many key factors which help of hinder the involvement of science in the policy revolve around the nature 'well-being'. It is easiest when the sense of well-being is personal and quick. Personal well-being involves things such as health, economics and pleasurable gratification. It is easy to incorporate scientific knowledge into policy in the case of an item such as the disease smallpox or polio. The benefit of vaccination is very clear indeed. Where the issue has been longer term and less tangible it has been more difficult to obtain consensus and the progression from scientific knowledge to beneficial policy has taken time.

Examples are the abandonment of DDT and the removal of lead from gasoline and paint. In the area of climate change, actions to counteract ozone depletion have been quite successful and science has contributed substantially to policy in the matter of acid rain. But these initiatives took many years and they demonstrate the difficulty and the time required to bring together larger groups into consensus before policy can be agreed upon and implemented.

The question of ozone depletion is instructive. Here a rather abstract problem has a strikingly emotional factor attached – the potential of skin cancer. Resolution of this issue was also simplified in the developed countries once DuPont, the main supplier round an alternative chemical to replace CFCs in the cooling devices. However, because of concerns related to economic well-being, action in developing countries has been delayed.

THE ROLE OF INDUSTRY

Industry is a widely used term with many different definitions. Broadly used to refers to the collective of individuals and groups who are carrying out some form of economic activity. We must always remember that 'industry' is driven by self-interest and it is usually forced to account to itself on a short-term basis, such as financial statements, etc.

POLICY AND CLIMATE CHANGE

Let me now focus on climate change. Connecting the physical and social science of climate change with policy making is in many ways the ultimate challenge. Here the community is the population of the world, the time span is so long that it appears irrelevant to many, and the relationship to personal well-being is fragmented. Even at the national and regional levels, we must embrace very large groups. There is often conflict between sub-groups and policy shifts will be negative to some. Clearly, responding to this concern will be more complex than ever before.

We know scientific input to policy is critically important. Case histories show it is achievable. We can see that human nature responds best to personal and urgent questions of well-being. Experience has shown that the more complex problems have taken years and indeed decades to move from confident scientific knowledge to effective policy. What then is the future of the science and policy of climate change?

We have made a start. The Framework Convention on Climate Change is a major achievement. And COP1 and COP2 have helped keep the process going. However, we have not yet advanced to the stage where adverse impacts on sub-groups are being accepted in the interest of overall improvement in the collective well being.

WHAT THEN DO WE NEED FOR FURTHER PROGRESS?

First we need ever-improving scientific knowledge. The work of climate scientists around the world including many of you here today is contributing to an overwhelming body of information which demonstrates beyond doubt that the global climate is changing and that mankind is contributing to this change. This research must be continued and enhanced.

Just as the world's economy is becoming increasingly global, so too will policies and regulations governing environmental behavior. This is being displayed by the comments and contents of meetings such as the second Conference of the Parties (COP2) last year and by policy statements made over the past six months by senior officials from several countries, particularly the United States. It is certain that this new trend will include proposals for the use of economic instruments such as tradable greenhouse gas emission permits amongst others. The U.S. already has such a system working for sulphur emissions although the 'market' is still very simple and slow. Of obvious concern will be the nature and amount of permits allocated to different nations and sectors.

At the national level, we must be seriously concerned that Canada, increasingly regarded as a poor performer in terms of emissions, will be constrained to a great extent by restrictions on our allowable levels. On the other hand, as has been pointed out by groups such as the Greenhouse Emissions Management Consortium (GEMCO) here in Vancouver, a free market of emissions permits will provide a procedure whereby there is created a true financial incentive for improved performance and hence offers a business opportunity.

Many scientific statements are fuzzy at best and we can hardly wonder that the audience (including policy makers) is uncertain.

At this meeting today, we have heard speakers say, (1) …"We really don't know what is going to happen" (2) … "people don't listen to us" (3) …"change is probable". Even though it is a unified message from 1600 eminent scientists, the IPCC report still uses language which suggests that there is plenty of room for very real doubt about man's contribution to global climate change. Is it any wonder that policy makers are divided on the appropriate actions, and that society is confused?

Scientific statements related to time are very poor. When scientists project that sea level may rise 4 millimetres per year or that the temperature has climbed on average less than 1 degree over 20 years it is not surprising that these quantities appear insignificant to listeners. The audience lives in a world which relates to this weekend's weather forecast, or to the month-end bank statement. Politicians live in a world where long-term means for many, 'until the next election'.

We must consciously learn a new language, understandable and clear for communication with non-scientists. We can no linger afford the arrogance of expecting the majority to seek out the means of translation. We must find the wording which conveys the message in clear, unambiguous terms. We must get closer to language which clearly identifies different categories and different topics with messages which leave no room for error.

Responding to the challenge of global climate change is a much more complex policy arena than any that has gone before. We are all contributing to the greenhouse gas emissions that are man's main addition to natural climatic change. We do this as individuals, as regions and as countries. Some are contributing small amounts, others much more. We are also all contributing to the soaring world population which further compounds the impact. There is probably no single or simple solution that will not affect someone, a group, a region, or a country in an adverse way.

And so, the scientists involved in the investigation of climate change face a fascinating challenge of immense importance. That includes all of you here today. Your work will continue to build an ever clearer picture of the nature of natural and anthropogenic climate change. But we must learn better how to make this knowledge understood and relevant to all other sectors of our community; the population, the elected representatives and administrators. We must learn how to meet with them, how to communicate with them and how to collaborate with them in changing and improving the way in which we do things. We, the scientists, must accept the task of bringing science into the realms of policy.

APPENDIX 1

CLIMATE CHANGE SCENARIOS FOR BRITISH COLUMBIA AND YUKON

PART 1. USER'S GUIDE FOR CLIMATE CHANGE IMPACTS

PART 2. BACKGROUNDER: CHARACTERISTICS AND LIMITATIONS OF GENERAL CIRCULATION MODELS

PART 3. CLIMATE CHANGE PROJECTIONS FOR THE LATTER HALF OF THE 21^{ST} CENTURY DUE TO DOUBLING OF ATMOSPHERIC CO2 CONCENTRATIONS

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PART 1. USER'S GUIDE FOR CLIMATE IMPACT STUDIES

Purpose

The purpose of this User's Guide is to make GCM information accessible to users involved in climate impacts studies. The document has several objectives:

- To make available mean monthly or mean seasonal temperature and precipitation scenarios from three different GCMs: CCC GCMII equilibrium model, GFDL transient model, GISS transient model.
- To provide some assistance in interpreting the results of these models.
- To indicate the limitations and caveats of the application of these scenarios based on what is currently known about GCMs.

More detailed information about GCMs and their application may be found in the "Backgrounder" which accompanies this guide.

Interpretation of Climate Change Charts

Charts depicting mean seasonal temperature and precipitation changes from three GCMs for British Columbia and Yukon are attached.

Temperature Changes: Temperature changes are expressed as the difference between the doubled carbon dioxide (CO_2) experiment ($2xCO_2$) and the control run ($1xCO_2$). The difference ($2xCO_2$-$1xCO_2$) is contoured in one degree intervals. Shading becomes darker with increasing values such that darker areas indicate the regions of greatest warming.

Precipitation Changes: For precipitation, the ratio of the $2xCO_2$ and $1xCO_2$ simulations expressed as a percentage of base ([$2xCO_2$-$1xCO_2$] / $1xCO_2$ *100%) is shown, contoured at 10% intervals. As with temperature, darker shades of gray represent higher values. Areas which are expected to be drier are indicated with lighter shading and wetter areas with darker shades.

Application of Climate Change Scenarios

Because GCMs lack sufficient resolution to accurately represent the present climate on a regional basis, the method recommended by the Intergovernmental Panel on Climate Change (IPCC) for producing future climate scenarios is to use GCM differences and ratios in conjunction with historic station data. The method assumes that any systematic errors in the control run are also present in the $2xCO_2$ run and therefore not present in the difference.

Temperatures. The procedure is to adjust station data by the *DIFFERENCE* between the $2xCO_2$ and base temperatures ($2xCO_2$ - $1xCO_2$). This temperature difference may be obtained directly from the climate change charts.

Precipitation. Station data are multiplied by the *RATIO* of the $2xCO_2$ to $1xCO_2$ simulations ($2xCO_2$/$1xCO_2$). An exception to this method concerns the application of precipitation ratios to dry regions where the effect of applying a percentage to a low or zero value may produce unrealistic results. In that case it may be advisable to obtain precipitation differences rather than ratios. NOTE: The precipitation change displayed on the contoured charts is expressed as a percentage of base. Thus, a projected 25% increase in precipitation is the equivalent to a ratio of 1.25, and a projected 25% decrease corresponds to a ratio of 0.75.

Historical climate baseline data may be obtained from Environment Canada. Climate data for over 2000 Canadian stations are archived in various forms including hourly, daily, and monthly summaries. Stations with sufficiently long periods of record are included in the Canadian Climate Normals. Thirty-year climate means are published and updated every 10 years. The current Normals are for the 1961-90 period although the 1951-80 Normals are also suitable for use with the GCMs included here.

The attached climate charts, when used in conjunction with the 1951-80 or 1961-90 Climate Normals, are considered valid for the latter half of the twenty-first century. While this may at first seem vague or too broad, there are a number of reasons why we are unable to identify a more precise valid period for the scenarios (see Backgrounder).

Caveats and Limitations

GCM resolution is still fairly crude (e.g. 600 km. for the CCC GCMII). At this scale, GCMs are incapable of simulating the topographically induced climate features of mountainous regions such as British Columbia and Yukon. Users are advised to exercise caution in applying the GCM climate scenarios to small areas as well as geographically diverse regions including mountains and coastlines.

The uncertainty inherent in GCMs is reflected in the differences among various GCM scenarios. Users should not put too much faith in any one model, but rather should consider the full range of possibilities expressed by several different models. These differences may be particularly problematic for estimating changes in precipitation since some models simulate increases while others simulate decreases for the same region. At the present time, there is no means of resolving these inconsistencies.

The base maps used to prepare the climate change charts are in units of latitude and longitude. Lines of longitude which naturally converge toward the poles appear parallel on the map. This projection is true only at 60°N, so the shapes and areas of the map are distorted in proportion to their distance from 60°N. Areas north of 60°N appear relatively large, and areas to the south of 60°N appear relatively small.

The GCMs should be regarded as plausible future climates or climate projections rather than climate forecasts. Despite the realism of the GCM scenarios, the models still contain too much uncertainty to be considered accurate predictions of the future climate.

Further Information

Further assistance may be obtained from the following sources at Environment Canada.

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PART 2. BACKGROUNDER: CHARACTERISTICS AND LIMITATIONS OF GENERAL CIRCULATION MODELS (GCMs)

INTRODUCTION

Global climate change, resulting from rising concentrations of atmospheric greenhouse gases, is gaining increased attention from many environmental and economic sectors within Canada. To assess the impacts of climate change within these sectors requires some knowledge about the possible future state of the climate. Climate change scenarios produced by General Circulation Models (GCMs) are widely accepted as a basis for making projections about the magnitude and timing of climate change.

This paper is a companion to the User's Guide for Climate Change Impact Studies which was prepared to assist impacts researchers in interpreting GCM climate change scenarios. The types and characteristics of GCMs, their potential application in impact studies, and their limitations and uncertainty are discussed.

It is not a purpose of this paper to evaluate the relative merits of the various GCMs. Nor does it attempt to explain the difference among the models in terms of their physical and mathematical formulations. For a thorough review of GCMs in current use, the reader is referred to the scientific publication entitled "Contribution of Working Group I to the Second Assessment Report of the IPCC" (IPCC, 1995).

MODELLING THE EARTH'S CLIMATE

The earth receives its energy from the sun. This energy heats the lower atmosphere and the Earth's surface and drives the water cycle, atmospheric winds and ocean currents. However, much of the long wave radiation emitted back to space by the Earth's surface is absorbed within the atmosphere by so called greenhouse gases which include carbon dioxide (CO2), methane, water vapour, ozone and nitrous oxide. The amount of warming of the atmosphere is proportional to the concentration of greenhouse gases and their radiative properties. Since a great deal of heat is absorbed by the ocean, there is a lag between the climate forcing due to the rise in greenhouse gases and the climate response.

Over the past several decades, a long term increase in greenhouse gases has occurred primarily as a result of human activities. Since the industrial revolution, global concentrations of CO2 have increased from roughly 280 parts per million (ppm) to 358 ppm by 1994 (IPCC, 1995).

Another influence on climate, which in some regions acts to mask the effects of greenhouse gases by cooling the Earth's surface, is the increase in the presence of atmospheric aerosols. Aerosols are fine particles and very small droplets having both natural and human origins. Natural causes of aerosols include dust storms and volcanic activity, while human origins include industrial activities involving fossil fuel emissions and biomass burning. Particularly important are sulphate aerosols, which directly affect the climate by reflecting and scattering back to space some of the incoming solar radiation. These aerosols also affect the climate indirectly by modifying the optical properties of clouds (IPCC, 1995). Such aerosols tend to be concentrated over their source regions such as industrial areas, thereby masking the effects of global warming regionally. However, these regional affects can also influence the pattern and average amount of global change.

GCMs are mathematical representations of the physical laws of conservation of momentum, mass, moisture, and energy to create a detailed three dimensional model of the climate system. GCMs are capable of performing climate simulations based on varying concentrations of greenhouse gases, but none of the climate change scenarios described here includes the regional cooling effects of aerosols.

AN OVERVIEW OF GCMs

Included here are scenarios of three GCMs: Environment Canada's second generation CCC GCMII (Boer et al., 1992), Princeton University's Geophysical Fluid Dynamics Laboratory (GFDL) GCM (Manabe et al., 1991), and NASA's Goddard Institute for Space Studies (GISS) GCM (Russell et al., 1995; Hansen et al., 1983). Each GCM produces a unique climate change scenario according to its particular mathematical and physical formulations. Differences among the simulations of different models, particularly on a regional scale, reflect the inherent uncertainty in the climate model predictions.

A conventional GCM experiment involves comparing climate simulations under base (1xCO2) conditions and doubled CO2 (2xCO2) concentrations. GCMs produce estimates of climatic variables for a set of global grid points. The GCM is first run under base radiative conditions, known as the control run, to attempt to reproduce the recent climate. Values for temperature (degrees C) and precipitation (millimetres/day) and a large number of other climate variables are computed for each grid point. To the degree that a model reproduces a good approximation of observed climate values is a measure of our confidence in the GCM to simulate future radiative forcing under conditions of doubled CO2. The GCM is then run under increased CO2 concentrations and new values for these climate variables are computed for each grid point. The difference between the control and the 2xCO2 experiment may then be used to assess the magnitude of climate change at each grid point.

According to the Intergovernmental Panel on Climate Change (IPCC), "no method yet exists of providing confident predictions of future climate", and it cautions against using the scenarios as climate forecasts due to the uncertainty in the models (IPCC, 1994). Since the actual climate response to a doubling of carbon dioxide (CO2) will not occur until well into the twenty first century, model validation is not possible, and all climate change scenarios must be considered useful examples of future climate.

