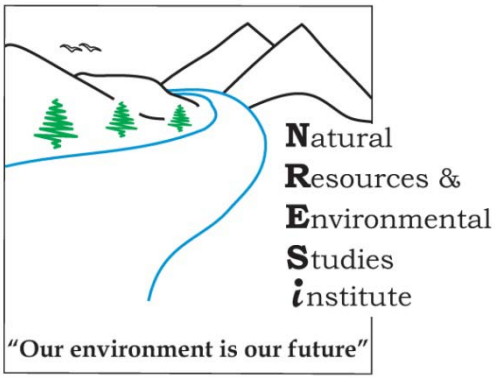


OCCASIONAL PAPER SERIES

NO 7 – October 2010

Climate Change Adaptation for British Columbia Forest and Range Ecosystems: An Analysis of Existing Research Frameworks and Research Needs for the Future Forest Ecosystem Scientific Council (FFESC)

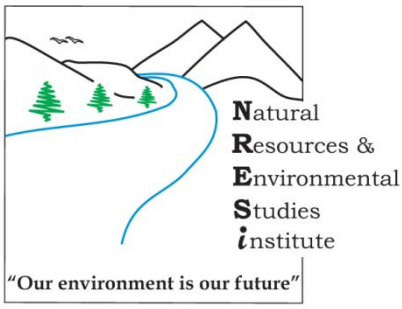
By
Sybille Haeussler

Dr. Haeussler is Research Coordinator, Future Forest Ecosystem Scientific Council, Ecosystem Science and Management Program, University of Northern British Columbia, 2041 Monckton Rd., Smithers, BC, V0J 2N4, Canada.

The correct citation for this paper is:

Haeussler, S. 2010. Climate Change Adaptation for British Columbia Forest and Range Ecosystems: An Analysis of Existing Research Frameworks and Research Needs for the Future Forest Ecosystem Scientific Council (FFESC). Natural Resources and Environmental Studies Institute Occasional Paper No. 7, University of Northern British Columbia, Prince George, BC, Canada.

This paper can be downloaded without charge from http://www.unbc.ca/nres/occasional.html



The Natural Resources and Environmental Studies Institute (NRES Institute) is a formal association of UNBC faculty and affiliates that promotes integrative research to address natural resource systems and human uses of the environment, including issues pertinent to northern regions.

Founded on and governed by the strengths of its members, the NRES Institute creates collaborative opportunities for researchers to work on complex problems and disseminate results. The NRES Institute serves to extend associations among researchers, resource managers, representatives of governments and industry, communities, and First Nations. These alliances are necessary to integrate research into management, and to keep research relevant and applicable to problems that require innovative solutions.

For more information about NRESI contact:

Natural Resources and Environmental Studies Institute
University of Northern British Columbia
3333 University Way
Prince George, BC Canada
V2N 4Z9

Phone: 250-960-5288
Email: nresi@unbc.ca
URL: www.unbc.ca/nres

CONTENTS

Supplmentary Databases

Executive Summary

The Future Forest Ecosystem Scientific Council of BC (FFESC), a partnership of the BC Ministry of Forests and Range (MFR), University of BC, and University of Northern BC, was formed in 2008 through a $5.5 million grant-in-aid from the Province of BC to promote research supporting adaptation of BC's forest and range management framework to anticipated effects from climate change.

This report and its supplementary databases were initially prepared for FFESC in March 2009 to (1) identify institutional arrangements for delivering climate change adaptation research and making the results available to stakeholders, (2) assess the status of research relevant to the FFESC mandate, and (3) recommend research and delivery needs that should be addressed by FFESC. In March 2010, after allocation of the majority of FFESC funds, databases were updated and an evaluation was made of how well the research program addressed the identified needs. The report provides an overview of international- to regional-level agencies and institutional networks conducting and funding climate change research relevant to BC's forest and rangeland social-ecological systems. There are also syntheses of recent directions in climate change research and links to supplementary databases listing relevant research topics and funded research projects. All opinions and evaluations in this report are my own and do not represent the position of the Scientific Council.

I made 7 general and 14 specific recommendations to guide the FFESC call for 2-yr research proposals in May 2009. The recommendations called for a balanced program of scaled-down impacts, adaptation, vulnerability, and adaptation-mitigation research in the natural and social sciences. Interdisciplinary case studies building on the best-available international science and using existing multi-scaled modeling frameworks were recommended. I proposed that any new fieldwork provide improved parameter estimates for modeling. Focused projects addressing climate and disturbance interactions, grassland carbon sequestration, background tree mortality rates, benefits and risks of assisted tree migration were suggested. A cross-scale evaluation of BC's land and resource management plans, and legal and economic analysis of policy options was also recommended.

By December 2009, FFESC had committed $4.8 million to 25 research projects ranging in size from $10,000 to $700,000. Five projects were direct-awarded in 2008/09, 16 were competitively awarded through the Call for Proposals and 4 were internal MFR projects funded by redirecting MFR's portion of the FFESC administration budget to research. I used quantitative indicators (e.g., % of budget allocation) to evaluate the 21 original recommendations and determined that 9 were well-addressed, 6 moderately well-addressed, and 6 poorly-addressed by the FFESC research program grants. Recommendations for more international engagement and to address institutional barriers to change by embedding young researchers in the policy environment were not achieved. FFESC opted to fund only interdisciplinary social-natural sciences projects, thus several narrower priorities were not funded. Overall, the research program is geographically well distributed (albeit no projects in the far north of BC), and has an excellent balance among the four FFESC objectives of understanding changes, forecasting impacts, developing adaptation options, and researching economic and social consequences of climate change.

Introduction

The Future Forest Ecosystem Scientific Council (FFESC)[1] is a partnership of the BC Ministry of Forests and Range (MFR), the University of British Columbia (UBC), and the University of Northern British Columbia (UNBC), established in March 2008 by means of a $5.5 million grant-in-aid from the Province of BC to promote research supporting adaptation of BC's forest and range management framework to anticipated effects from climate change. Three representatives from MFR, and two each from UBC Faculty of Forestry and UNBC College of Science and Management sit on the Scientific Council and make decisions related to the disbursement of the funds. The FFESC partnership will terminate March 31, 2012.

This report was prepared for FFESC to assist in developing and evaluating its research program. The original (March 2009) objectives for the study were: (1) to identify institutional arrangements or frameworks for delivering climate change adaptation research and making the results available to stakeholders; (2) to assess the status of research relevant to the FFESC mandate; and (3) to identify research and delivery needs and recommend how they should be addressed by FFESC. In March 2010, after the majority of FFESC funds were committed, an evaluation was made (4) to determine how well the identified needs and recommendations were addressed by the FFESC research program. All opinions and evaluations in this report are mine, as a member of the FFESC support staff. They do not represent the position of the Scientific Council.

[1] A list of abbreviations with links to organization websites is found on page 36

FFESC Research Objectives

FFESC, in its Terms of Reference and Charter, established four specific objectives (Table 1a), and also committed to supporting delivery of MFR's Future Forest Ecosystem Initiative (FFEI), whose Research Objectives (Table 1b) and Research Priorities (Table 1c) were also listed in the FFESC Charter.

The FFESC objectives (Table 1a) were broad and essentially delineated four steps in the acquisition and application of knowledge related to climate change effects on forest and rangeland ecosystems and their social and economic consequences:

1. Understanding climate change impacts on ecosystems (basic research and monitoring).
2. Projecting climate change impacts on ecosystems (forecasting, modeling, vulnerability assessments).
3. Developing adaptation measures to reduce ecosystem impacts (methods, policies and applications).
4. Evaluating economic and social consequences of ecological impacts and adaptation measures (Steps 1 to 3 above as they relate to interdependent social-ecological systems).

These objectives did not constrain the research topics or suggest priorities but rather indicated that any type of climate change impacts, social sciences pertaining to the management of forest and range ecosystems and the BC communities that depend upon them, lay within the research mandate of FFESC.

The FFEI objectives and priorities (Table 1b and c) were more specific. They also explicitly added carbon sequestration and accounting in forest and range ecosystems (mitigation), to the impacts, vulnerability and adaptation scope defined by the FFESC objectives. After discussion, FFESC concluded that it would engage in forest carbon research, provided that this work

Table 1. FFESC and FFEI Objectives and Priorities listed in FFESC Charter, March 2008.

(a) Future Forest Ecosystem Scientific Council (FFESC) objectives

1. Increase our understanding of how forest and range ecosystems can be expected to change over time as a result of climate change.
2. Develop projections to forecast those changes.
3. Develop methods of adapting forest management in response to climate change that will help reduce the impacts on forest and range ecosystems and productivity.
4. Research the economic and social consequences to BC of the changing forest and range ecosystems, and of the effects of the proposed adaptation option.