TYPES AND CHARACTERISTICS OF GCMs

GCMs may be classified as either equilibrium or transient (time-dependent) response (IPCC, 1995). The equilibrium response model is first initialized with current CO2 concentrations to produce the control run. CO2 is then doubled, abruptly, and the model is run until the simulated climate achieves a new equilibrium. The 2xCO2 scenario thus produced represents the full response of the climate to an instantaneous increase in CO2 without the delay or reduction due to the thermal inertia of the ocean (Manabe et al., 1991). Equilibrium models utilize a mixed layer, or "slab" ocean, in which the heat exchange between this layer and the deeper ocean is fixed. A limitation of equilibrium models is their inability to realistically portray climate change as it happens over time.

Since greenhouse gas concentrations will rise gradually rather than experience an sudden doubling, a more realistic climate response is obtained by modelling a progressive increase in concentrations of CO2 over a period of time (eg. 1% per year). This modelling approach is known as a time-dependent or transient response and is achieved by coupling the atmosphere with a fully circulating ocean system such that the heat exchange between the atmosphere, the sea surface, and the deeper ocean layers changes with time. The transport of heat into the deeper ocean has a moderating effect on sea surface temperatures which in turn alters the climate response. Models having this capability to link the ocean circulation to the atmospheric circulation are called "coupled models".

The CCC GCMII is an equilibrium model and utilizes a non-circulating slab ocean where the transfer of heat between the ocean's surface layer and the deep ocean is prescribed and invariant. The GISS and GFDL models are transient response GCMs and are also coupled models for their ability to link the atmospheric circulation to a circulating ocean. Due to these differences in the types of models, the scenarios produced by equilibrium and transient models are not directly comparable. Modellers at the Canadian Centre for Climate Modelling and Analysis are now developing a third generation CCC GCM which will also be coupled to a full circulating, interacting ocean (G. Boer, pers. comm.).

The characteristics of the three GCMs described above are summarized in Table 1. Information concerning the base year or initial CO2 concentration as well as the basis for computing the monthly and seasonal means are included under the "Comments" column. The grid spacing (horizontal resolution) of these three models is shown for Canada in Figures 1(a), (b), and (c).

Table 1. A comparison of three GCMs.

GCM name	Model type	Horizontal resolution (degrees)	Ocean represen -tation	Principal investigators	Comments
CCC[1]	equilibrium	3.75 lon x 3.7 lat (Gaussian)	slab, 50 m mixed layer	Boer et al. (1992)	1. Control run: 20 year run initialized at 330 ppm CO2. 2. Equilibrium: 660 ppm CO2 3. Monthly means calculated from 10 years: 1 to 10.
GFDL[2]	transient	7.5 lon x 4.5 lat (Gaussian)	coupled	Manabe et al. (1991)	1. Control run: 100 years initialized to 1958 (approx 315 ppm CO2). 2. Transient run: 1% increase per year for 100 years. 3. Monthly averages computed from years: 60 to 80.
GISS[3]	transient	5.0 lon x 4.0 lat	coupled	Russell et al. (1995) after Hansen et al. (1983)	1. Control run: 74 years initialized to 315 ppm CO2. 2. Transient run: 1% increase per year for 74 years. 3. Seasonal averages computed from 10 years: 65 to74.

Monthly means of temperature and precipitation for the CCC GCMII control run and the 2xCO2 run were calculated from ten years of data from year 1 to year 10 of the simulation. GCM data are also available for years 11 through 20 of the simulation, and these data were used previously to produce a set of contoured climate change charts for British Columbia and Yukon. There are considerable differences between these two data sets with respect to both temperature and precipitation at the regional scale.

The two transient models, GFDL and GISS, are initialized at global CO2 concentrations of 315 ppm which

[1] Canadian Centre for Climate Modelling and Analysis (CCC GCMII)
[2] Geophysical Fluid Dynamics Laboratory
[3] Goddard Institute of Space Studies

Figure 1(a) Grid-point spacing for the CCC GCM. (3.75 degrees longitude x 3.7 degrees latitude (Gaussian)).

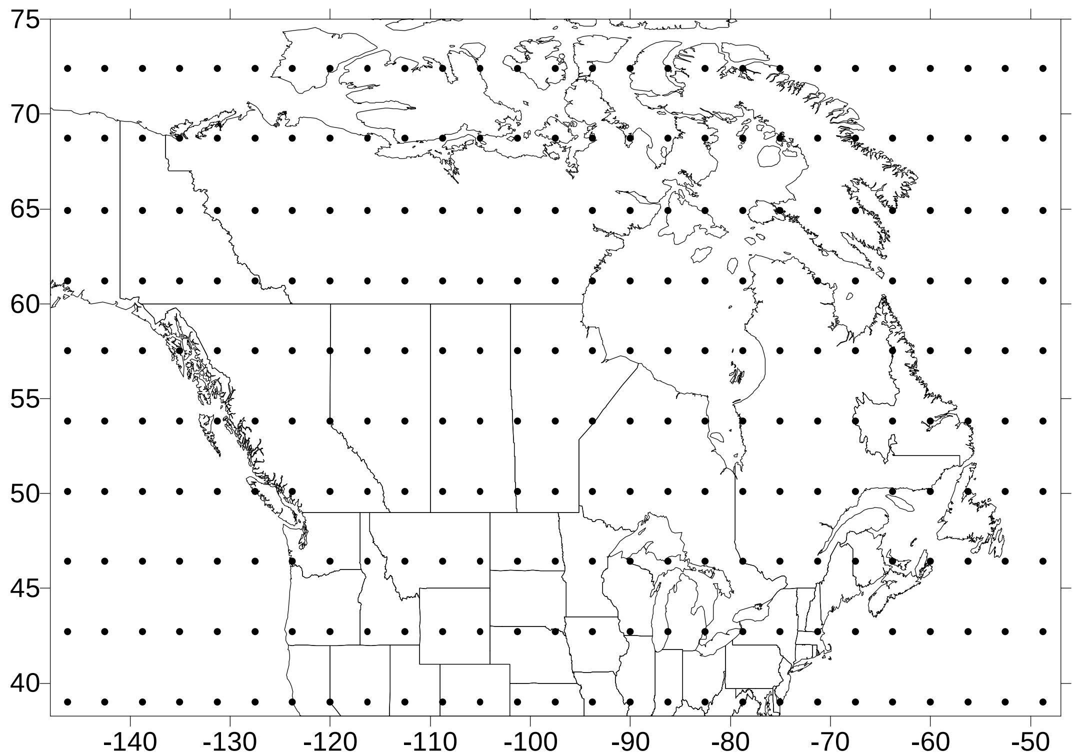


Figure 1(b) Grid-point spacing for the GFDL GCM. (7.5 degrees longitude x 4.5 degrees latitude (Gaussian)).

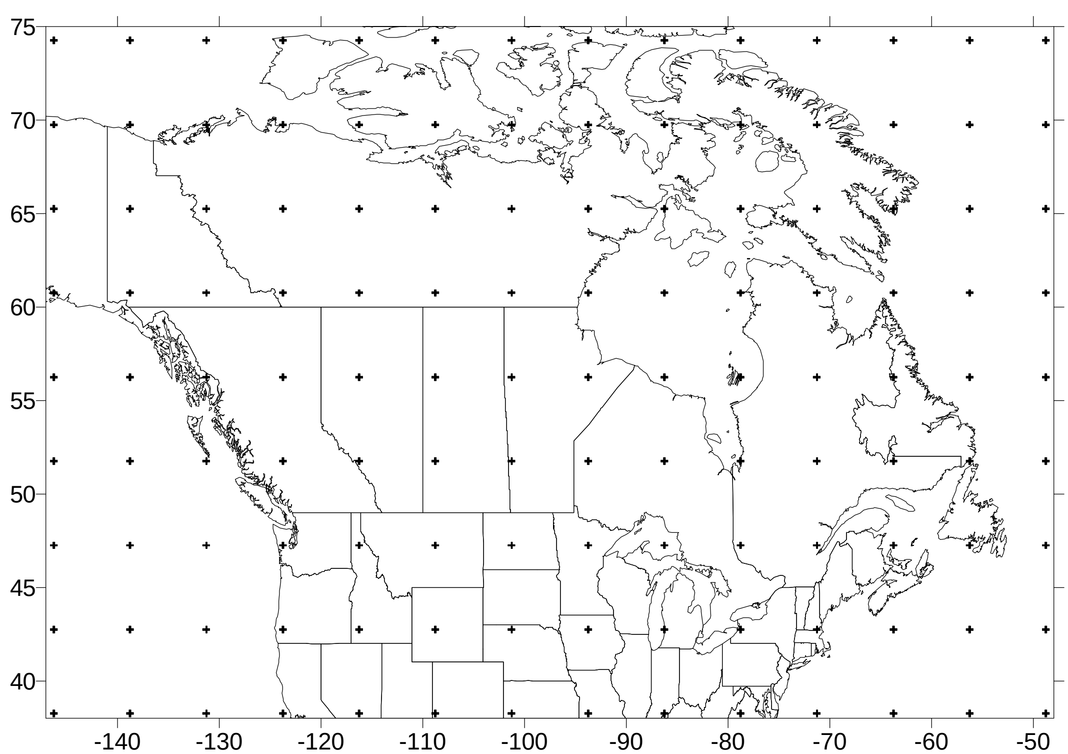
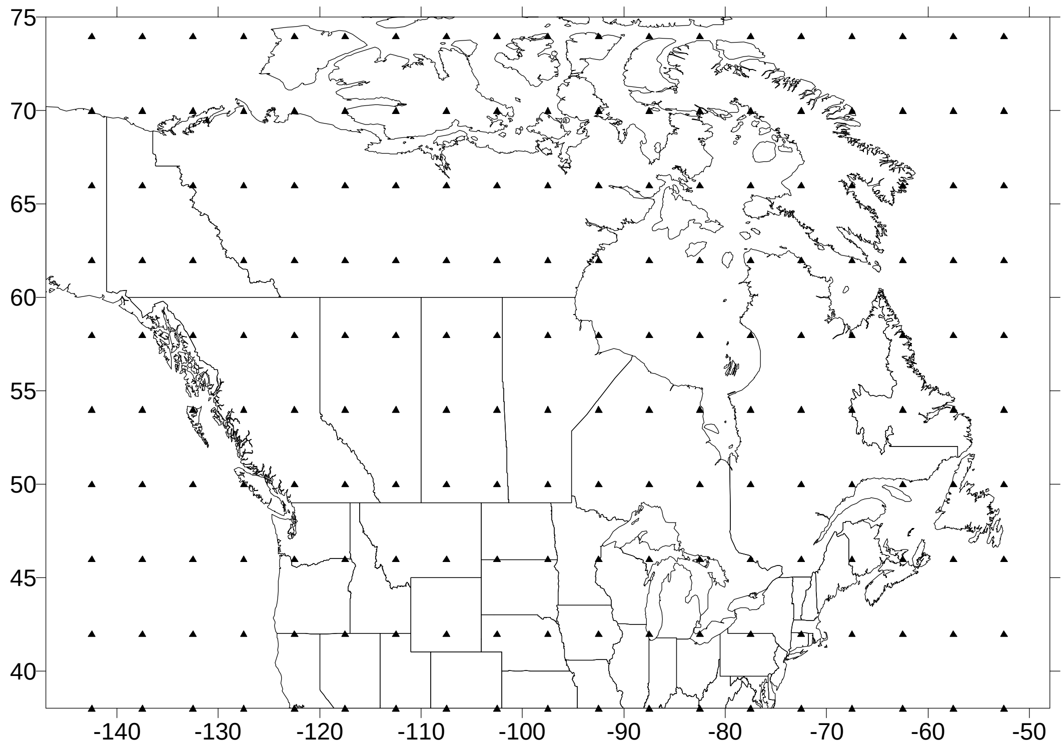


Figure 1 (c) Grid-point spacing for the GISS GCM (5.0 degrees longitude x 4.0 degrees latitude).



corresponds to a base year of 1958. At a compounded rate of increase of 1% per year, it takes 70 years to reach doubled CO2 (2xCO2) concentrations. Seasonal and monthly averages, respectively, are computed on the basis of ten years for the GISS, and 20 years for the GFDL, centred on year 70 of the simulation.

The scenarios produced by the GCMs may change as enhancements are made to the models. In order to identify which versions of the models were used to produce the scenarios described here, the attached climate change charts have been labeled to incorporate the type of model (equilibrium or transient) and the year in which the associated journal article appeared. For example, the CCC GCMII scenarios are labeled “CCC GCMII (equilibrium, 1992)”. Note that the GISS produces seasonal values while the CCC and GFDL provide monthly scenarios.

GCM RESULTS AND LIMITATIONS

Based on the results of an ensemble of GCMs, the IPCC estimates the rise in long term global average annual temperature to be between 1 and 4.5 Celsius degrees under 2xCO2 conditions (IPCC, 1995). With the inclusion of aerosol masking effects in heavily industrialized regions, this estimate decreases globally to 1 to 3.5 Celsius degrees. These projected changes in the global temperatures will not be evenly distributed in space or time. For example, Canada’s northern regions are expected to experience greater warming than the south. Winter is expected to sustain a greater rise in temperatures than summer and the warming will be greater over continents than over oceans. Precipitation scenarios are even more uncertain. GCMs are much less reliable in simulating the present distribution of precipitation than temperatures, so conclusions about changes to the temporal and spatial distribution of rain and snow are highly uncertain.

On the sub-continent scale, there is considerable uncertainty in the model results, and it is not possible to know with confidence the fine details of how the climate will change regionally. This is particularly true of mountainous areas such as British Columbia and Yukon where there is high spatial variability in the climate. Since GCMs were designed to model the global climate, the uncertainty at regional scales may be assumed to be very large. McBean et al (1992) reviewed the state of GCMs with regard to their applicability to estimating the impacts of climate change on hydrology, coastal currents and fisheries in British Columbia. It was concluded that GCMs simulated reasonably well the global climate features but could not represent the characteristics of regional climates, let alone the finer scale climate effects of the complex topography of British Columbia.

The degree of uncertainty associated with GCMs at the regional scale is well illustrated when the monthly simulations produced by two different ten-year CCC GCMII data sets (years 1-10 and 11-20) are compared. While there is a strong resemblance in the general pattern of temperature and precipitation changes between the two data sets, there are important differences in the magnitude of the changes, especially in the fine detail at the regional scale.

Recent research has focused on improving the resolution of GCMs by nesting high-resolution limited area models (LAM) within them to account for local topographic forcing factors (Caya et al., 1995; Georgi, 1990). Information from the low resolution GCM is transferred to the LAM by forcing its lateral boundaries with the values of the GCM. Until higher resolution regional models are available, the crude approximations provided by the current state of GCMs may represent the best available estimates of future climate change at the regional level.

APPLICATION OF GCM SCENARIOS

Since the resolution of GCMs is usually too coarse to reliably estimate regional climate, it is customary to use observational data as a baseline as opposed to using the simulated climate of the 1xCO2 control run (IPCC, 1994). Historical station data are then adjusted by the GCM-projected changes in temperature and precipitation. Station temperatures are adjusted by the *difference* between the control and 2xCO2 runs (2xCO2 - control) and observed precipitation values are multiplied by the *ratio* of the 2xCO2 run to the control run (2xCO2/control). An exception to this method concerns the application of precipitation ratios to dry regions where the effect of applying a percentage to a low or zero value may produce unrealistic results. In that case it may be advisable to use precipitation differences rather than ratios.

Climate stations rarely coincide with GCM grid point locations, and a variety of methods may be employed to interpolate from GCM grid points to station sites (IPCC, 1994). One technique is to make use of the value of the nearest grid point while another involves objectively interpolating the differences between the values for adjacent grid points. The contoured charts which accompany the User's Guide were produced using an objective technique called kriging. A shortcoming of this method is that it introduces a false precision to the estimates since fine topographic features cannot be resolved by coarse resolution GCMs.

GCMs produce scenarios for a variety of climate elements, but only temperature and precipitation are included here because these tend to be the ones most often used in impact studies. In order to apply the scenarios, it is necessary for the user to obtain base climate data corresponding to the control (1xCO2) model run and apply GCM temperature and precipitation changes as described above. Often, a recent period will be chosen as a baseline because of the availability of climate data as well as other baseline environmental and socio-economic measures. The baseline climate value will usually be a time series or a long time average of observed temperature or precipitation such as the 1961-90 Canadian Climate Normals (Environment Canada, 1993).

BASELINE AND DOUBLING DATES

A source of much confusion about the GCM scenarios is the period in the future for which they are valid. That timing depends upon many factors including the initial concentration of CO_2 used in the simulations and on how well the control run simulation agrees with the current climate. It also depends upon our assumptions about the future rate of greenhouse gas emissions. When used in conjunction with the 1951-80 or 1961-90 Normals, the valid period for the climate change projections shown on the attached charts is for the latter half of the twenty-first century. While this may seem vague or too broad, there are several reasons why a more precise time period is not provided.

Non-linear growth rate of CO_2

Projected doubling dates are dependent on both the choice of base period as well as CO_2 emission scenarios. Since pre-industrial times, atmospheric CO_2 has risen from roughly 280 ppm to 358 ppm in 1994. This increase was initially very slow, but the growth rate has risen sharply just in the past few decades and is now roughly 0.7% per year (IPCC, 1995). At that rate, CO_2 concentrations would double in about 100 years relative to the recent past. By comparison, the transient models included in this report assume a 1% increase in equivalent CO_2 per year which gives a doubling time of 70 years. According to IPCC emission scenario IS92a, a doubled pre-industrial CO_2 concentration of 560 ppm would be reached by the year 2065 (IPCC, 1995). Other IPCC scenarios suggest doubling of pre-industrial CO_2 may occur as early as the year 2050 or as late as well beyond 2100.

Unequal base periods

As a first approximation, the base period may be identified by selecting the year corresponding to the initial concentrations of CO_2 used in the control ($1xCO_2$) simulation. However, different GCMs are initialized with different CO_2 concentrations (eg. 330 ppm for the CCC vs. 315 ppm for the GFDL and GISS). The control run CO_2 levels of the CCC GCMII equilibrium model coincides with the year 1975 while that for the GFDL and GISS corresponds to the year 1958. The CCC GCMII model also starts with the climate in equilibrium with climate forcing, a condition which does not exist in the present climate.

CO_2 alone vs CO_2 equivalent

GCM scenarios reflect the change in global climate resulting from a doubling of CO_2 concentrations or an equivalent increase in other greenhouse gases. The projected dates for doubling CO_2 alone occur much later (at least 30 years) than a date for doubling equivalent CO_2 which considers an increase in concentrations of all greenhouse gases.

Realized vs equilibrium warming

Due to the thermal inertia of the oceans, there is a lag between the increase in CO_2 and the climate response. Thus, the amount of warming realized by the transient models is generally less than for equilibrium models.

Aerosol effects

The cooling effect of aerosols, which counteracts global warming, is not included in the models presented here. The cooling effects may act to delay the amount of warming shown on the attached charts.

Inherent problems with coupled models

Transient models commonly exhibit drift in their control runs which means that the global mean temperature at the end of the control run deviates from that at the start (IPCC, 1994). Transient models also suffer from what is referred to as the “cold start” problem. This arises from starting the simulation with the climate in equilibrium which does not account for the historical build-up of CO_2 relative to pre-industrial times in the actual climate. For the first few decades of the simulation, global warming is inhibited by the thermal inertia of the oceans (IPCC, 1994).

To summarize, the precise timing of the changes in temperature and precipitation indicated on the attached charts cannot be known due to the many uncertainties in GCM scenarios at the regional scale. If the 1951-80 or 1961-90 Normals are used as a baseline, then the period for which climate change charts are valid is sometime in the latter half of the twenty-first century.

SUMMARY

GCMs can be a valuable tool in environmental impact studies. When used in conjunction with historical climate records, GCMs provide plausible climate scenarios under conditions of increased concentrations of greenhouse gases projected for the twenty-first century. GCMs are currently limited in their ability to produce accurate and high resolution climate simulations for several reasons, not the least of which is the speed and capacity of today's super-computers. However, GCMs remain the best available tool for making projections about the future climate, and research continues into improving the accuracy and resolution of these models for regional applications.

ACKNOWLEDGEMENTS

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Glossary

aerosols -suspensions of liquid or solid particles in the air, (eg. dust, sea salt particles, soot from volcanoes, forest fires and human activities, as well as nitrates and sulfates) excluding cloud droplets and precipitation. Aerosols have a cooling effect on the climate by absorbing or scattering incoming solar radiation.

control (1xCO2) - the base climate simulation according to some specified concentration of CO2 (eg. 330 ppm for the CCC GCMII).

coupled model - a GCM capable of incorporating the interaction of the ocean circulation and atmospheric circulation.

equilibrium response - the steady state of the climate. The term is applied to a model that allows the climate system to reach a new equilibrium following a change in radiative forcing.

equivalent CO2 - the concentration of CO2 that would cause the same amount of radiative forcing as the given mixture of CO2 and all other greenhouse gases.

General Circulation Model (GCM) - a mathematical representation of the physical laws of conservation of momentum, mass, moisture, and energy to create a detailed three dimensional model of the climate system. The computation of these mathematical equations is performed on very powerful, high speed computers.

greenhouse effect - the warming of the Earth's surface due to the selective absorption of outgoing longwave radiation by trace gases in the atmosphere. The average temperature of the Earth due to the greenhouse effect is estimated to be roughly 33°C higher than it would be without it. The ***enhanced greenhouse effect*** refers to the additional warming of the Earth due to the buildup of greenhouse gases due to human activities.

greenhouse gas - trace atmospheric gases including carbon dioxide (CO2), methane (CH4), water vapour (H2O), nitrous oxide (N2O), ozone (O3), and halocarbons which have the characteristic of enhancing the greenhouse effect.

kriging - an interpolation scheme which relies on optimally weighting the influence of neighbouring data points. The weights are determined according to the covariance of the values depending on their distance apart, and by fitting a function to this relationship.

limited area model - a high resolution climate model which is restricted to a fairly small spatial area and nested in a low resolution GCM. The resolution of GCMs (eg. about 600 km for CCC GCMII) is constrained by the computing power required for the decades-long integrations and global coverage. The resolution of the Canadian Regional Climate Model (CRCM) is 45 kilometers at 60° North (Caya et al., 1995).

precipitation change - the ratio of mean total precipitation under 2xCO2 scenario to the control scenario. (2xCO2/control).

radiative forcing - a perturbation to the Earth's radiation budget (units: Wm^{-2}). In particular, this refers to the change in climate brought about by a change in the concentrations of greenhouse gases.

scenario - a coherent, internally consistent and plausible future state of the climate.

sector - environmental and economic interests which are likely to be impacted by climate change, including forestry, fisheries, agriculture, tourism, transportation, energy, health, water resources, etc.

temperature change - the difference between the mean temperature under the 2xCO_2 and the control (1xCO_2) scenario. (2xCO_2-control).

transient response - the term which applies to a model in which a radiative forcing, due to increased CO_2 concentrations, is gradually increased.

2xCO2 - the climate simulation produced by doubling the CO_2 concentration of the base climate scenario.

uncertainty **-** the degree of confidence in the GCM scenarios with regard to the timing, magnitude and regional patterns of climate change. Uncertainty is due to the simplifications used in the models, our lack of complete understanding of the climate system, and the practical limitations of present day computers.

CCC GCMII

CLIMATE CHANGE SCENARIOS

FOR BRITISH COLUMBIA AND YUKON

SEASONAL

TEMPERATURE CHANGE (CELSIUS DEGREES)

PRECIPITATION CHANGE (%)

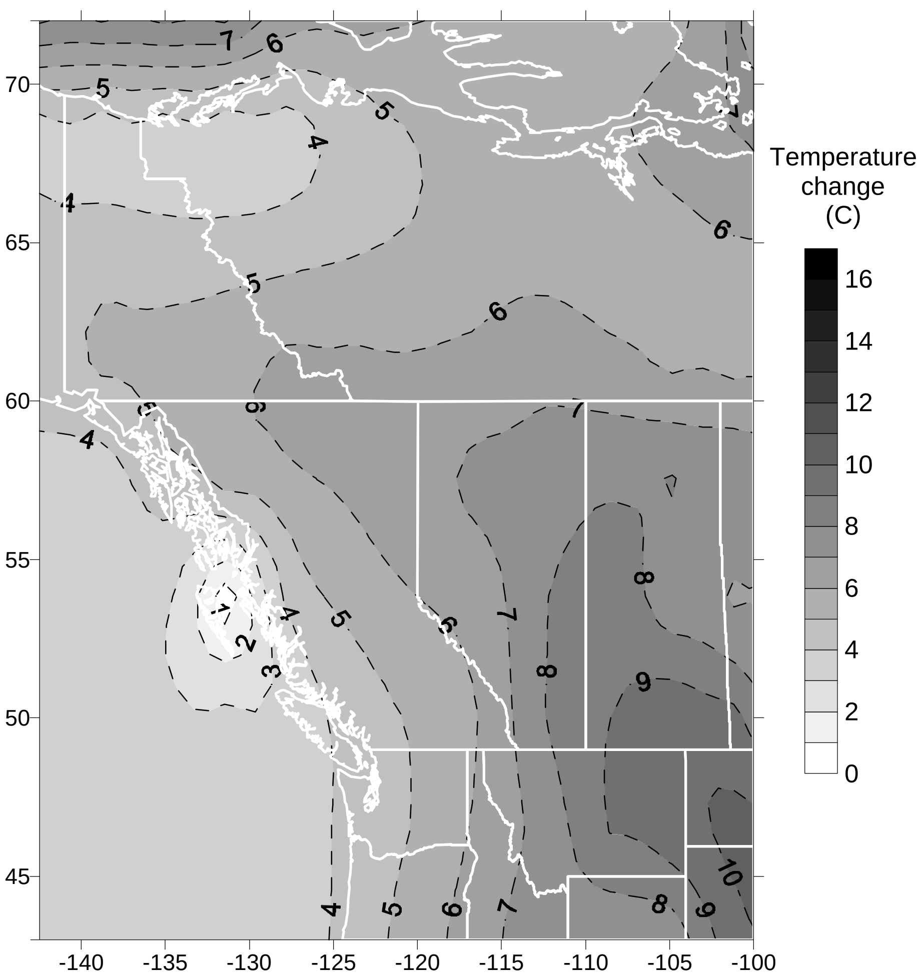
CANADIAN CENTRE FOR CLIMATE MODELLING AND ANALYSIS
GENERAL CIRCULATION MODEL

CCC GCMII (EQUILIBRIUM, 1992)

Climate change projections for the latter half of the 21st Century
due to doubling of atmospheric CO2 concentrations

CCC GCMII (equilibrium, 1992)
Change in Mean Seasonal Temperature (C)

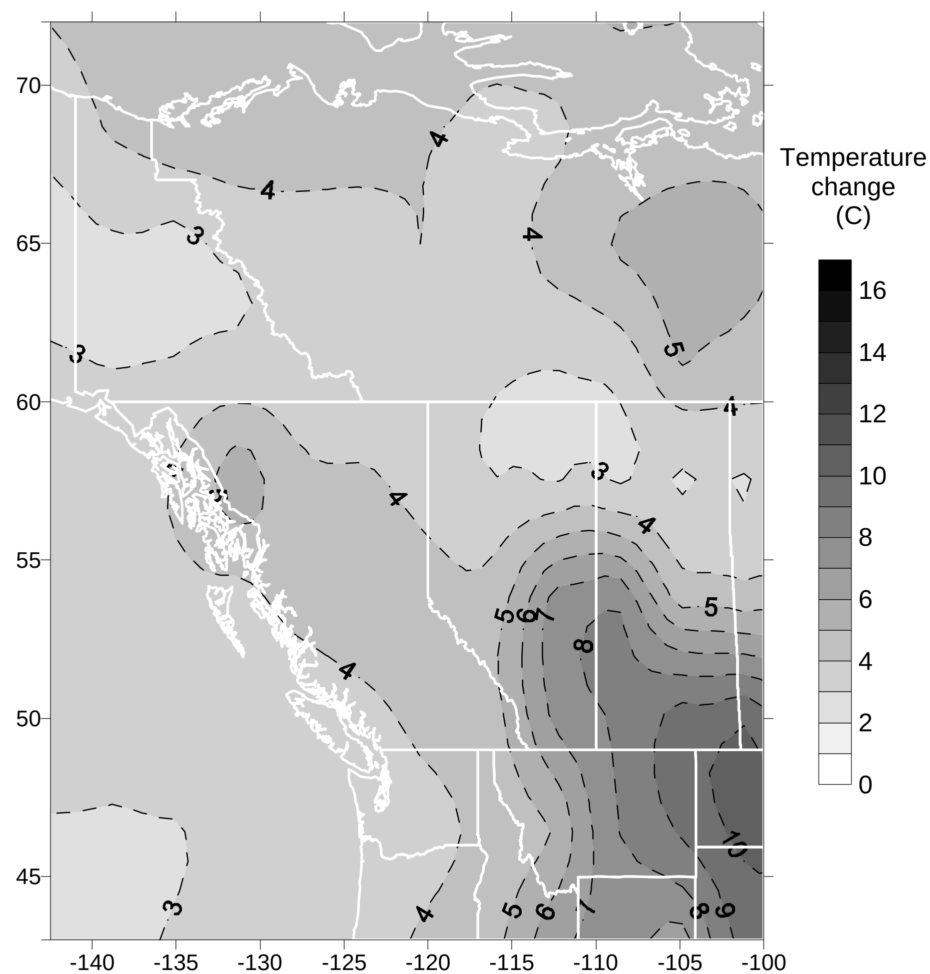
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