(b) Future Forest Ecosystem Initiative (FFEI) research objectives

1. Identify functional constraints for key species and ecological processes to establish a baseline of information for forecasting and monitoring ecosystem changes.
2. Develop forecasting models to determine how key species and ecological processes might respond to potential future climates.
3. Develop scientific approaches to (a) monitoring ecosystem changes and (b) evaluating existing and new approaches to forest and range management under changing ecological and climatic conditions.
4. Monitor and document the effects of climate change on key species and ecological processes.
5. Carry out experimental tests or trials of existing and new approaches to forest and range management for their effectiveness under changing ecological conditions.
6. Assess the environmental, economic and social risks and benefits associated with implementing climate change adaptation strategies and practices.
7. Communicate and extend knowledge gained through research activities to the forest and range management community.

(c) Future Forest Ecosystem Initiative (FFEI) first set of research priorities

1. Studies on the impacts of forest management actions such as harvesting in mountain pine beetle areas and fertilizing on the coast, on the forest carbon balance and CO_2 emissions.
2. Predict effects of climate variability on forest growth at the regional level to assist in long-term timber supply analysis.
3. Develop understanding of the effects of declining species in forest stand composition on the management of the current and future timber supply (e.g. yellow cedar decline along the coast).
4. Expand our ability to forecast future risk of insect and disease pests of commercial conifer and hardwood species.
5. Understand the effects of a warming environment to Northern BC hydrology and geomorphology, where there is evidence of increasing landslides.
6. Understand the effects of climate change on wildfire and wildfire prediction, and the impacts on hydrologic and geomorphologic processes.
7. Assess the vulnerability of dominant tree species to successful regeneration under various climatic projection scenarios.
8. Determine the primary vulnerabilities, adaptation opportunities and challenges to BC and Canada's main tree species (including genetic, mortality and pest susceptibility issues).
9. Identify the tolerances of major grasses, forbs, and shrubs to predicted levels of climate change and determine implications for the range industry.
10. Determine how changing climate will affect wildlife habitat supply, (especially where there are compounding environmental impacts such as in the mountain pine beetle region).

considered interrelationships or trade-offs between mitigation and adaptation (Klein et al. 2007). Carbon sequestration research that did not address how carbon budgets, ecosystem health and socio-economic systems might change as a result of a warming climate, nor how the mitigation activities themselves might affect forest and rangeland social-ecological systems would not be undertaken by FFESC.

Institutional Frameworks for Climate Change Research

The purpose of this section of the report is to summarize the status of institutions, agencies and networks engaged in climate change research at international, national, provincial and regional levels and to indicate how their work is relevant to the objectives of FFESC. Sources of funding for climate change adaptation research at the international, national and provincial level were also compiled (Supplementary Database I).

International

The United Nations Environmental Program (UNEP) together with a host of related international bodies has conducted two major intergovernmental assessments of particular relevance to the work of FFESC. The most important of these is the well-known *Intergovernmental Panel on Climate Change (*IPCC), which completed its Fourth Assessment Report (AR4) in 2007 and published several earlier special reports on forestry and land use (Watson et al. 2000, Penman et al. 2003a,b). IPCC sets international standards for climate change research and policy and develops terminology (see Glossary) and frameworks that allow for efficient communication and data-sharing. IPCC Assessments are completed by three working groups: Working Group I assesses the current state of climate science (topics related directly to the atmosphere, weather and meteorology); Working Group II assesses climate change [2] impacts, adaptation and vulnerability in natural and human systems; and Working Group III assesses the mitigation of climate change (ways to reduce emissions and increase sequestration of greenhouse gases). The four FFESC Objectives (Table 1a) neatly encompass the scope of work addressed by Working Group II (Parry et al. 2007) within the context of BC forest and range ecosystems.

The second recent intergovernmental assessment that is highly relevant to FFESC is the Millennium Ecosystem Assessment (MEA), which assessed the consequences of ecosystem change for human well-being. The MEA was broader than the work of IPCC in that it recognized climate as just one of many drivers causing ecosystem change, but the assessment focused exclusively on ecosystems. The MEA analytical frameworks and terminology have rapidly gained worldwide currency. Two particularly important contributions of the MEA were (1) advancing and systematizing the ecosystem services concept as a way of formally valuing the benefits people obtain from healthy ecosystems, and (2) refining integrated social-ecological assessment techniques such as scenario analysis.

Both the IPCC and MEA clearly stated that natural and social scientists and policy makers cannot continue to work in independent orbits and provided new tools for achieving the much-needed integration. Their global-scale analytical frameworks need, however, to be adapted and applied to regional and local scale contexts. By adopting the IPCC and MEA research frameworks and terminology, FFESC can improve two-way information exchange. Results from FFESC research should be

[2] IPCC and MEA terms highlighted in the text are defined in the glossary (page 37)

available in time to inform the IPCC's Fifth Assessment Report (AR5) scheduled for completion in 2013 - 2014. Moreover, new directives from the IPCC and other world bodies will more readily be translated into MFR policy and practices if FFESC outputs are compatible with their approach.

Beyond the intergovernmental processes sponsored by the United Nations and related agencies, there are many national-level climate change research initiatives occurring around the world that can inform the activities of the FFESC and its research scientists (Almuedo 2008). For example, the United States Global Change Research Program (USGCRP) has produced a set of synthesis and assessment reports that address topics such as best practices for incorporating scientific uncertainty in decision-making (Morgan et al. 2009b), thresholds of climate change in ecosystems (Fagre and Charles 2009), and adaptation options for climate-sensitive ecosystems and resources (Julius and West 2008). Similar science and policy overviews are being generated around the world at a staggering rate (e.g., Feix et al. 2009, Steffen et al. 2009). These reports contain useful synthesis information, backed up by field and modeling studies, that closely address the objectives of the FFESC.

National/Federal

The Federal Government of Canada divides climate change and ecosystem-related policy and research among several Ministries or Departments such as Natural Resources Canada (including the Canadian Forest Service), Environment Canada, Parks Canada, Agriculture and Agri-Food Canada. These programs are in an ongoing state of flux with acronyms that appear to change yearly. Most climate science and mitigation work and a small amount of the impacts, adaptation and vulnerability work is carried out within Environment Canada. Since 2005, Environment Canada has hosted the Canadian Climate Change Scenarios Network (CCCSN) whose purpose is to support climate change impact and adaptation research in Canada and other countries. The Network provides access to global and regional climate scenarios and links to the work of the Adaptation and Impacts Research Division (AIRD), an Environment Canada research group that conducts research at the UBC Faculty of Forestry and other Canadian universities. In BC, Environment Canada has been most active in addressing climate change impacts and adaptation related to water availability in the Okanagan Basin (Cohen and Neale 2006).

Natural Resources Canada (NRCan) supports most of the impacts and adaptation research at the federal level though its Climate Change Impacts and Adaptation Division (CCIAD) within the Earth Sciences Sector, headquartered in Ottawa. CCIAD has produced a high level Canada-wide impacts and adaptation assessment report (Lemmen et al. 2008) based on the work of the now-defunct Canadian Climate Impacts and Adaptation Research Network (C-CIARN). The Network's BC Region was initially located at the UBC's Institute for Resources, Environment and Sustainability (IRES), and later at its Department of Sociology. C-CIARN Forest Sector group was headquartered at the Canadian Forest Service's Northern Forestry Centre in Edmonton. These sub-networks produced publications, presentations and conferences proceedings, many highly pertinent to the objectives of FFESC, available on the C-CIARN Archives website. In 2004, the Forest Sector Sub-Network produced a list of climate change impacts and adaptations research needs (Supplementary Database II-A). C-CIARN engaged researchers from universities, government and other institutions across Canada, many of whom also contributed to the IPCC Working Group II report).

CCIAD's report (Lemmen et al. 2008) made general climate change recommendations for

BC ecosystems and the forestry sector, emphasizing the importance of building adaptive capacity at the local level by engaging local stakeholders, strengthening governance, and integrating climate change adaptation into other planning and community development activities. The report highlighted a need for down-scaled, locally relevant impact assessments and forest modeling, as well as more research on alternative industrial and economic activities, such as agriculture and biofuels, to support economic diversification.

CCIAD and its predecessors have been involved since the 1990s in studying the implications of climate change on water availability in the Okanagan Basin (Leith and Whitfield 1998). In 2009, CCIAD launched a program of Regional Adaptation Collaboratives (RACs) to work with provincial and regional governments across Canada to catalyze coordinated action on climate change adaptation planning and decision-making. A $6.9 million RAC for BC, involving a partnership with the Fraser Basin Council, BC Ministry of Environment, Okanagan Water Basin Council and other agencies to focus on water resources in southern BC, was awarded in January 2010 (NRCan 2010). The project addresses water allocation and use, hydrology of forest watershed, flood protection and floodplain management, and community adaptation, and will include both research and implementation components.