DEC - JAN - FEB

CCC GCMII (equilibrium, 1992)
Change in Mean Seasonal Temperature (C)

Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



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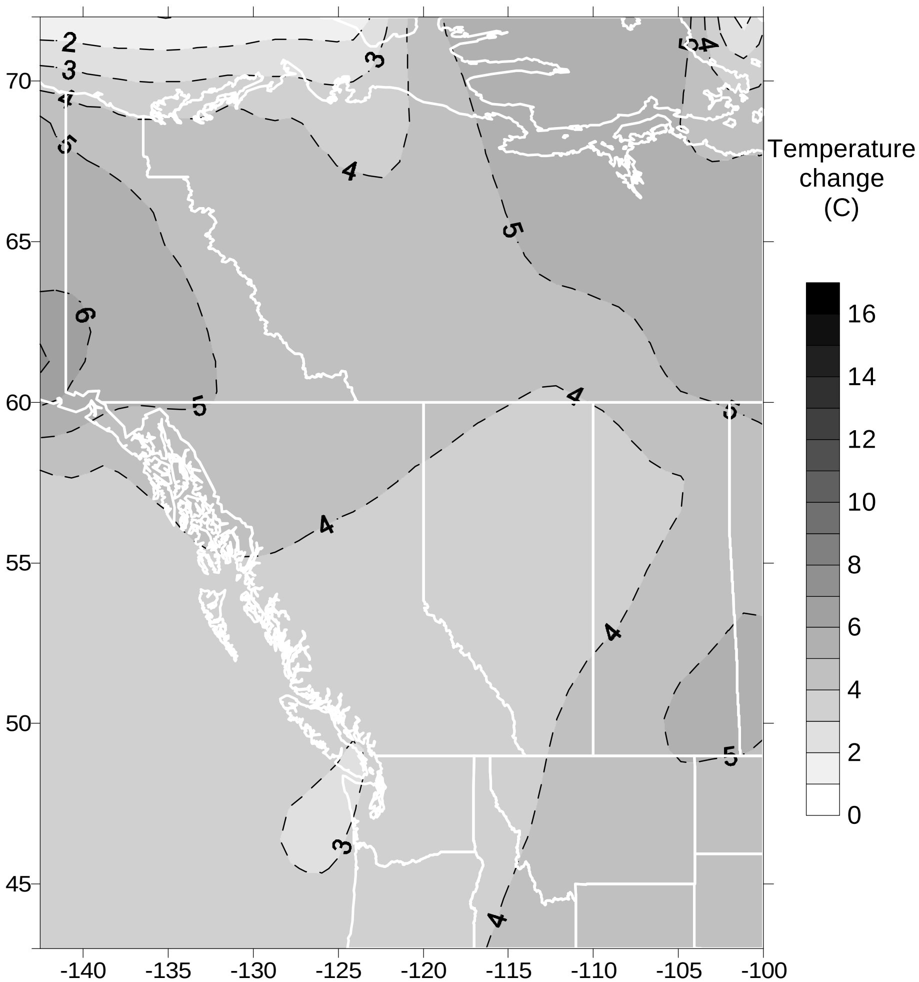
CCC GCMII (equilibrium, 1992)
Change in Mean Seasonal Temperature (C)

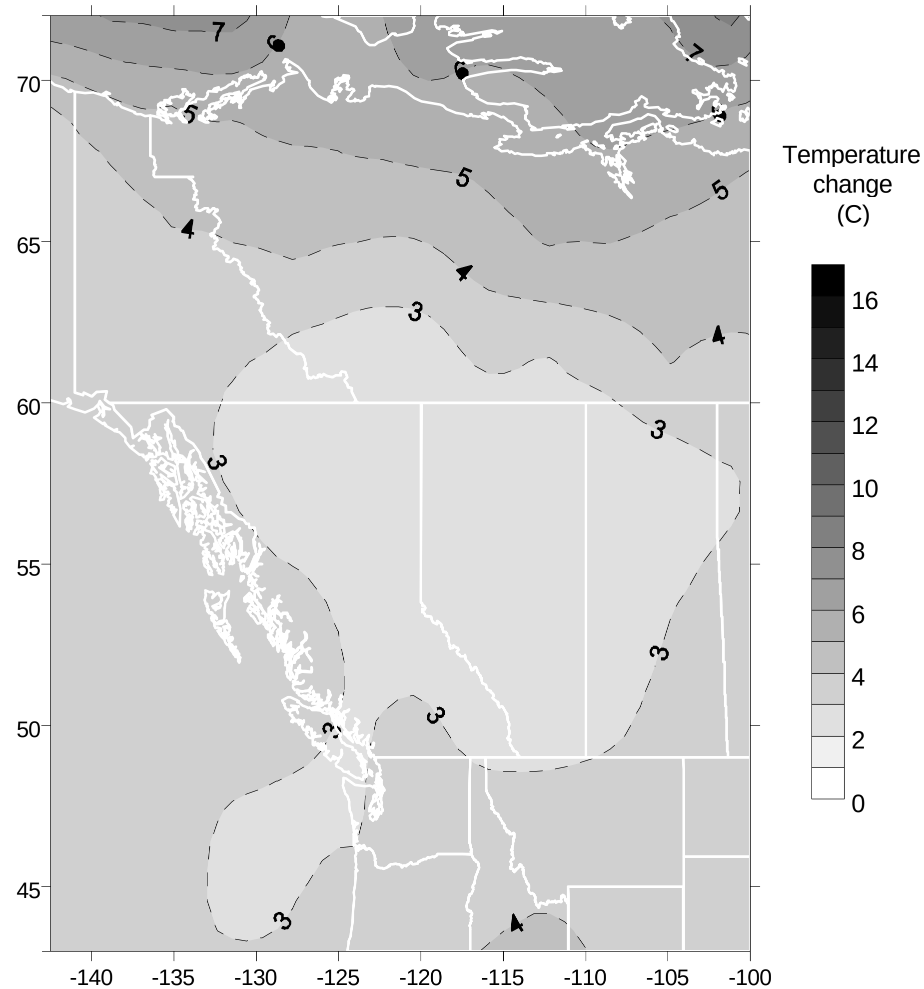
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



JUN - JUL - AUG

CCC GCMII (equilibrium, 1992)
Change in Mean Seasonal Temperature

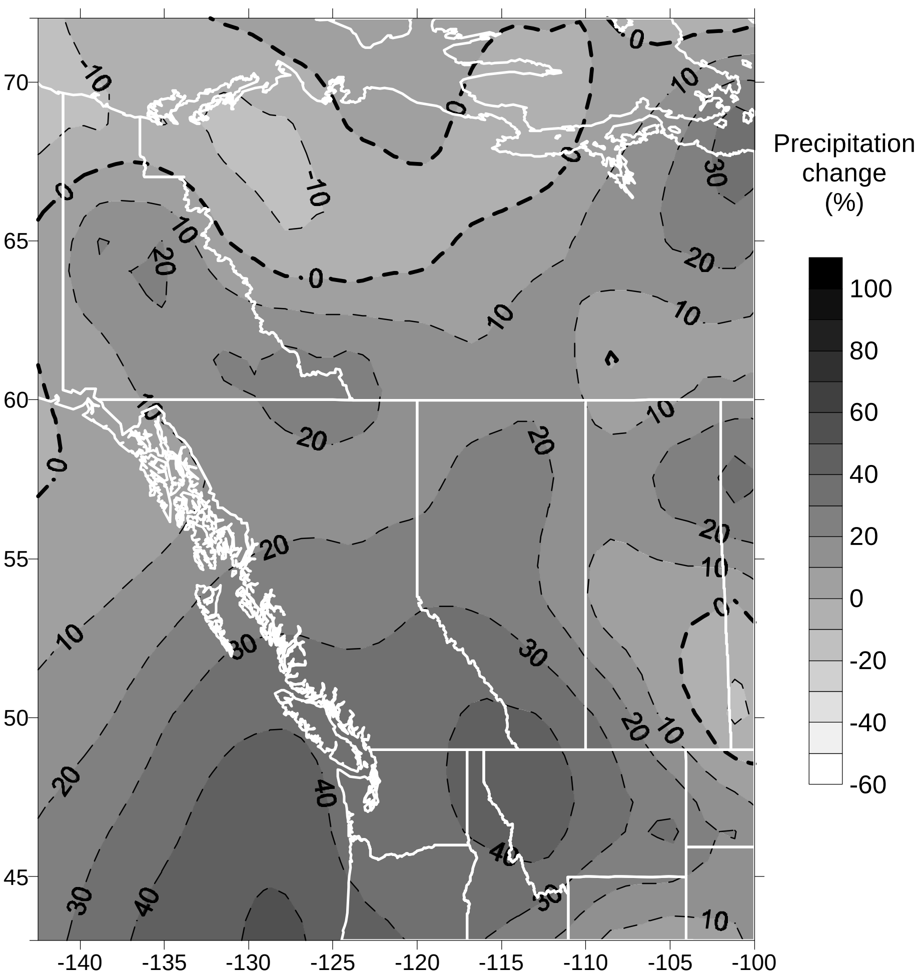
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



SEP - OCT - NOV

CCC GCMII (equilibrium, 1992)
Change in Mean Seasonal Precipitation (%)

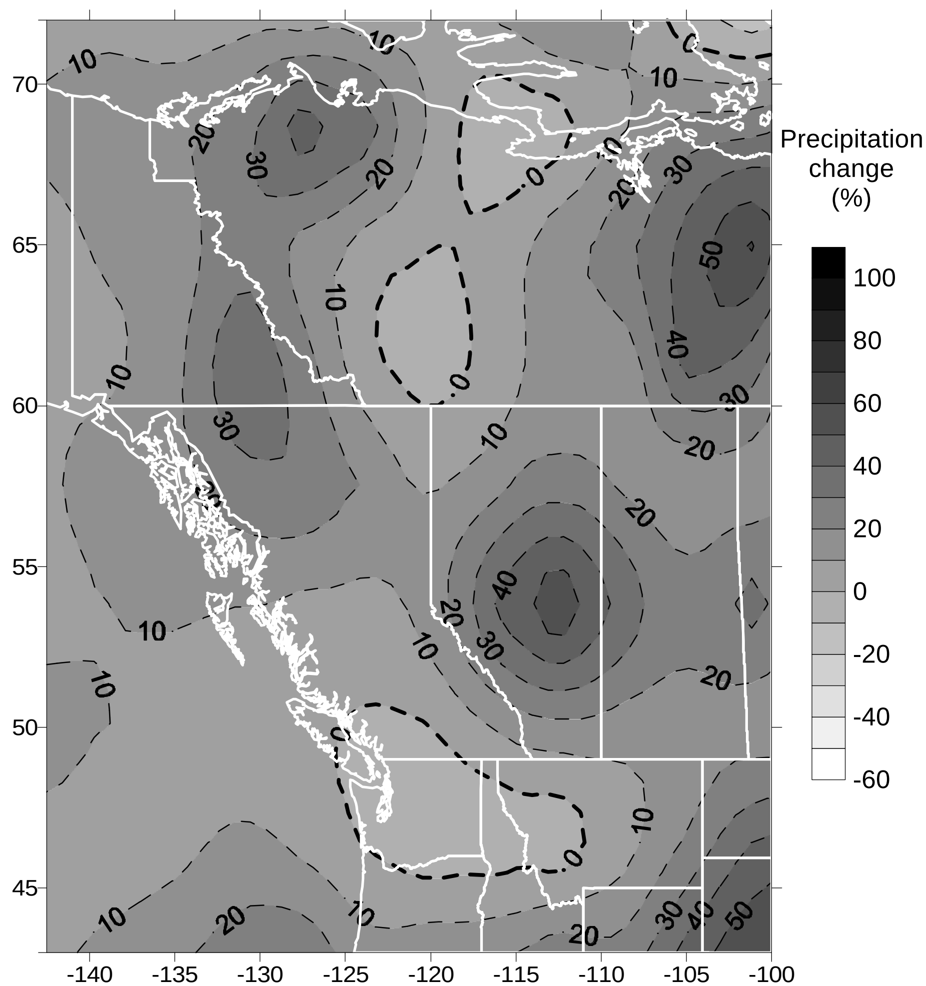
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



DEC - JAN - FEB

CCC GCMII (equilibrium, 1992)
Change in Mean Seasonal Precipitation (%)

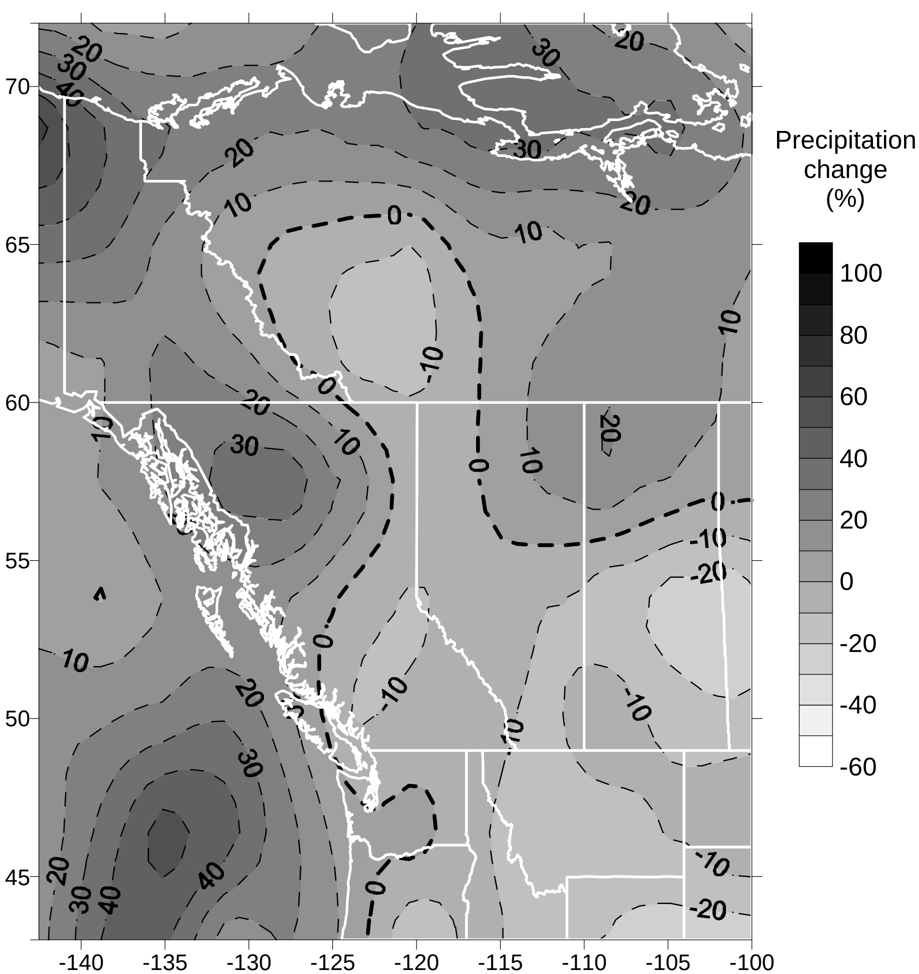
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