The Canadian Forest Service (CFS), which has western research stations in Victoria, Edmonton and a small research group at UNBC in Prince George, is engaged in a wide variety of climate change research including:

- assessing the sensitivity of Canadian forests to climate change (e.g., Chhin et al. 2008, Williamson et al. 2009);
- determining the contribution of Canadian forests and their management to the carbon cycle, including the CBM-CFS3 carbon dynamics model (Kurz et al. 2009) and Fluxnet-Canada carbon monitoring installations on Vancouver Island, Prince George and Saskatchewan (Grant et al. 2009);
- changes in ecosystem function and changes in disturbance regimes related to fire, insects, and diseases (e.g., Burton et al. 2005, Aukema et al. 2008);
- climate change impacts on the productivity and health of aspen, including Fort Nelson, BC study sites (Hogg et al. 2005, 2008);
- vulnerability of forest-based communities to current and future climate (Williamson et al. 2007, 2008);
- implications of climate change for forest management (e.g., Wellstead et al. 2006, Lempriere et al. 2008);
- impacts of climate change on protected area management (e.g., Freedman et al. 2009, Rose and Burton 2009).

Moreover, much of the CFS's ongoing research that is not currently focused on climate change also bears directly on topics of interest to FFESC, for example, modeling forest insect and disease dynamics and multi-scaled economic analyses of forest-dependent communities.

At the Agriculture and Agri-Food Canada Range Research Unit in Kamloops, plant physiological and soil science researchers are investigating some effects of climate change on rangelands (e.g., Bai et al. 2004, 2005). The Pacific Agri-Food Research Centre in Summerland studies water supply and demand issues in the Okanagan Basin under climate change (e.g., Neilsen et al. 2000).

The Sustainable Forest Management Network (SFMN) was a forest research initiative funded through the federal Networks of Centres of Excellence of Canada program (NCE) that addressed many topics of interest to FFESC. SFMN began in 1995 and terminated in 2009. Headquartered at the

University of Alberta, it emphasized collaborative and interdisciplinary research among natural and social scientists at universities and government agencies across Canada, in partnership with the forest industry, First Nations and forest-dependent communities. While relatively few SFMN-supported research projects specifically targeted climate change (Supplementary Database IV), and most research took place outside BC, many of the theoretical and methodological advances made during the 15-yr duration of the program directly address issues of importance to FFESC. These include:

- direct engagement of First Nations in forest sector adaptation (Stevenson and Natcher 2009);
- social-ecological resilience and adaptive co-management of natural resources (Davidson-Hunt and Berkes 2003, Armitage et al. 2009);
- advances in simulation modeling including cross-scale and social-ecological analysis (Duschesneau 2005, Sturtevant et al. 2007);
- forest sector vulnerability assessments and scenario analysis (Duinker and Greig 2007);
- risk assessment and decision-support models (Martell et al. 2004, Gardiner et al. 2008);
- improved forest monitoring through the use of sustainable forest management indicators (Kneeshaw et al. 2000, Leake et al. 2002, Adam and Kneeshaw 2009);
- enhanced communication among researchers and policy makers, and translation of research findings into high level policy (e.g., SFMN KETE Subcommittee 2006, SFMN 2009b).

FFESC stands to benefit greatly by building on lessons learned by SFMN, rather than duplicating its efforts in a BC climate-change context. MFR and FFEI have prepared a set of climate change vulnerability assessments for BC forestry (Morgan et al. 2008, 2009a) that grew directly out of the work of SFMN.

The Federal Government, through the Canadian Forest Service, also funded the Canadian Model Forest Network (1997-2007) and funds its successor, the Forest Communities Program (2008). Although the program does not focus on climate change, it includes case studies of local adaptation to climate change and efforts to better integrate forest science with social science and management practices. Resources North (2010; formerly the McGregor Model Forest Association) is funded through this program. The McGregor Model Forest hosted a climate change conference in Prince George (Wainright and Zimmerman 2006) which led to the formation of the Northern Climate Change Network (NCCN), now housed with Resources North. NCCN serves as an extension service for all climate-change related topics in northern BC, not strictly those affecting the forest and range sector.

The Canadian Council of Forest Ministers (CCFM) produced a "Vision for Canada's Forests" (CCFM 2008) that stresses integration of climate change readiness into all aspects of sustainable forest management. CCFM focuses on national-and international-level integration of forest policy across Canada and undertakes higher level policy research and synthesis on issues related to forest sector innovation, stewardship and sustainability with funding from the federal, provincial and territorial government agencies responsible for forest management. In 2008 and 2009, FFESC contributed funding on behalf of MFR for a Canada-wide collaborative climate-change adaptation strategy whose first product was a national-level assessment of tree species vulnerability to climate change (Johnston 2009). CCFM oversees Canada's Criteria and Indicators program to ensure that it meets international treaty commitments. Policy research and recommendations related to monitoring of

climate change indicators in BC (Eddington et al. 2009) need to be compatible with the CCFM framework.

The BIOCAP Canada Foundation was a network of Canadian university and governmental researchers sponsored by federal and provincial agencies and the energy and agricultural industry that operated from 1997 to 2008 to fund Canadian university research to develop biomass-based solutions to the challenges of climate change and energy security. BIOCAP issued publications on bio-energy, research integration, carbon sequestration in forests and climate change challenges for the forest sector, including 'Adapting Forest Management in Canada to Climate Change (Johnston et al. 2006) and "Threats and Impacts of Exotic Pests under Climate Change: Implications for Canada's Forest Ecosystems and Carbon Stocks" (Hunt et al. 2006; Supplementary Database IV). BIOCAP established the Fluxnet-Canada Research Network now renamed the Canadian Carbon Program (CCP) which studies carbon cycling in Canadian forests and peatlands.

Canada's Natural Sciences and Engineering Research Council (NSERC) has several funding programs that specifically address climate science and climate change adaptation as well as general Discovery Grants and Graduate and Postdoctoral Scholarships that support climate change research. From 2000 to 2010, NSERC funded more than 170 research projects (totaling approximately $12 million) relevant to climate change impacts and adaptation in BC forest and rangeland ecosystems (Supplementary Database IV).

The Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) is the primary NSERC-supported funding body for university-based research on climate, atmospheric and related oceanic work in Canada. Its 10-year lifespan will end in 2010. CFCAS has focused primarily on climate science but funded several projects related to the FFESC mandate, notably the Fluxnet-Canada Research Network and CCP, the CBM-CFM3 carbon model, and the Western Canadian Cryospheric Network (WC^2N) which studies links between climate change and glacial ice conditions in Western Canada and is hosted at UNBC.

NSERC also funds climate-related research related to biodiversity and sustainable water supplies through the Healthy Environment and Ecosystems envelope of its Strategic Project Grants program (NSERC 2010). April 2010 will be the final call for Healthy Environment and Ecosystems proposals and NSERC is defining new research Strategic Project target areas for 2011 – 2015. Recent emphasis has been on interdisciplinary research collaborations that extend outside the natural sciences and engineering to include social and health scientists and non-governmental partners.

The Social Sciences and Humanities Research Council of Canada (SSHRC) funds research focusing on the social, cultural, economic and public policy dimensions of climate change impacts, adaptation and mitigation, mainly through its Community-University Research Alliances (CURAs) and the one-time 2008 Canadian Environmental Issues Special Call (SSHRC 2010a). Since 2000, SSHRC has funded some 100 research projects (totaling approximately $4.1 million) on topics relevant to FFESC's mandate (Supplementary Database IV). These include the Resilient Communities Project (2006) and the Coastal Communities Project (2008) which addressed climate change adaptation along with other social-ecological resilience and capacity-building issues in remote First Nations communities of coastal BC. None of the 2009-10 climate change CURAs announced in February 2010 addressed BC forest or rangeland ecosystems (SSHRC 2010b).

NSERC and SSHRC recently joined forces with the Canadian Institutes of Health Research (CIHR) and the International Development Research Centre (IDRC) to fund the $12.5 million International Research Initiative on Adaptation to Climate Change (IRIACC). IDRC is a Canadian Crown Corporation supporting researchers in the developing world. The program targets vulnerable populations, resources and ecosystems in Canada along with those of lower income countries. Topics include impacts of extreme weather events, water shortages, fire, exotic species and pests on ecosystems and vulnerable human populations, and strategies that enhance societal capacity to adapt. There may be opportunities to leverage FFESC research through this program. IRIACC's first proposals should be approved by late 2010. It is unknown whether there will be future proposal calls.