MAR - APR - MAY

CCC GCMII (equilibrium, 1992)
Change in Mean Seasonal Precipitation (%)

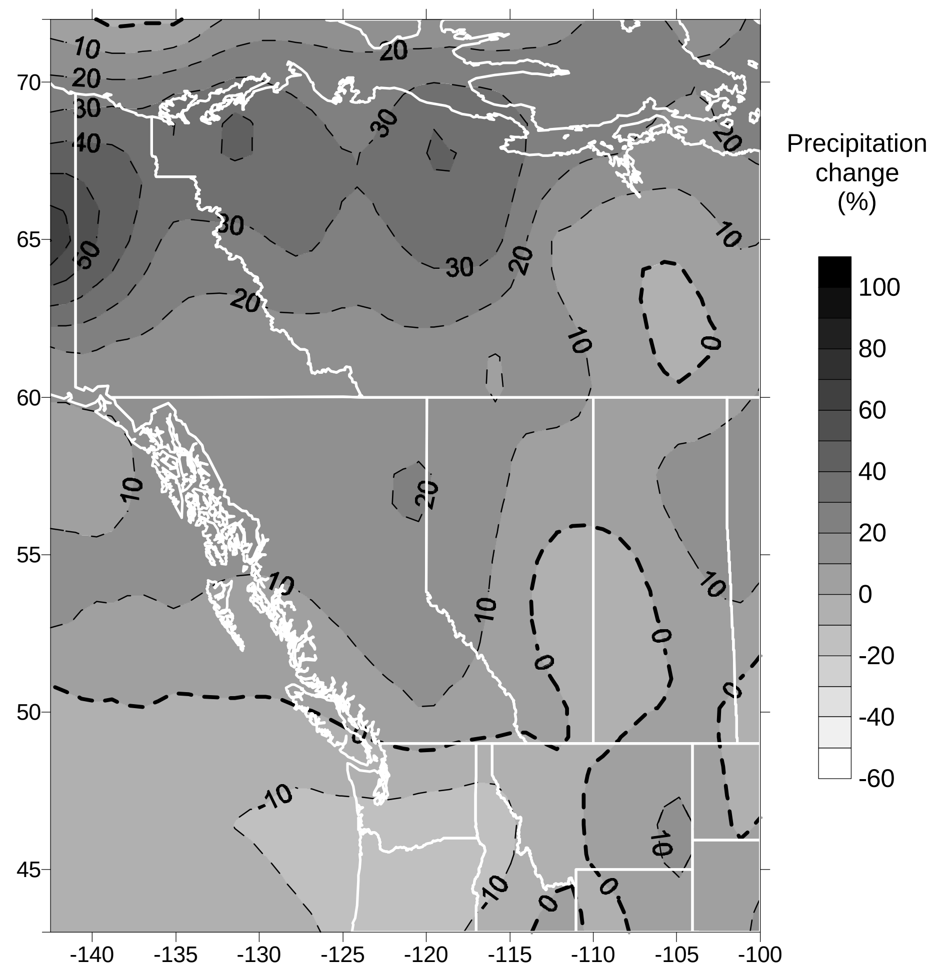
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



JUN - JUL - AUG

CCC GCMII (equilibrium, 1992)
Change in Mean Seasonal Precipitation (%)

Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



SEP - OCT - NOV

GFDL

CLIMATE CHANGE SCENARIOS

FOR BRITISH COLUMBIA AND YUKON

SEASONAL

TEMPERATURE CHANGE (CELSIUS DEGREES)

PRECIPITATION CHANGE (%)

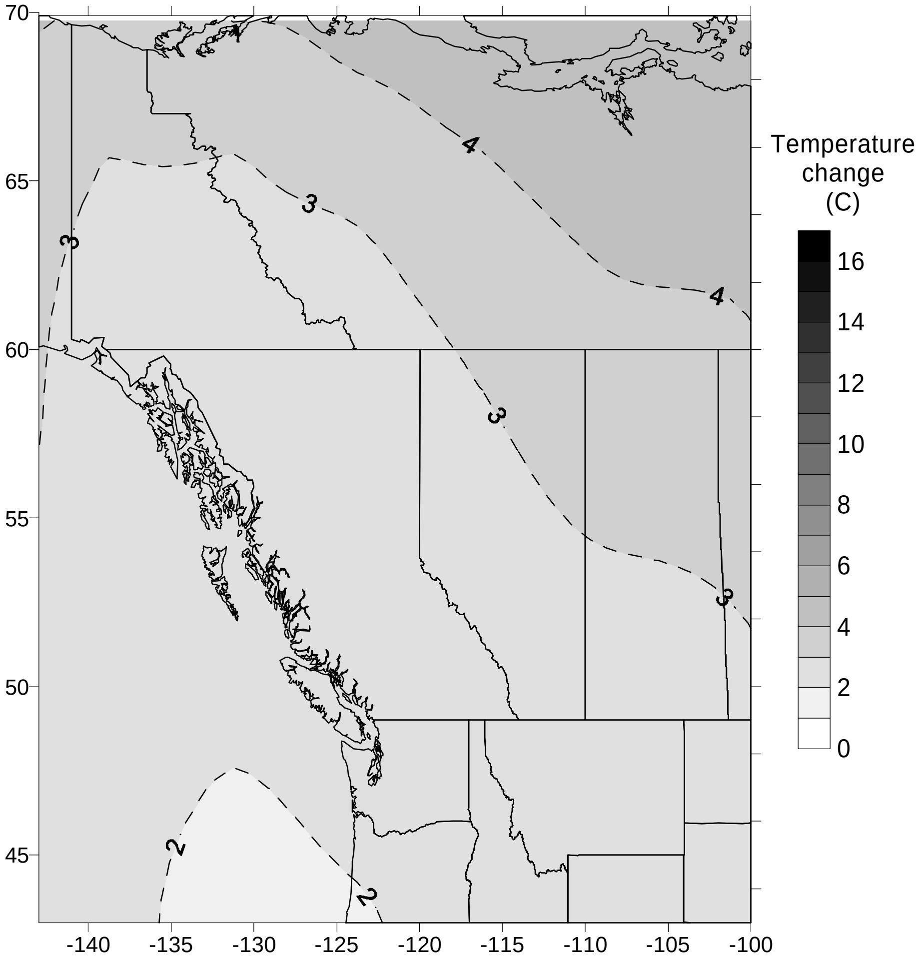
GEOPHYSICAL FLUID DYNAMICS LABORATORY
GENERAL CIRCULATION MODEL

GFDL (TRANSIENT, 1991)

Climate change projections for the latter half of the 21st Century
due to doubling of atmospheric CO_2 concentrations

GFDL (transient, 1991)
Change in Mean Seasonal Temperature (C)

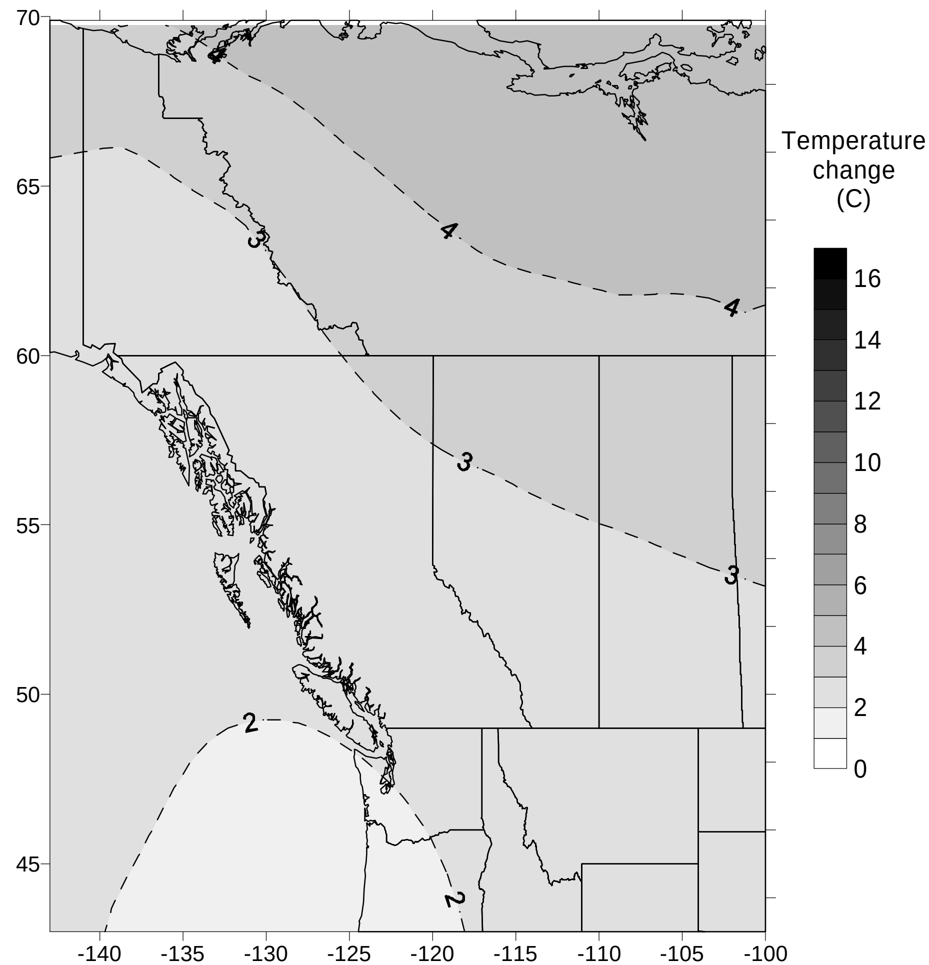
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



DEC - JAN - FEB

GFDL (transient, 1991)
Change in Mean Seasonal Temperature (C)

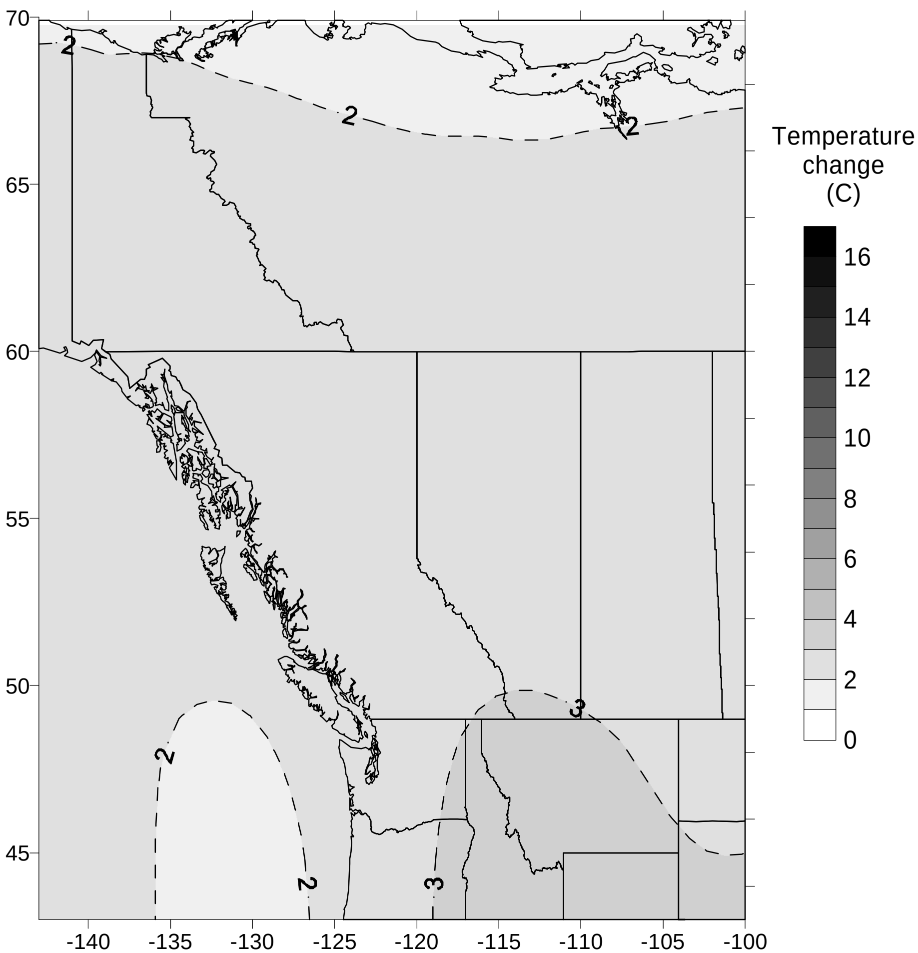
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



MAR - APR - MAY

GFDL (transient, 1991)
Change in Mean Seasonal Temperature (C)

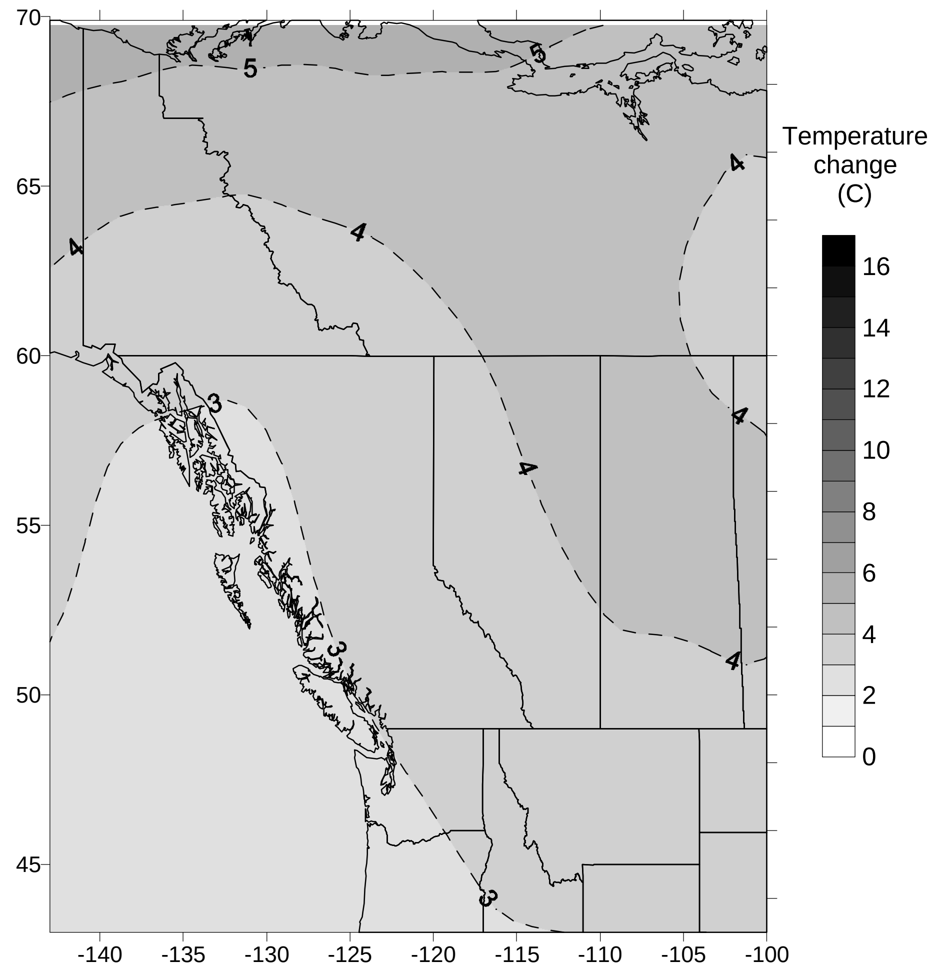
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