National environmental non-governmental organizations (ENGOs), such as the Pembina Institute, David Suzuki Foundation, Yellowstone to Yukon Conservation Initiative and Canadian Parks and Wilderness Society (CPAWS), often with funding from major US or Canadian philanthropic foundations, are becoming significant players in climate change research in BC. Increasingly, ENGOs are combining advocacy work with scientific collaborations that involve universities, land management agencies, First Nations and graduate students in sophisticated GIS analyses and other science-based undertakings. The Nature Conservancy of Canada, for one, has partnered with UNBC, CFS and MFR to undertake a climatic analysis of protected areas in central BC (Rose and Burton 2009). In northwest BC, CPAWS and Rivers Without Borders (supported by the Tides Canada Foundation) are collaborating with the Taku River, Tlingit First Nation, Pacific Climate Impacts Consortium (PCIC) and BC's Integrated Land Management Bureau (ILMB) to incorporate climate change research and planning into a conservation strategy for the Atlin-Taku planning area (CPAWS 2010). Recently, the Working Group on Biodiversity, Forests and Climate, an alliance of 7 ENGOs, produced a scientific synthesis of the implications of climate change for biodiversity conservation and carbon storage in BC's forests (Pojar 2010).

Provincial

The Province of BC has created a variety of climate-change initiatives since 2007 including the over-arching Climate Action Team (CAT) and Climate Action Secretariat (CAS) which work with all government ministries, a Climate Change Branch within the BC Ministry of Environment (MOE), and many climate change- or carbon-focused work groups within individual government ministries. BC also created the Pacific Carbon Trust (PCT) a provincial Crown corporation whose purpose is to deliver made-in-BC greenhouse gas offsets, the Pacific Institute for Climate Solutions (PICS), and PCIC. CAT, CAS and PCT focus almost exclusively on mitigation. MOE Climate Change Branch, PICS and PCIC address climate science, impacts, vulnerability and adaptation as well as mitigation. Within government, however, most impacts, adaptation and vulnerability work is carried out by existing staff within individual government departments responsible for the resources affected by climate change rather than by climate change specialists.

In 2007, MFR created the FFEI to address climate change impacts, adaptation and vulnerabilities and carbon accounting in BC forests and rangelands. MFR has a small Climate Change and Forest Carbon work group, but FFEI mostly involves research scientists and professionals in other Victoria-based and regional work units. In 2008, MFR created FFESC with a $5.5 million grant-in-aid to support climate change research

relevant to its mandate. MFR initially had an in-house budget for FFEI work and also funded climate-related projects through the Forest Investment Account – Forest Science Program (FIA-FSP; Supplementary Database IV). In 2009, MFR's internal FFEI budget was essentially eliminated and FIA-FSP cancelled funding of new projects. Since then, MFR has funded almost all non-salaried costs of FFEI work through the FFESC grant.

MOE is responsible for the diversity of provincial ecosystems, fish and wildlife species and their habitat, fish and wildlife recreation services, marine resources and fisheries. It also manages lands and resources within provincial parks, ecological reserves and other protected areas and is responsible for water allocation and protection from floods and drought. There are many areas of overlap between the concerns of MOE and MFR. MOE has very limited research capability and mostly collaborates with researchers in universities, ENGOs, MFR and federal agencies. In September 2009, MOE completed a Climate Change Adaptation Research Agenda that identified priority topics (Supplementary Database II-B). MOE has sought funding for this agenda by participating in the FFESC proposal call, through a submission to PICS, and by encouraging other academic, government and ENGO researchers to consider their priority issues when developing research proposals.

Other BC government departments such as ILMB, Transportation and Infrastructure, and Aboriginal Affairs and Reconciliation also have climate change interests that overlap those of MFR. These agencies rarely conduct in-house scientific research, but are involved in planning initiatives that may include a climate change research component undertaken on their behalf by academics, contractors or NGOs. For example, ILMB partnered with the Taku Tlingit First Nation, PCIC and several ENGOs to map and model climate change vulnerability in the Atlin-Taku planning area (see CPAWS above).

PICS and PCIC are hosted at the University of Victoria (UVic) and funded by a $94.5 million grant from MoE. PICS is a partnership of UVic, Simon Fraser University (SFU), UBC and UNBC. Its mission is to research, monitor, and assess the potential impacts of climate change and to develop and promote viable mitigation and adaptation options. In 2008, PICS released 8 discussion papers on policy questions for BC including (1) adaptation planning for BC (Harford et al. 2008), (2) carbon sequestration in BC's forests (Black et al. 2008), and (3) sustainable communities (Robinson et al. 2008), each with a list of key research needs. PICS has a "Resilient Ecosystems" research theme (Hall and Higgs 2010) that overlaps the FFESC mandate and hosted a forestry and climate change workshop in March 2010. To date, PICS has funded 12 graduate and postdoctoral fellowships for research on forest and rangeland ecosystems and adaptation in rural communities (Supplementary Database IV). It also maintains the Climate Solutions Network (CSN), a database of climate change specialists.

PCIC was formed in 2005 by MoE, BC Hydro and UVic to capitalize on UVic's internationally renowned Canadian Institute for Climate Studies (CICS). Its purpose is to stimulate collaboration between government, universities and industry to reduce vulnerability to extreme weather events, climate variability and the threat of global change … and to make practical information available to government, industry, and the public". PCIC has focused on downscaling and analysis of climate data for regions and communities (e.g., Dawson et al. 2008, Picketts et al. 2009), watershed hydrology (Rodenhuis et al. 2009), ocean impacts, and forest health (Abbott et al. 2007; Murdock and Flower 2009), but also plans to undertake socio-economic research. PCIC staffers

collaborate with MFR scientists and others in the forest and range science community, and seek research funding from a variety of sources in addition to PICS, including FIA-FSP, BC Hydro, MFR, MOE and FFESC.

Regional

Within BC there are several regional centres that disseminate climate change information and carry out climate-related extension work. These include the NCCN, based at Resources North in Prince George (see above), and the Fraser Basin Council (2010) which monitors sustainability indicators and operates the BC Climate Exchange (2010). For forest and range issues, FORREX, a provincial extension network centred in the Southern Interior, provides a similar service. Regionally-focused climate change research is done by BC government regional offices, smaller universities such as UNBC (including the NRES Institute), Thompson Rivers University (TRU), UBC Okanagan and Vancouver Island University, and regional not-for-profit research centres such as the Columbia Mountains Institute in Revelstoke (CMI) and Bulkley Valley Research Centre in Smithers (BVRC). FFESC can work with these agencies to deliver extension throughout BC rather than creating an independent communication arm.

Research Topics and Information Needs

A detailed list of climate change research topics addressing the objectives of FFESC was compiled from the documents, assessment reports and websites of the organizations described above (Supplementary Database III, summarized in Table 2). Mitigation was included, but climate science was not, except for a few topics that accommodate climate downscaling and integration of climate models with forest and range models. Although the integration of social and economic research with natural sciences research is an emergent worldwide phenomenon, it proved to be inefficient for this analysis since already-funded research projects were highly segregated between the natural and social sciences.

A list of 418 climate change research projects (2000 – 2010) relevant to BC forest and rangeland ecosystems and to the communities that depend on them was compiled (Supplementary Database III). For the natural sciences, the list included projects located in BC or in similar mountain and grassland ecosystems of Western Canada (includes some southern Yukon, Alberta and western Saskatchewan sites). For the social sciences, projects from across Canada were included where they appeared to be highly relevant to the social and policy questions faced by BC forest and rangeland decision makers or communities. No US or overseas research projects were included.

For the March 2009 analysis, the topics in Database III and an initial list of 170 BC-based projects were cross-tabulated to identify research needs that could be addressed by FFESC. Research recommendations and priorities were subsequently developed. This was a subjective synthesis, based on the recent literature, my personal experience and limited discussions with FFEI team members, UBC and UNBC forest scientists. Its intent was to rapidly move forward with a call for FFESC research proposals, rather than to conduct an in-depth analysis of a complete database. There was no attempt to formally survey or interview key players in the climate change adaptation sciences and policy arena.

The results showed a wide range of topics, with emphasis on the vulnerability of commercial tree species (ca. 10% of projects), effects of climate change on major tree insect and diseases (ca. 14%), forest carbon accounting experiments (ca. 15%), and high level socio-economic vulnerability

Table 2. Potential FFESC research topics (detailed list in Supplementary Database III)

1	**Mitigation = Increasing carbon sequestration and reducing greenhouse gas emissions from the forest and range sector**
1.1	Land based research -that directly contributes to models such as CBM-CFS3 (Black et al. 2008)
1.1.1	Forest and rangeland carbon cycles across multiple scales and multiple forest types
1.1.2	Multi-scale analysis of forest and rangeland management practices to enhance carbon storage
1.2	Industrial research -that directly contributes to carbon cycle models
1.2.1	Carbon cycling and storage in the wood products lifecycle, including salvaged and novel wood products.
1.2.2	Carbon cycling and reduction of GHG emissions in forestry operations
1.3	Mitigation-adaptation integration
1.3.1	Effects of adaptation measures to promote ecosystem and community resilience on carbon sequestration
1.3.2	Effect of mitigation measures to promote carbon sequestration on ecosystem and community resilience
2	**Impacts = Monitoring, predicting, and modeling change, vulnerability and risk assessments in forest and range ecosystems**
2.1	Predicting climate change impacts on forest and range species and ecosystems
2.1.1	Genomics, epigenetic effects, common garden experiments, hybridization studies (Aitken et al. 2008)
2.1.2	Physiology and population ecology of tree species, other plants, animals, microbes, invasive species
2.1.3	Community, ecosystem & landscape shifts, disturbance regimes, wildlife habitat supply
2.1.4	Hydrological and geomorphological impacts
2.1.5	Interactions of forest and range with aquatic ecosystems
2.1.6	Forest and rangeland growth and yield modeling for a changing climate
2.1.7	Cross-scale meta-modeling approaches that integrate levels of biological organization and disciplines
2.2	Monitoring and risk assessment
2.2.1	Improved methods for risk assessment (rapid, multi-scale, complex interactions)
2.2.2	Mapping and display tools for communicating climate change impacts
2.2.3	Improved monitoring indicators and technologies
3	**Adaptation of forest and range policies and practices to reduce social-ecological consequences of climate change**
3.1	Gene management (assisted migration, selection and breeding of commercial species and species at risk)
3.2	Forest protection (fire, insects, diseases, other invasive species) & Protection Forests
3.3	Regeneration and silviculture
3.4	Forest, range and recreation operations (harvesting, grazing management, road access)
3.5	Wildlife and biodiversity management in forests and rangelands
3.6	Forest and range land use planning
4	**Social and economic impacts, vulnerability and adaptation**
4.1	Social and economic impact analyses of climate change with and without mitigation and adaptation strategies
4.2	Forest and range sector and community communication, education and public participation
4.3	Behavioural research (adapting best available science to forest & range sectors)
4.4	Policy and legal analysis

assessments or community capacity building exercises (ca. 15%). There was a reasonable distribution of projects between the four major categories of research, but Forest and Range Practices Adaptation (ca. 15% of listed projects) had received considerably less attention than Forests and Range Resources Impacts and Vulnerability (ca. 30% of listed projects). Most of the key topic areas were recently reviewed at a high level. There was, however, relatively little detailed, site-specific or resource-specific modeling work, and little translation of overview assessments into concrete policy measures or adaptation practices, although some of this work was underway through FFEI.

It wasn't possible to determine from the cross-tabulation whether a concentration of effort indicated that solutions were close at hand, or whether the problem was a difficult one requiring much additional research. Deficiencies in certain topic areas (e.g., policy and sociological analyses) were partly an artefact of databases included in the initial search. Adding the SSHRC database identified 88 additional research projects related to policy and sociology, with 65% of the relevant work taking place outside BC (Supplementary Database IV).

Review of the climate change assessment literature found no lack of recent high level syntheses providing broad or generic recommendations for science and policy approaches to better understand, predict, and adapt to climate change effects on ecosystems and human communities. A considerable international consensus on the key approaches and necessary changes to current science and policy has emerged (Table 3). Recurring themes are: (1) better treatment of risk and uncertainty and enhancing flexibility of management response; (2) working with and learning from other disciplines in science and management; (3) resilience and complex systems approaches (4) cross-scale processes and linkages in modeling; (5) integration of natural science with policy and social behaviour.

Important progress has been made in recent years in the development of analytical frameworks that are designed for practical decision-making (Parry et al. 2007). Where there are still significant knowledge gaps and a lack of consensus within all thematic areas and disciplines, is in the application of these analytical frameworks to specific problems, policies and practices in the BC forest and range sector. Recent reports usually include one or more descriptive case studies, typically involving the mountain pine beetle epidemic as a wake-up call for BC (e.g., Lemmen et al. 2009), and generic solutions are proposed, but we are just at the beginning of seeing these recommendations translated into well-documented local or regional scale case studies with quantitative analyses and concrete recommendations for action.

Practical recommendations for forest and range sector adaptation to climate change have appeared in the literature since the mid 1990s and were well summarized for BC by Spittlehouse and Stewart (2003; Supplementary Database II-C). Their list is still highly relevant and makes one wonder exactly what has been accomplished over the past 7 years. No items can yet be crossed off the list as having been substantially achieved.

There is one important issue related to climate change adaptation with significant policy and research investment implications about which no consensus has been achieved. A divide exists between those who believe that more data and better multi-scale climate and ecological models are badly needed to predict and respond to climate change impacts and those who believe that complex and chaotic system behaviour and the butterfly effect (Hilborn 2004) mean that the future will always be impossible to predict with certainty. For the latter group, resources should not be invested in more sophisticated predictions

Table 3. Major points of consensus on how forest and range science and management must change to address climate change.

Uncertainty and Risk Management

- Conduct research that not only reduces uncertainty, but also better quantifies and communicates uncertainty
- Enhance understanding of uncertainty and risks by decision-makers and stakeholders
- Identify and estimate risks and opportunities, by adapting risk management approaches from other disciplines such as the insurance industry, public health, and finance
- Leverage scientific efforts in other complex system disciplines (e.g., epidemiology)
- Identify critical system thresholds to be avoided using rigorous, reliable tests and better models that provide advance warning of threshold behaviour and enable action to be taken.
- Increase flexibility of management response rather than further bureaucratizing decision-making processes
- Adopt a diversity of approaches

Cross-Scale Resilience

- Enhance social and ecological resilience by determining major cross-scale drivers and linkages that influence resilience, monitoring rigorously, and taking action to reduce known stressors and reinforce linkages
- Improve understanding of effects of decreasing or increasing complexity on resilience
- Increase cross-sectoral and cross-scale linkages in research and decision-making (stand-to-regional scale, interdisciplinary research, interagency coordination, working with adjoining jurisdictions)
- Enhance functional diversity and redundancy in ecological and social systems
- Reduce other ecosystem or management stressors

Multi-scale Modeling and Scenario Analysis

- Model across scales –combine top-down (climate-driven) drivers and bottom-up (local level) processes
- Model interactions among major drivers of change
    - At the ecosystem level, consider especially interactions among climate, wildfire, insects and diseases, novel species and nutrient cycling processes
    - At the socio-ecological level, consider especially interactions among ecosystem, demographic, cultural and economic drivers
- Conduct interdisciplinary, integrative vulnerability assessments that capture bio-geophysical and socio-economic processes
- Create scenarios and storylines that bound the range of possible outcomes
- Analyse, manage and prepare for climatic and disturbance extremes and ranges rather than for means
- Use a consistent set of climate scenarios across sectors and scales that encompasses a range of possible climate futures and their extremes rather than merely central tendencies
- Better integrate spatially explicit and aggregate (non-spatial) assessment models

Monitoring

- Improve monitoring to provide feedback and early warning using repeated, standardized, high quality inventories of both provisioning (fibre, food, water) and non-provisioning ecosystem services
- Better integrate high quality monitoring data across scales & sectors
- Improve ability to examine trade-offs between ecosystem services affected by climate change and

adaptation measures (e.g., timber vs. biodiversity)

Table 3. Continued

- Improve understanding of the link between biodiversity and ecosystem function or provision of ecosystem services and how these are affected by climate change and adaptation measures
- Construct and make better use of large, integrated databases and networks using advanced technology
- Improve capability to generalize the results of high quality local data
- Monitor adaptation successes, failures, costs and trade-offs
- Emphasize adaptive management – learning-by-doing and adjustment

Social Behaviour and Governance

- Enhance community capacity to cope with change and uncertainty, including strengthening governance, co-management and identifying robust coping strategies
- Better integrate climate change adaptation with economic capacity building for First Nations and single industry resource-dependent communities
- Identify behavioural and policy barriers to change
- Integrate climate change preparedness with regular business at all levels
- Re-evaluate management plans and policies through a climate change lens
- Analyse trade-offs and synergies between mitigation and adaptation practices including social costs
- Enhance dialogue and awareness-building to gain trust and improve decisions using consistent language

about climates, ecosystems and species, but rather in (1) building more flexible and adaptable institutions and societies to respond to the inevitable surprises and (2) moving immediately forward with precautionary policies and practices that can be adapted as better information becomes available. The epistemological split is not new−indeed it has always existed between researchers and managers− but climate change has increased the level of doubt about the efficacy of traditional scientific approaches within the scientific community itself. Those who seek a resolution to this conflict believe it can be found in non-linear models that specifically address surprise and uncertainty and better integrate ecological and social feedbacks (Folke 2006; Chapin et al. 2009).

Recommendations and Evaluation

In March 2009, I made 7 general recommendation and 14 specific recommendations to guide development of the FFESC competitive call for research proposals in May 2009.