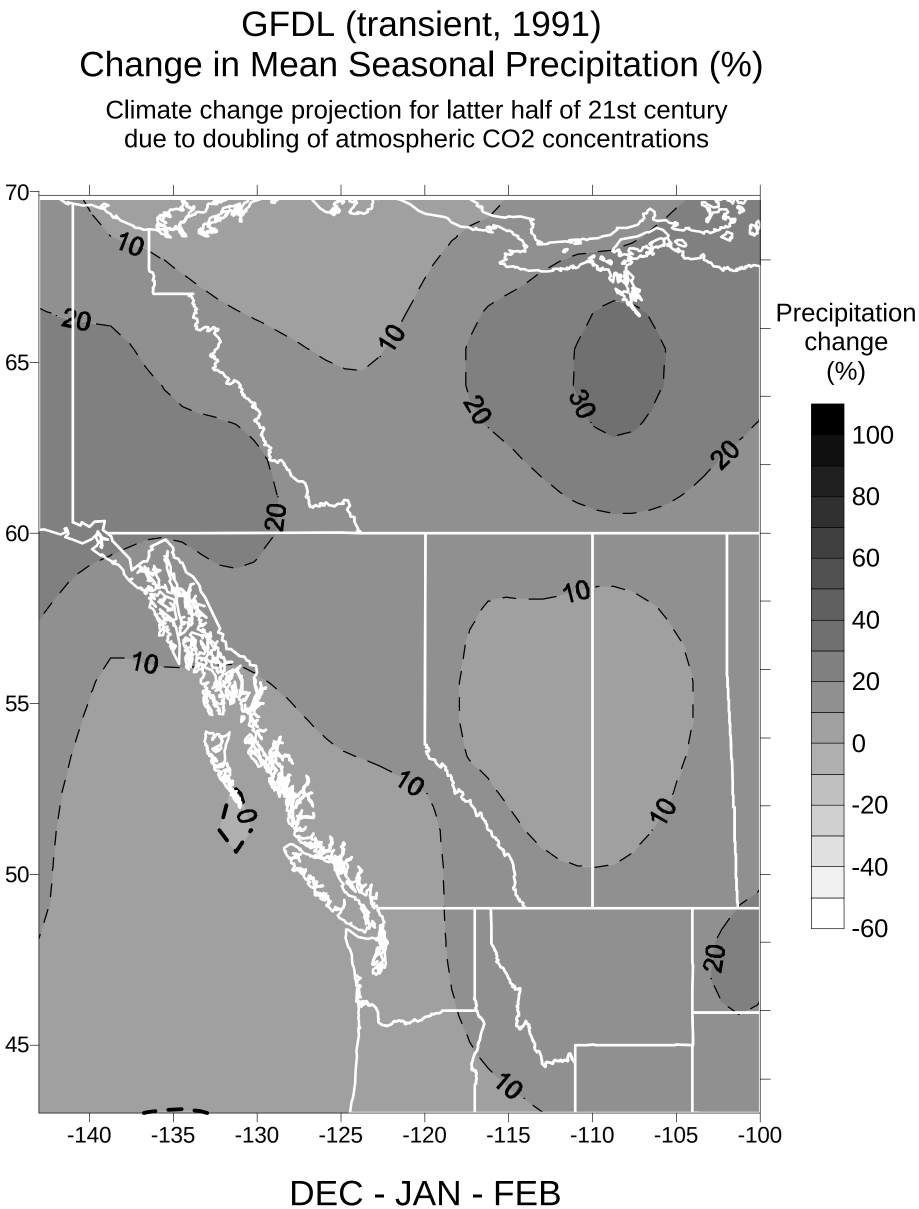
JUN - JUL - AUG

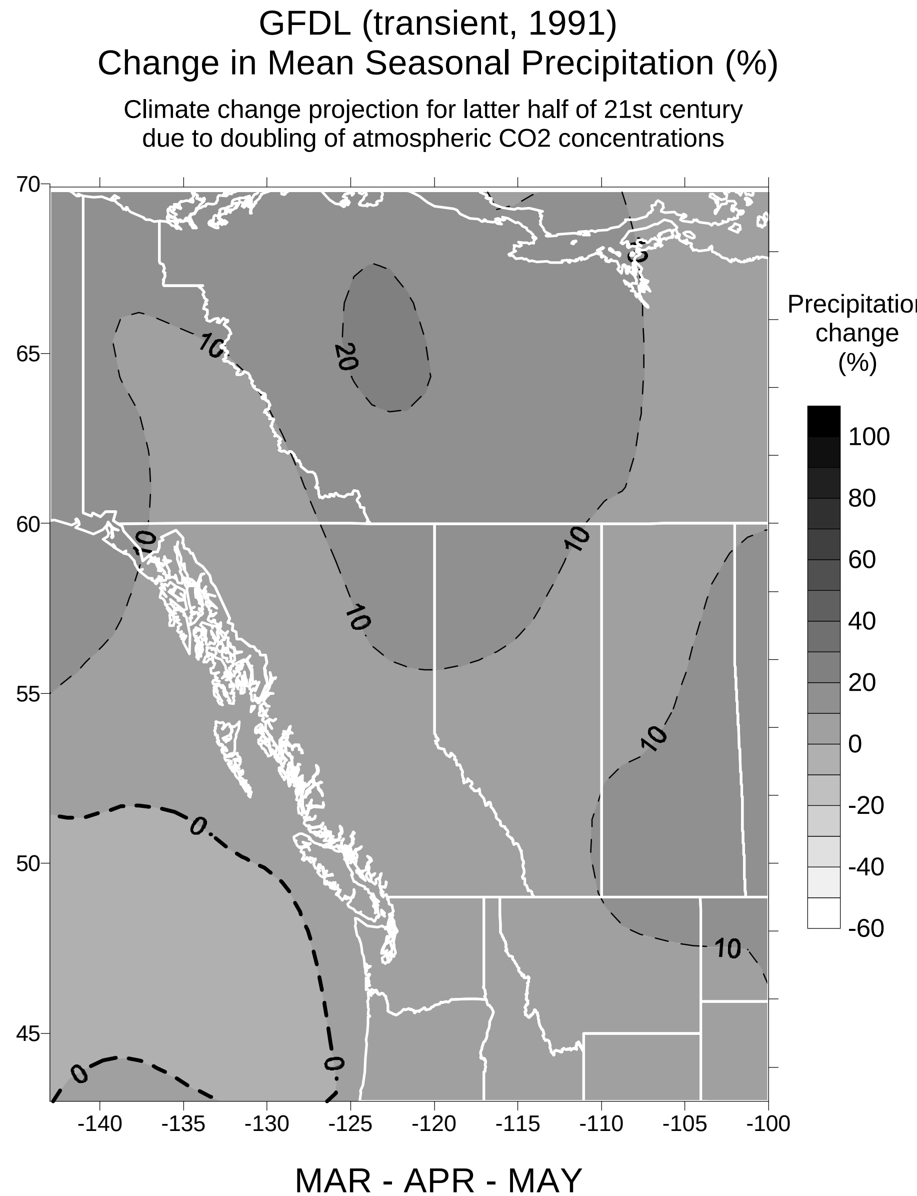
GFDL (transient, 1991)
Change in Mean Seasonal Temperature (C)

Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations

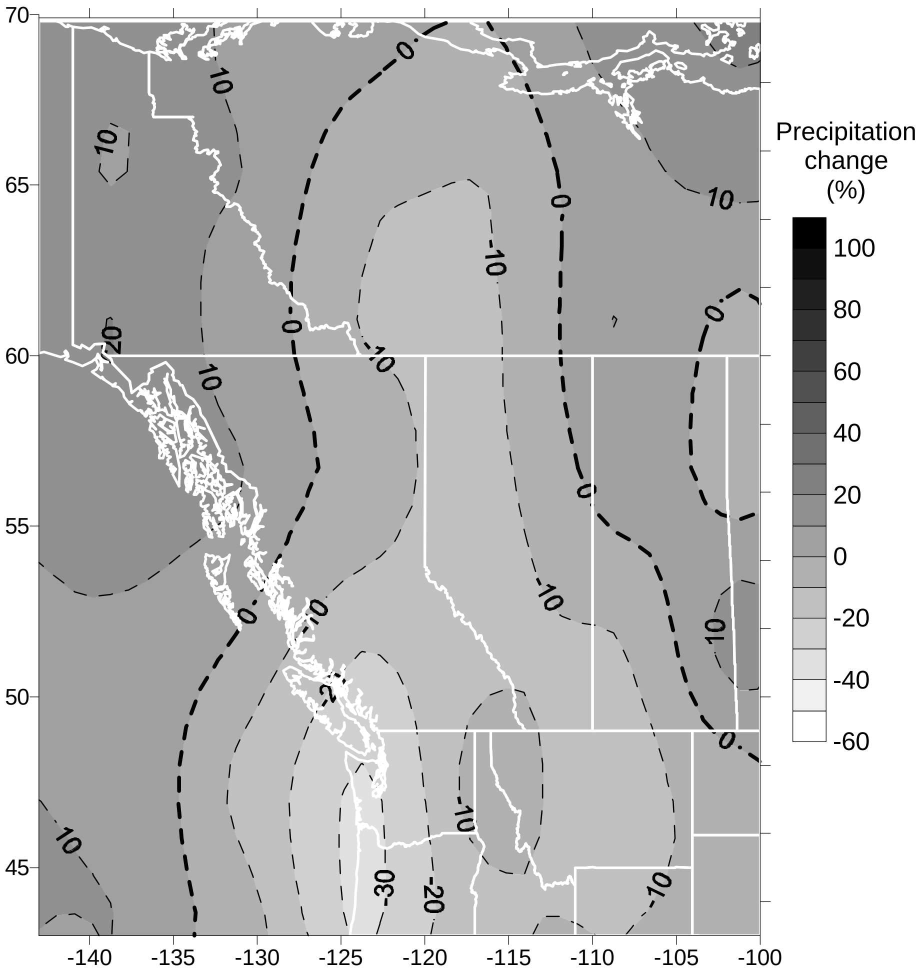


SEP - OCT - NOV


GFDL (transient, 1991)
Change in Mean Seasonal Precipitation (%)
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations
Precipitation
change
(%)
100
80
60
40
20
0
-20
-40
-60
70
65
60
55
50
45
-140
-135
-130
-125
-120
-115
-110
-105
-100
10
20
30
0
DEC - JAN - FEB

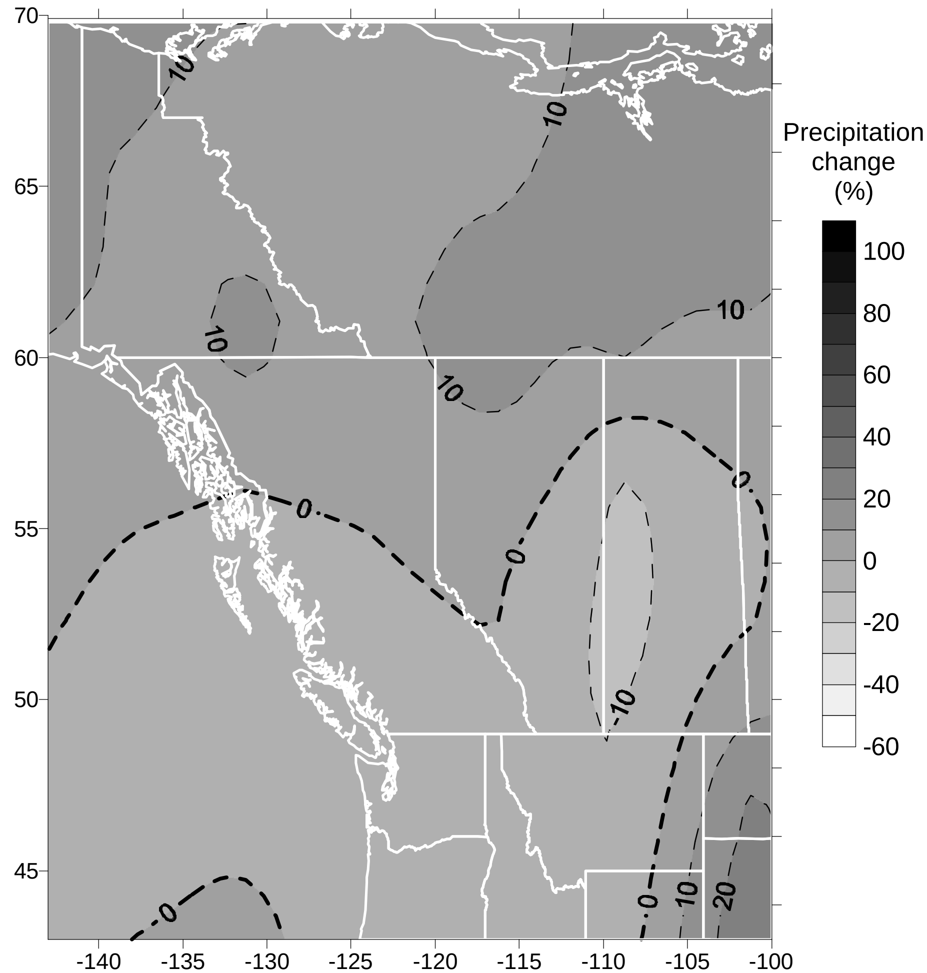

GFDL (transient, 1991)
Change in Mean Seasonal Precipitation (%)
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations
Precipitation
change
(%)
100
80
60
40
20
0
-20
-40
-60
70
65
60
55
50
45
-140
-135
-130
-125
-120
-115
-110
-105
-100
10
20
0
MAR - APR - MAY

GFDL (transient, 1991)
Change in Mean Seasonal Precipitation (%)
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



JUN - JUL - AUG

GFDL (transient, 1991)
Change in Mean Seasonal Precipitation (%)
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



SEP - OCT - NOV

GISS

CLIMATE CHANGE SCENARIOS

FOR BRITISH COLUMBIA AND YUKON

SEASONAL

TEMPERATURE (CELSIUS DEGREES)