By December 2009, FFESC had completed an interdisciplinary call for proposals (FFESC 2009a) and allocated $4.8 million to a program of 25 research projects, including 5 external direct award contracts (2008-2010), 16 competitively awarded projects, and 4 internal MFR projects (FFESC 2009b; Supplementary Database IV). In March 2010, I evaluated how well each of my recommendations were addressed during the process of allocating funds to the FFESC research program. Quantitative indicators (e.g., % of research team, % of total budget; defined below and in Table 4) were used to

Table 4. Evaluation of Specific Recommendations

Topic and Recommendation	Evaluation	Indicator[1]	Comments
Mitigation: 6 projects will devote an estimated 5-20% of project to carbon sequestration issues amounting to ~6% of total FFESC research budget			
1.Address research priorities identified by Black et al. (2008) but also include rangelands	MODERATELY WELL	33% topics addressed (~6% of budget)	2 of 8 priorities are well-addressed (use of nitrogen fixers, alternative harvest and retention of old growth forests re: C sequestration); 2 of 8 are marginally-addressed (disturbance regime shifts and post-MPB management); 4 of 8 priorities (forest fertilization, remote sensing and recalcitrant C) are not addressed. Rangeland C stocks addressed.
2.Include contributions of secondary stand structure to carbon accounting models of forests affected by MPB	POORLY	< 1% of budget	No projects specifically address carbon in post-MPB forests. The Kamloops Future Forest project will include MPB-affected forests in its carbon modeling, but is unlikely to be sufficiently detailed to consider stand secondary structure. Uses FORECAST rather than CBM-CFS3.
3. Favour mitigation studies that are fully integrated with adaptation research	WELL	100% (~6% of budget)	All 6 carbon sequestration studies are integrated into interdisciplinary projects that primarily address adaptation strategies, for example, inland temperate rain forest, coastal red alder, and Northwest Skeena adaptation.
4. Collaborate with the Canadian Carbon Program, CBM-CFS3 group but address BC-specific policy and adaptation actions	MODERATELY WELL	2 of 6 teams; 4 of 275 scientists	Inland temperate rainforest project includes member of Canadian Carbon Program. Northwest Skeena project includes consultants with extensive experience using CBM-CFS3 (though not part of CFS group).
Future Non-Forest Ecosystems?			
5. Conduct interdisciplinary research on consequences of forest shift to non-forested ecosystems (scrub &grassland)	WELL	Strong: 9% of budget. Weak: ~40%	One major interdisciplinary grasslands project was funded; 1 bioclimatic envelope modeling project (not interdisciplinary) improves projections of ecosystem and tree distributions; 4 regional vulnerability studies (Kamloops, West Kootenay, South Selkirk, Nadina) address social consequences of forest shift to non-forest ecosystems; 4 projects model consequences of increasing drought for tree survival & growth
6. Address hydrological issues and tradeoffs between managing for timber and managing for water in semi-arid areas	WELL	Strong: 4% of budget. Weak: 29%	Upper Penticton Creek hydrological study directly addresses this topic. Four regional vulnerability studies (Kamloops, West Kootenay, South Selkirk, Nadina) consider socio-economic tradeoffs associated with increasing drought; Watershed sciences compendium provides up-to-date extension information on this topic.
7. Address feedbacks between intensifying human use, declining land productivity, and human well-being in	MODERATELY WELL	Weak: ~50% of budget	Five adaptation/vulnerability studies in (potentially) semi-arid areas (Grasslands, Kamloops, West Kootenay, South Selkirk, Nadina) will consider feedbacks among declining land productivity, human use and well-being. Three risk analyses directly address declining tree productivity and one feeds

Table 4. Continued

semi-arid areas and use knowledge to assist developing countries			directly into a community planning process addressing human well-being. None of these areas has high population densities & there are no direct links to developing countries.
Other			
8.Develop complex models that address interactions, esp. between climate & disturbance, and ecological & social factors	WELL	Strong: 5 projects (32% of budget) Medium: 10 (36%) Weak: 4 (20%)	19 of 25 FFESC projects (88% of research budget) involved complex models or suites of linked models. Most models address interaction of climate and disturbance, species & ecosystems, or ecological & social factors, by adapting models that operate at one scale and linking these to models or qualitative decision-support tools that operate at another scale. To develop new models that fundamentally change the way we address complex social-ecological interactions is more than a 2-year endeavour.
9. Link suites of stand to landscape to socio-economic models			
10. Field and laboratory data should provide improved parameter estimates for models	MODERATELY WELL	Strong: 2 (2-5%) Medium: 4 (~10%)	Two projects use field data to directly validate/improve existing models. For 4 projects, the link between data and predictive models is less clear. No comprehensive sensitivity analysis has been carried out to determine highest priorities for field data collection to improve climate change predictions.
11. Study background rates of tree mortality in BC forests and their relationship to climate	POORLY	<0.1% of budget	No projects directly involve monitoring rates of background tree mortality. The FFEI Monitoring Framework project may include tree mortality as an indicator but does not involve actual monitoring.
12. A comprehensive risk/benefit analysis of assisted tree migration is needed	POORLY	Moderate: 3 (<6%) Weak: 4 (<9%)	Three projects that directly address assisted migration consider risks/benefits to tree growth only; Johnston's (2009) CCFM study made only generic recommendations. Four may indirectly identify sites where assisted migration is needed to reduce losses in tree productivity. Six vulnerability/adaptation case studies may discuss this option, but none have identified it as a priority topic.
13. Evaluate climate change implications for BC land use plans	WELL	Strong: 3 (17%) Medium: 3 (17%) Weak: 5 (27%)	Eleven projects (64% of total budget) have a direct or indirect link to existing land use plans and involve stakeholder consultations that will address climate change implications of those plans. Three projects (Kamloops, Quesnel , Nadina) involve a comprehensive reassessment of existing forest plans at TSA and other scales, while others address more localized land areas (community forests) or a specific resource (water, grasslands).
14. Analyse legal and economic implications of climate change for BC forest and range legislation and policy	MODERATELY WELL	Strong: 5 (4%) Medium: 5 (8%) Weak: 5 (2%)	FFESC is contributing to Canada-wide CCFM review, and has budgeted $40,000 for high level policy review of all FFESC research projects in 2012. Other projects address policy & economics for specific ecosystems (grasslands, inland rainforests, red alder) or a narrow policy question (e.g., seed transfer). Most projects allocate only a small proportion of total funds to legal and economic analysis and recommendations.

[1]Strong: project directly & significantly addresses recommendation; Medium: project partially addresses recommendation; Weak: project marginally addresses recommendation.

assign a rating of "well-addressed", "moderately well-addressed" or "poorly-addressed" to each recommendation. But ultimately, these are subjective ratings. Since most research projects were barely underway at the time of the evaluation, the composition and budget allocation of the research program were assessed, rather than the outcomes of the research. For each general recommendation, the evaluations appear below; for each specific recommendation the evaluations are summarized in Table 4.

General Recommendations

1. High level climate change impact, adaptation and vulnerability assessments are being generated around the world at an overwhelming rate. These reports summarize the state of the science and best practices for climate change adaptation. To a certain extent these reports, whether from Australia, Sweden, U.S., Ottawa, a tropical ENGO, or the IPCC, and whether they deal with forest, marine, urban or agricultural ecosystems, cover the same ground. There is no reason for the FFESC to invest its limited resources on high level, generic research (e.g., on risk assessment procedures) that does not deal in a concrete or quantitative way with BC forest and range ecosystems, forest policy and management practices, or forest-dependent communities.

Evaluation (March 2010): Well-addressed. Of 25 climate change adaptation research projects funded by FFESC, 1.5 projects (representing 6% of total research budget) were high level syntheses that did not address the BC context in a concrete or quantitative way. These projects represented BC's financial contribution to the CCFM climate change adaptation strategy. The first project (Johnston 2009) was a Canada-wide tree species vulnerability assessment and overview for policy makers and practitioners. The next project will have two phases, the first being a high level vulnerability assessment of Canada's sustainable management framework. The second phase of that project is a BC-specific case study that will focus on developing decision-support tools such as shifts in ecosystem classifications. Thus, although FFESC did contribute 6% of its research budget to national-level assessments, an effort was made to ensure that the results contribute directly to adaptation in BC.

2. Much of the climate change research being produced around the world is of very high quality and represents the best available science on topics such as integrating complex social-ecological systems, multi-scale meta-modeling practices, dealing with uncertainty and risk, and translating science into policy action. FFESC research projects must take advantage of the best available science and translate it into regional or local scale assessments and adaptation practices. FFESC researchers should demonstrate that they are familiar with and can build on the best available international science rather than reinventing a 'made in BC' approach.