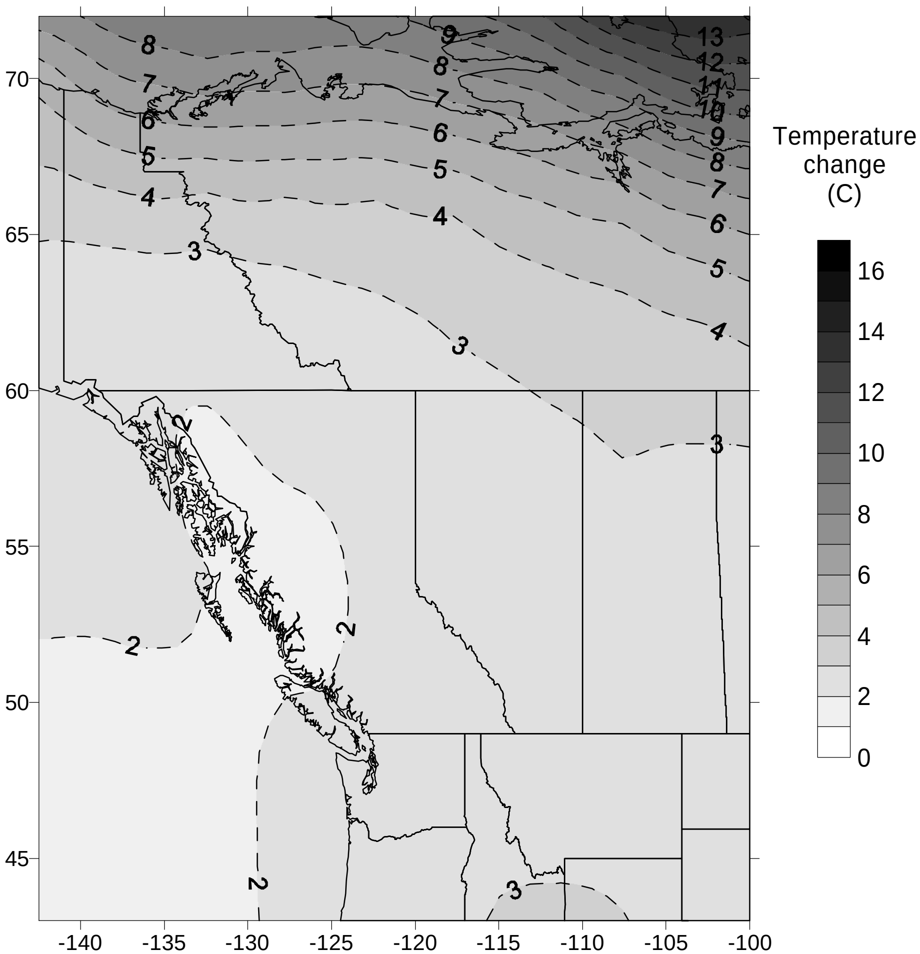
PRECIPITATION CHANGE (%)

GODDARD INSTITUTE FOR SPACE STUDIES
GENERAL CIRCULATION MODEL

GISS (TRANSIENT, 1995)

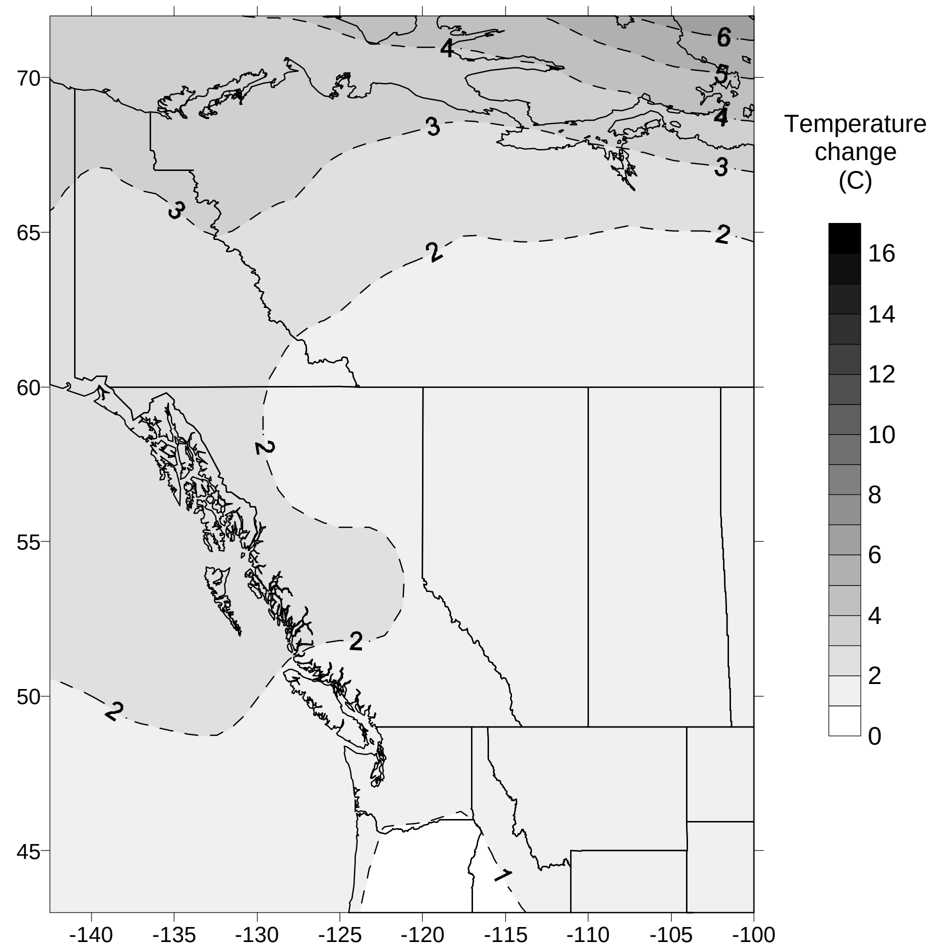
Climate change projections for the latter half of the 21st Century due to doubling of atmospheric CO2 concentrations

GISS (transient, 1995)
Change in Mean Seasonal Temperature (C)
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations

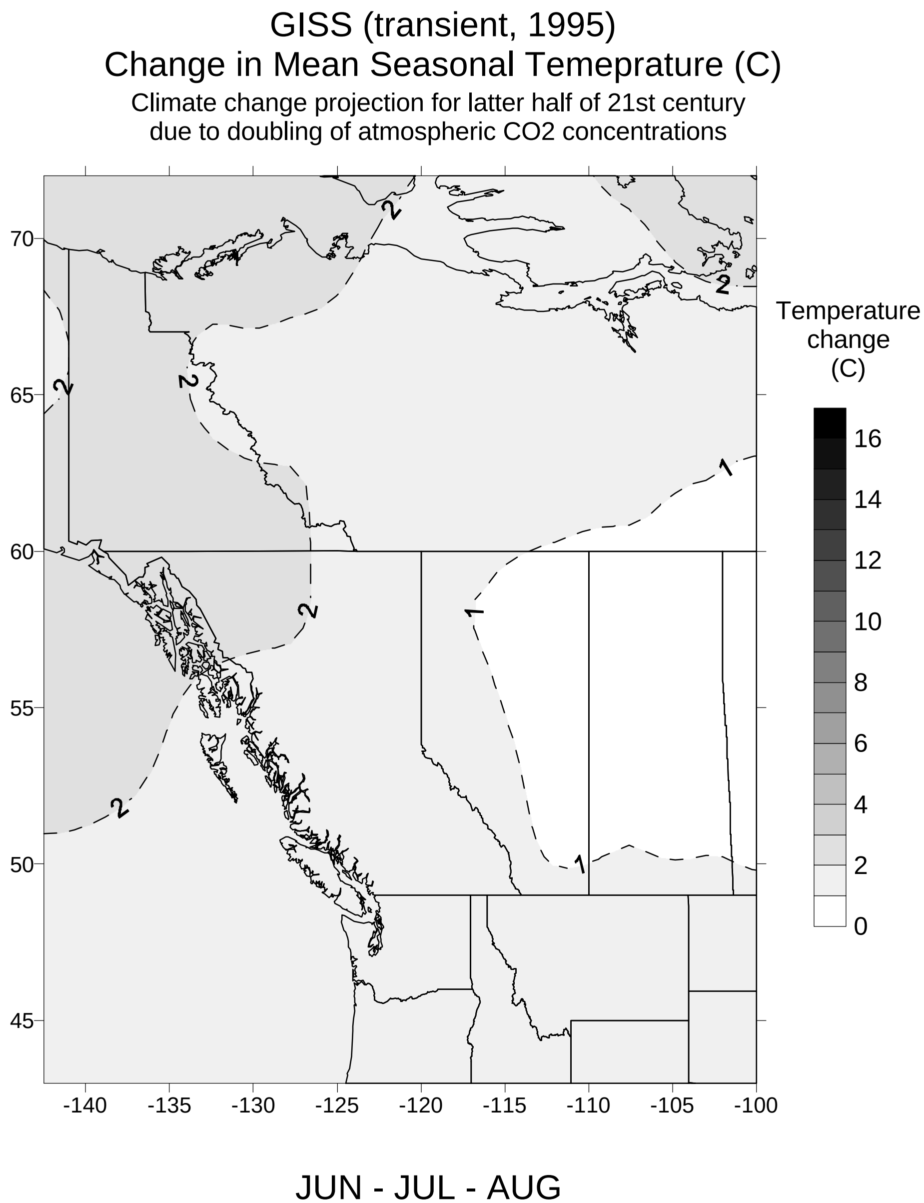


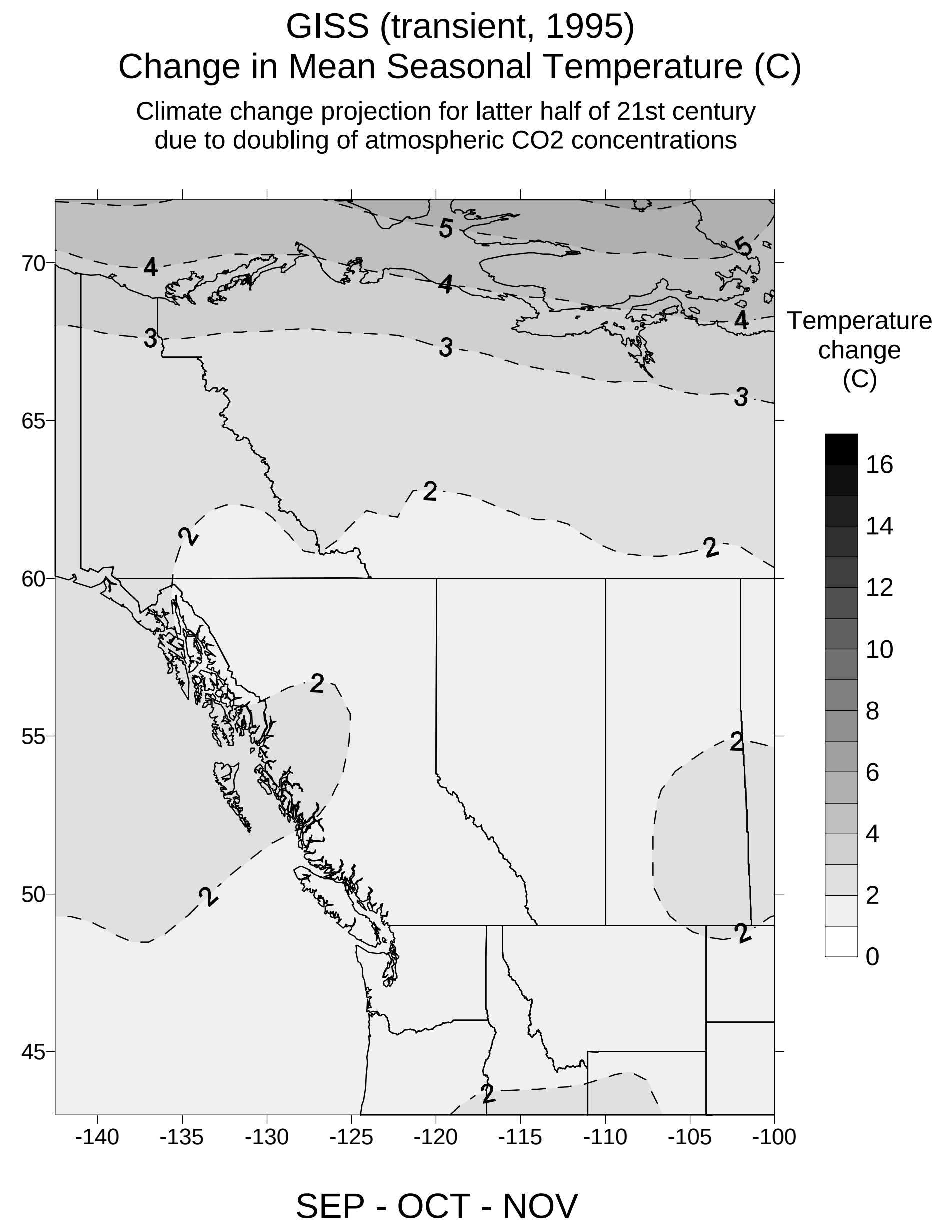
DEC - JAN - FEB

GISS (transient, 1995)
Change in Mean Seasonal Temperature (C)
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



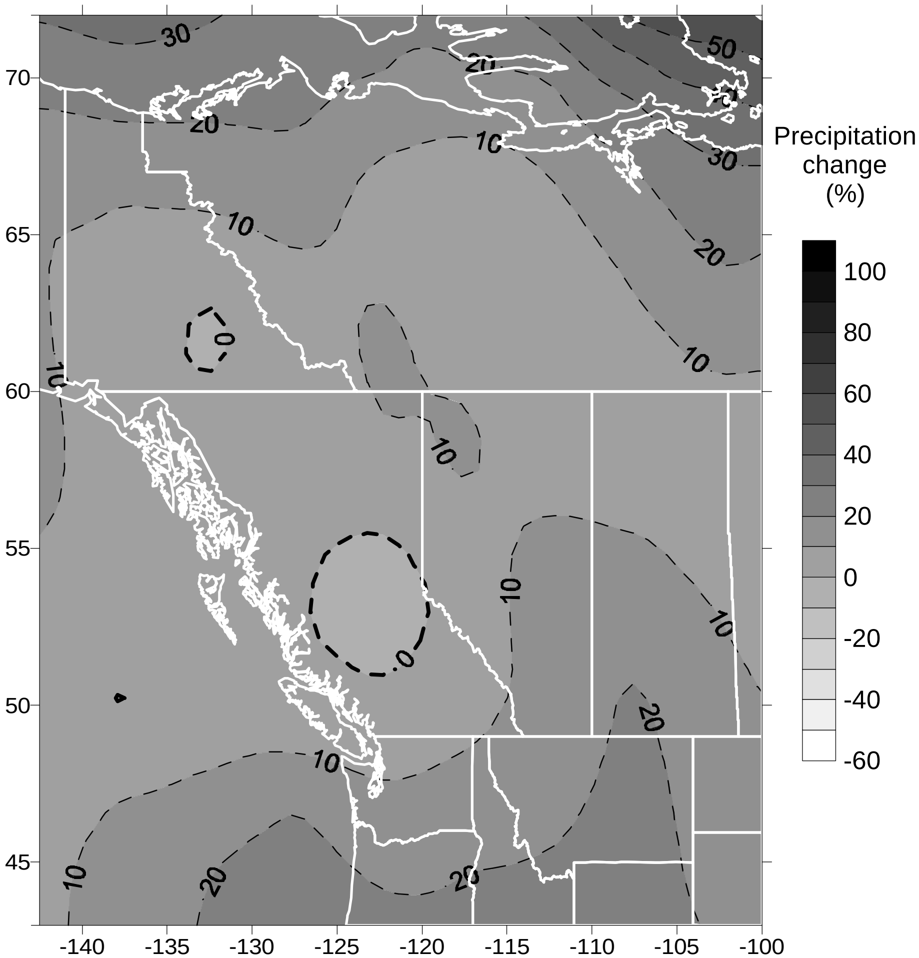
MAR - APR - MAY


GISS (transient, 1995)
Change in Mean Seasonal Temeprature (C)
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations
Temperature
change
(C)
0
2
4
6
8
10
12
14
16
70
65
60
55
50
45
-140
-135
-130
-125
-120
-115
-110
-105
-100
JUN - JUL - AUG