Evaluation (March 2010): Well-addressed. Through its competitive call for proposals FFESC was able to select the 16 best projects from 168 Expressions of Interest and 69 submitted Letters of Intent through a process of external and internal peer review that included an evaluation of the proponents' familiarity with the international scientific literature and best adaptation practices (FFESC 2009a). There was also an opportunity for proponents to improve their literature review and methods during Full Proposal development, where these were deemed to be too provincially-focused. A random sample of 8 accepted Full Proposals found

that 74% of citations were from international peer-reviewed journals and books and also indicated that the proponents were largely publishing their own research in refereed international journals. For the 9 direct-award projects, the same level of oversight was not available; however, it appears that most, if not all, of these projects are looking outside of BC to ensure that the work incorporates the best science available. For example, the Climate Change and Fire Management Research Strategy workshop (MFR 2009) included speakers and participants from 6 Canadian provinces and territories and Washington State. Based on 30 years of observing the BC forest and rangeland research scene, I conclude that this outcome reflects a steady improvement in the quality, or at least the level of external engagement, of provincially-funded forest and range science in BC, which 15 years ago was dominated by BC-centric work rarely subjected to outside peer-review.

3. BC is a world leader in forestry and forest science. Because of its large, contiguous, ecologically diverse, publicly-owned land base and an established tradition of forest research and public forest management, BC has a scientific advantage in certain areas of climate-change adaptation research that should be fully exploited by the FFESC. For example, networks of long- and mid-term forestry experiments across strong climatic gradients can contribute to internationally-significant advances in climate change research, as exemplified by forest genetics work utilizing BC's comprehensive network of provenance trials (Rehfeldt et al. 1999; O'Neill et al. 2008). The provincially-funded biogeoclimatic ecosystem classification (BEC) and forest inventory databases are world-leading resources that are vastly underutilized for modeling purposes. In the social sciences arena, BC's global advantage is its highly engaged citizenry, well-established provincial and regional land use planning processes, and highly developed social networks for forestry planning that can be readily adapted to the challenges of climate change. Benefits for the FFESC in taking full advantage of these globally important resources lie not only in the potential for scientific prestige and the opportunity to help solve critical global issues. The best databases attract the best scientists, and thus should result in quicker and better problem-solving for BC. Through collaborative research, the FFESC should encourage the world's best scientific teams to use our provincially-funded research and planning networks and databases to their fullest possible extent to help solve BC and the world's climate crisis.

Evaluation (March 2010): Poorly-addressed. The FFESC Call for Proposals failed to attract the recommended level of interest from international researchers, eager to work with BC scientists and BC databases. At the Expression of Interest stage, only 13 of 554 proponent team members (2.3%) were Canadians from outside BC, and only 10 (1.8%) were from outside Canada. Approved project teams include 6 Canadians from outside BC, 4 American, and 2 French scientists out of a total of 272 team members (4% non-BC). It is likely that some FFESC projects are part of a larger, research program involving outside collaborators not reported in the Full Proposal, or that some projects may later evolve into national and international collaborations. For example, several FFESC researchers are now actively engaged in the CCIAD Okanagan Basin RAC, which involves federal scientists. BC-based researchers undoubtedly sought to keep FFESC funds within the province to support their own

programs. There is little evidence that outside researchers are willing to contribute their own funds to build research partnerships in BC. If MFR wishes to engage more fully with international collaborators on climate change adaptation, both proposal development and project timelines will need to be longer, the call for international partners must be an explicit part of the evaluation criteria, and dedicated funds will be needed to actively build collaborations, as is done by NSERC and SSHRC.

4. FFESC will more efficiently use its funds if it finds its own niche and minimizes duplication with other bodies – e.g., federally funded, PICS, internal MFR and MOE work, FIA-FSP. However, with the current global financial and forest sector crises, alternative funding programs are rapidly drying up and government agencies and university researchers will increasingly turn to FFESC and PICS funds to continue projects initiated elsewhere (e.g. CFCAS) and to fund costs for communication, travel, internal policy analyses, etc. that might previously have been covered by regular program budgets. The challenge for FFESC will be to find the balance between supporting important, productive projects that must be allowed to continue to prevent backsliding on scientific investments, and funding novel projects that will demonstrate substantive new delivery on FFESC objectives. For example: Socio-economic vulnerability assessments and adaptation strategies for rural communities are necessarily broadly focused and should have access to a variety of funds (e.g., SSHRC, PICS, private foundations). FFESC should probably limit its involvement in socio-economic research to partnerships where FFESC focuses on the forest sector component of the research and on the adaptation of forest policy to address community needs while other funding partners address other community drivers (eg health, education, and other economic sectors).

Evaluation (March 2010): Well-addressed. FIA-FSP and internal ministry budgets for forest and rangeland research were eliminated or severely cut back after March 2009. FFESC was able to provide continuity for 8 MFR research projects ($577,000) that would otherwise have been discontinued, while also funding 17 new projects ($4.2 million; 88% of total research budget). Five of the new projects built creatively on prior climate change adaptation research funded through other sources. FFESC decided in March 2009 to only award projects with a significant socio-economic or policy component through its competitive proposal call, but all projects are focused on the forest and range sector. Two projects had cash contributions ($30,000) from funding partners to address other community socio-economic drivers, while several projects had major in-kind contributions from clients and collaborators to address aspects of social resilience not addressed by the FFESC component. For example, a UNBC project is teaming up with the City of Prince George Community Sustainability Planning Initiative to provide the forest sector perspective on climate change adaptation needs for the city.

5. Adaptation of BC forest and range practices and policy to reduce climate change impacts on the delivery of ecosystem services is a clear niche for FFESC that is distinct from the mandates of most other provincial, national and international climate change science bodies. This is also an area that this preliminary gap analysis found to be relatively under-funded. When it comes to adaptation, however, there are many areas where the *science* is already clear (e.g.,

plant more mixed species plantations, encourage a diversity of practices; monitor forest and rangeland health and growth consistently and across scales), and the real challenge is addressing the barriers that inhibit putting knowledge into practice. Much of this ought to be the work of salaried MFR employees and thus shouldn't be a large drain on FFESC funds. Research shows, however, that institutional transformation is one of the single biggest obstacles to effective change. Training policy-makers and operational staff to understand uncertainty, risk and adopt more flexible practices is universally identified as a critical gap. Conferences and workshops often achieve very little concrete progress and quickly result in information overload for managers. It may be most efficient for FFESC-funded researchers (e.g. recent post-graduates) to work one-on-one with decision-makers and management staff on a specific policy or guideline (e.g., incorporating flexibility and uncertainty into provincial free-growing policy or species selection guidelines) to achieve the two-way dialogue and institutional transformation needed; in essence, embedded researchers.

Evaluation (March 2010): Poorly-addressed. This recommendation was not achieved due to an inflexible MFR workplace environment (no interns) and complete hiring freeze. No projects (0%) involved researchers embedded within government departments. An FFESC/UNBC post-doctoral researcher is, working with the City of Prince George Planning Department on an Integrated Community Sustainability Plan committee, but does not work at the city office. Government policy-makers are, however, present on all but a few FFESC research teams due this being part of the evaluation criteria.

6. Some climate change research topics appear to have benefitted from a unified, collaborative interagency approach; the work on forest genetics, flux towers and social adaptation comes to mind. Other topic areas such as tree growth performance, disturbance dynamics, wildlife and biodiversity impacts seem to be taking more of a scattergun approach with many different researchers working semi-independently with different models and case studies and often little link to higher level assessments or policy. These differences may be related to the large variety of species and ecosystems, the number of researchers, and the complexity of the topics. The benefits of a diversity of competing approaches should certainly not be undervalued. However, the literature suggests that forming an interdisciplinary research collective and working collaboratively on a limited number of intensive model systems (e.g. *Arabidopsis* work in plant genomics) is a proven route to scientific advancement. This was an approach adopted by SFMN. FFESC should adopt one or more interdisciplinary case study ecosystems for intensive work, building on established long term field experiments and existing modeling frameworks.

Evaluation (March 2010): Well-addressed. Interdisciplinary case studies are addressing (1) inland temperate rainforests, (2) coastal red alder ecosystems, and (3) southern BC grasslands, and are building on established field experiments and existing models for these ecosystems ($1.1 million; 23% of total project funding). The red alder adaptation study will analyse 32 long term red alder installations established along a latitudinal gradient from central Oregon to southern BC (Farnden 2010). The inland temperate rainforest study is adapting the SORTIE/BC model for the Interior Cedar Hemlock zone (Coates et al.

2003) for use in carbon modeling. In addition to these ecosystem-specific case studies, FFESC also funded 5 interdisciplinary community vulnerability and adaptation studies to address the northwest Skeena/Coast Tsimshian First Nations, West Kootenays, South Selkirks, Kamloops and Nadina Forest Districts ($1.75 million; 37% of total project funding). The projects build upon a wide array of existing forest, vegetation, wildlife and sociological models.