GISS (transient, 1995)
Change in Mean Seasonal Temperature (C)
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations
Temperature
change
(C)
0
2
4
6
8
10
12
14
16
70
65
60
55
50
45
-140
-135
-130
-125
-120
-115
-110
-105
-100
SEP - OCT - NOV

GISS (transient, 1995)
Change in Mean Seasonal Precipitation (%)

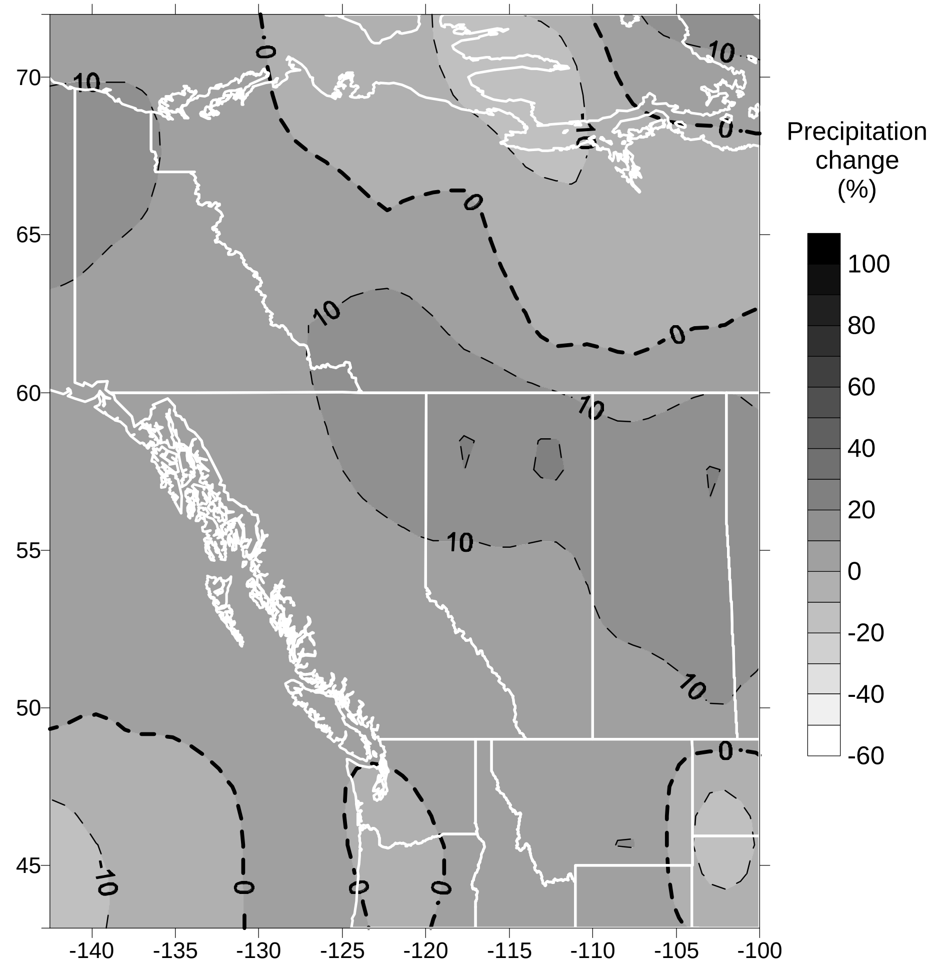
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



DEC - JAN - FEB

GISS (transient, 1995)
Change in Mean Seasonal Precipitation (%)

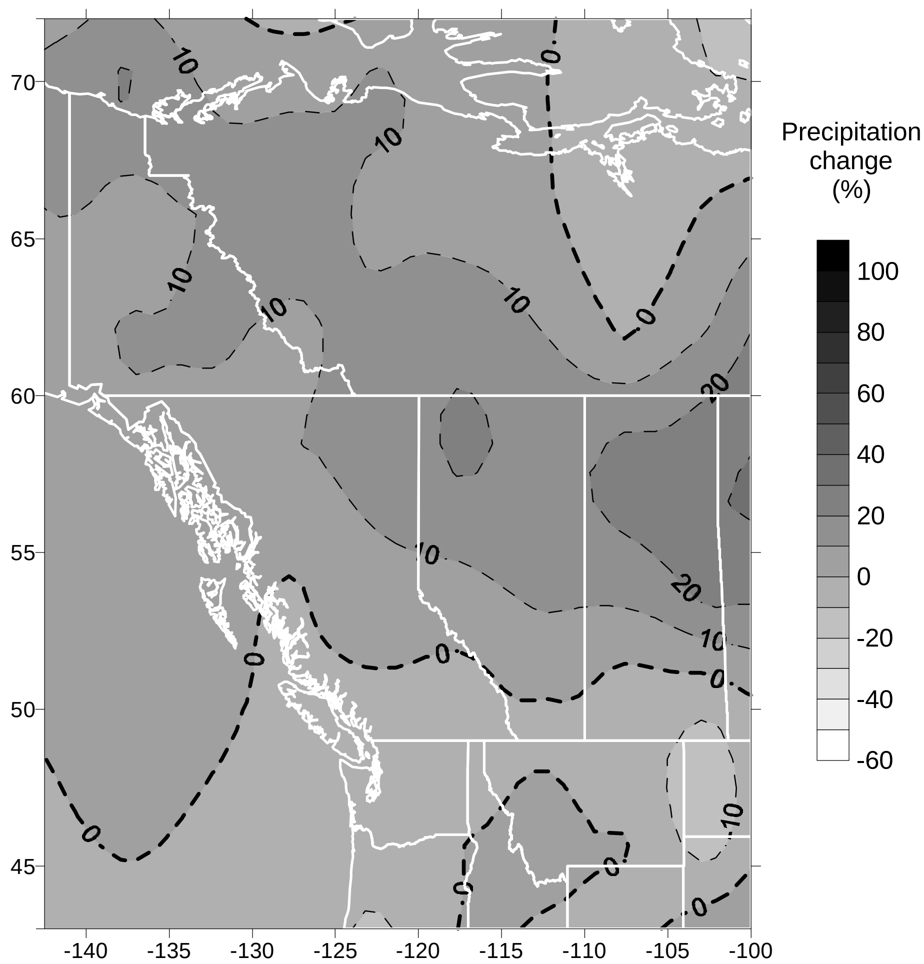
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



MAR - APR - MAY

GISS (transient, 1995)
Change in Mean Seasonal Precipitation (%)

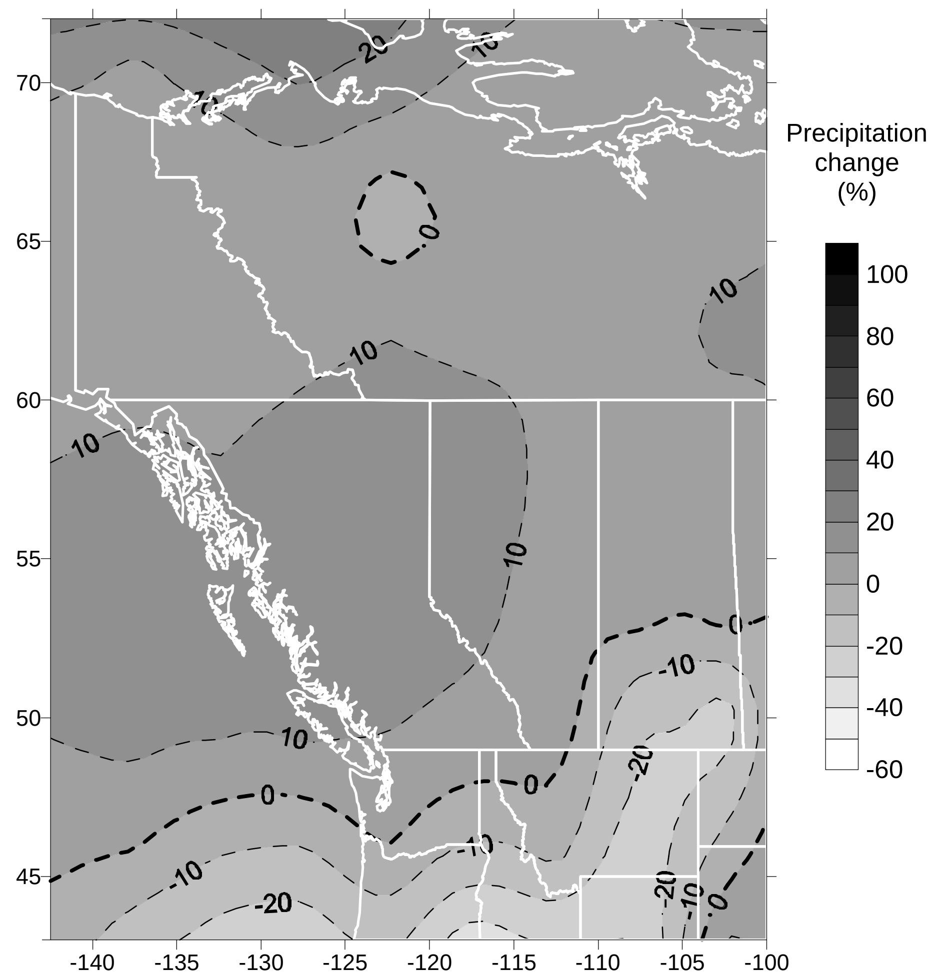
Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



JUN - JUL - AUG

GISS (transient, 1995)
Change in Mean Seasonal Precipitation (%)

Climate change projection for latter half of 21st century
due to doubling of atmospheric CO2 concentrations



SEP - OCT - NOV

APPENDIX 2

LIST OF SOME KEY CLIMATE CHANGE AGENCIES AND PROGRAMS

ACRONYM	**FULL NAME**	**FUNCTION**
PART A. INTERNATIONAL		
COP-FCCC	Conference of the Parties to the Framework Convention on Climate Change	Under the United Nations Framework Convention on Climate Change, Canada and other industrialized countries are working to stabilize greenhouse gas emissions at 1990 levels by the year 2000. (COP1- Berlin, 1995; COP 2 - Geneva, 1996; COP3 - Kyoto, 1997).
IPCC	Intergovernmental Panel on Climate Change	Jointly established by the World Meteorological Organization and the United Nations Environment Program to assess available scientific information on climate change, assess the environmental and socio-economic impacts of climate change, and formulate response strategies. Major reports were published in 1990 and 1995.
GEWEX	Global Energy and Water Cycle Experiment	Under the auspices of the World Climate Research Programme, the objectives of GEWEX are to study, on a continent-scale, the mechanisms controlling incoming and outgoing fluxes of solar and terrestrial heat energy, clouds, precipitation, evaporation, river runoff, and water storage. These continental scale projects focus on the Mississippi Basin and on the Mackenzie Basin.
PART B. NATIONAL		
NAPCC	National Action Program on Climate Change	Sponsored by federal, provincial and territorial Energy and Environment ministers, the NAPCC calls for cooperation and action by all levels of government, the private sector and other organizations in Canada to reduce greenhouse gas emissions. It sets out a number of strategies for addressing climate change, including a strong emphasis on using energy more efficiently.
VCR	Voluntary Challenge and Registry	As part of the National Action Program on Climate Change, the VCR encourages Canadian industry, business and government to make public commitments and to develop and implement voluntary action plans for reducing their greenhouse gas emissions. After two years of operation, the VCR has over 600 registrants who are responsible for more than 50 per cent of Canada's total greenhouse gas emissions.

CCS	Canada Country Study: Climate Impacts and Adaptation	The Canada Country Study is an Environment Canada initiative under which all regions of the country will contribute to the body of knowledge of climate variability and climate change impacts and adaptation in Canada.
CICS	Canadian Institute for Climate Studies	CICS is a not-for-profit Canadian Corporation created to further the understanding of the climate system, its variability and potential for change and the application of that understanding to decision making in both the public and private sectors.
CCP	Canadian Climate Program	A multi-agency organization whose objective is to provide governments and individuals with the best possible advice on the impact of climate on economic and social concerns, as well as its effects in natural ecosystems and resources. Work is accomplished through a structure of committees, sub-committees, and working groups consisting of federal and provincial government and universities.
CGCP	Canadian Global Change Program	Under the Auspices of the Royal Society of Canada, the CGCP is an independent inter-disciplinary and multi-agency network of scientists and specialists promoting awareness of global environmental change issues and interpreting research results to guide policy actions.
MBIS	Mackenzie Basin Impact Study	A six-year study by Environment Canada to assess the potential impacts of global warming on the Mackenzie Basin region and its inhabitants. The study takes an integrated approach in that it considers the interactions between the land and its people in addressing climate impact-related policy questions concerning water management, sustainability of ecosystems, economic development, infra-structure, and sustainability of native lifestyles.
MAGS	Mackenzie GEWEX Study	The Canadian component of GEWEX contributes to the better understanding and prediction of changes to water resources in Canada's north arising from climatic change. A series of large-scale hydrological and related atmospheric and land-atmosphere studies is being conducted within the Mackenzie River Basin.

PART C. REGIONAL AND LOCAL

	British Columbia Greenhouse Gas Action Plan	Prepared by the Ministry of Energy, Mines and Petroleum Resources and the Ministry of Environment Land and Parks, the plan contains more than 50 actions that the province will implement or evaluate over the next 2 to 3 years to slow the growth of greenhouse gas emissions.
BCYCCP	British Columbia and Yukon Climate Change Program	An informal association of representatives from various federal departments, provincial ministries, and other agencies located in British Columbia and Yukon. The BCYCCP provides government, industry and individuals advice on the possible impacts of climate change on the economy, natural ecosystems and resources of British Columbia and Yukon. It's goals are to encourage research into climate change impacts and adaptation, greenhouse gas emission reductions, and fostering communications with the public, stakeholders, and a link to he Canada Country Study.

APPENDIX 3

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