7. Climate change adaptation research, by necessity, relies heavily on forecasting and simulation modeling to predict the future. Field and laboratory studies funded by FFESC should be specifically designed to contribute to such research by providing estimates for parameters for which there is high uncertainty and which have been demonstrated through sensitivity analysis to have a large effect on the outcome. Field studies that can simultaneously address modeling needs and policy or practice questions within a short time frame are most urgently needed. There should be a systematic effort to identify the weaknesses of current climate change models that can be improved through (a) better use of existing empirical data and (b) new field and laboratory studies (see specific examples below).

Evaluation (March 2010): Moderately well-addressed. The FFESC research program includes only a small component of field data collection (6 projects, 10-15% of total research funding). Most of the field research is intended to parameterize or validate existing models or decision-support systems being developed for the project. Since most field research is being conducted by graduate students, it is unrealistic to expect this fieldwork to significantly inform models and policy within FFESC's 2-year timeframe. All of the field-intensive projects do, however, have a strong MFR connection. Thus, one can hope for sufficient continuity to allow some field data to find its way into decision support models, policy and practice after the FFESC program terminates. There have been 4 collaborative meetings among study teams to discuss data needs and analytical approaches but no systematic assessment of how field studies can most efficiently supply parameter estimates for modeling.

Specific Recommendations

Mitigation

1. The research priorities identified by Black et al. (2008) in their report to PICS (Section 1 of Table 2; Supplementary Database II-D) should also be followed by FFESC. Black et al. (2008) do not, however, consider carbon accounting needs in rangeland ecosystems, which should be a priority for FFESC given the large area of Crown land in southern BC that may no longer support commercial forest cover in a warmer climate. Evaluation: moderately well-addressed (Table 4).

2. The contributions of secondary stand structure (live trees and regeneration) to carbon cycling in BC pine forests affected by mountain pine beetle is reportedly not fully accounted for in he CBM-CFS3 model (Kurz et al. 2008). FFESC could make a significant contribution to improvements in CBM-CFS3 modeling and to BC carbon accounting by using secondary structure data collected and monitoring plots established through the Mountain Pine Beetle Initiative to improve these estimates. Evaluation: poorly-addressed (Table 4).

3. Carbon sequestration field and modeling studies that specifically address the trade-offs and synergies between mitigation and

adaptation (Klein et al. 2007) better address the research objectives of the FFESC and should be given priority over studies that do not address adaptation options. For example, a study of the effects of fertilization on carbon sequestration (Black et al. 2008) should also consider how fertilization may influence sensitivity to climate extremes and what genotypes and ecosystems are best able to continue sequestering carbon under future climates. Evaluation: well-addressed (Table 4).

4. Carbon sequestration research funded by FFESC should be conducted in partnership with existing research networks such as FluxNet and CBM-CFS3, but should go beyond the work of these networks to address specific policy outcomes and field and community-level adaptation actions. Evaluation: moderately well-addressed (Table 4).

Future Non-Forest Ecosystems?

5. Given anticipated declines in the forest sector, world food shortages, and climate envelope projections of large increases in steppe-savanna-woodland habitats throughout Interior BC (Hamann and Wang 2006, Aitken and Wang 2009), there is a clear lack of research addressing rangeland management challenges and opportunities and the dynamics of the forest-grassland transition. There is a strong disconnect between projected increases in non-forest conditions due to warming and drought (Hamann and Wang 2006; Nitschke and Innes 2008a,b) and recent research documenting tree encroachment into grassland (Bai et al. 2004, 2005). Integrated ecological and hydrological studies that address the interacting climate, disturbance regimes, soil and invasive species processes that influence forest-shrubland-grassland ecotones and their provision of ecosystem services (water, food, wildlife, amenities), as well as studies that examine resilient and adaptive rangeland societies and economies are warranted. Evaluation: well-addressed (Table 4).

6. Although the MFR does not have primary responsibility for water management, many observers have noted that provision of water from forests, rangelands, alpine tundra and glaciers may become equally or more important than fibre production in a climate-challenged future. The hydrological component must be an integral part of ecosystem-based research and better approaches to integrating the work of hydrologists, geomorphologists and soil scientists with silvicultural and plant ecology specialists are needed in assessments of the value of the future forest and the adaptation practices needed to sustain them. There are likely to be substantial tradeoffs between managing for fibre and managing for sustainable water supplies that are not adequately addressed within current frameworks. Experience from semi-arid regions of the U.S., Australia and elsewhere can be used to inform the work of the FFESC. Evaluation: well-addressed (Table 4).

7. For rangeland ecosystems in semi-arid areas, the most critical global information need identified by the MEA (2005a) is to understand feedbacks between intensifying use and declining soil fertility and productivity and how this affects human well-being. A need for indicators of land productivity and human well-being related to changes in land productivity was also identified. FFESC has an opportunity to contribute in this area. Evaluation: moderately well-addressed (Table 4).

Other

8. There is a critical need for complex models capable of addressing interactions among many ecological and social factors. Examples include (a) Multi-factor species

distribution models that improve upon existing climate envelope models by considering not only genetic variability within species but also interaction of other constraints limiting distribution (dispersal, disturbance, competition, soil). (b) Ecosystem models that combine individualistic (species-based) and holistic approaches to modeling ecosystem dynamics that integrate climate, disturbances and local scale processes such as plant-soil-microbial feedbacks (eg mycorrhizal networks). (c) The MEA stated that for boreal forests the most critical information need is for data on the interaction between disturbance regimes and global change that is causing the documented acceleration of rates of natural disturbances such as pests and fire. Evaluation: well-addressed (Table 4).

9. In most cases, a suite of tree-to-stand-to-landscape-to-socio-economic models will be needed to link sectors, spatial and temporal scales. Existing high level socio-ecological analysis frameworks are not adequately quantitative and could be substantially improved by making effective use of available, smaller-scale data by linking the best-available models at each scale and for each sector. Evaluation: well-addressed (Table 4).

10. Where field or laboratory experiments or monitoring plots are proposed, they should be specifically designed to provide data for input to climate change projection models. For example, the TACA model (Nitschke and Innes 2008a) uses mostly inferred rather than experimental data about tree species tolerances to extreme climatic events to make its projections, and does not fully incorporate genetic variability in tolerance to extreme weather that exists within most tree species. Sensitivity analyses with existing models will indicate those parameters for which accurate empirical data are most needed. Evaluation: moderately well-addressed (Table 4).

11. Recent Pacific Northwest research concludes that the background rate of tree mortality in undisturbed forests has approximately doubled over the past 30 years (van Mantgem et al. 2009). More work is needed to determine whether this finding applies across BC and how it may be tied to short- and mid-term climatic variability such as the Pacific Decadal Oscillation. Evaluation: poorly-addressed (Table 4).

12. Assisted migration of tree species to more suitable future climates has generated considerable interest and momentum within the MFR and one FFEI-sponsored trial is already underway (Supplementary Database IV). Assisted migration is controversial among ecologists, invasive species biologists, environmentalists and others (McLachlan et al. 2007). because of the potential for ecological surprises, including the uncertainty of current projections of ecological change A comprehensive review of international literature and experience on the benefits and risks of assisted migration and wider discussion with stakeholders should occur prior to operational implementation. There are also opportunities to capitalize on old exotic and range-extended species trials scattered around the province for information on growth performance, forest health, soil biology and interspecific interactions (e.g., Koot 2007). Evaluation: poorly-addressed (Table 4).

13. A systematic evaluation of BC's land and resource management plans (LRMP), landscape unit plans and other provincial-to-local scale forest and range land use plans to assess challenges and opportunities for adaptation to climate change is needed. Such a project may initially require the outside expertise of

climate change specialists (through an in-depth case study or rapid assessment, or combination of the two), but thereafter could become operationalized within government ministries. FFESC could become involved in the early stages of such an initiative to ensure adoption of the best available science and technical approaches. Evaluation: well-addressed (Table 4).

14. Policy, legal and economic analyses of forest and range management adaptation require additional study in a BC-specific context because BC's forestry legislation and Crown land context is unique. Evaluation: moderately well-addressed (Table 4).

Of the 14 specific recommendations, 5 were evaluated as well-, 5 as moderately-well and 4 as poorly-addressed (Table 4). The primary strengths of the program in relation to these recommendations are its interdisciplinarity, the use of linked suites of models that cross multiple scales, and the wide scope of geographic locations, ecosystems and resource sectors addressed. The program fared poorly in relation to the March 2009 recommendations where narrow topics (assessing secondary structure carbon sequestration, monitoring background tree mortality, and assessing assisted migration) were recommended. Projects that scored well against the FFESC Call for Proposal criteria had to have a wider scope than these narrow recommendations. Although the program is strong in modeling and addresses land use planning, policy and economic questions, these are three areas that will benefit from a comprehensive reassessment after the research program is completed.

Conclusions

FFESC made a strategic decision to fund only projects that combined natural and social science dimensions through its competitive call for proposals and was very successful in kick-starting the trans-disciplinary collaboration needed to successfully adapt BC's forest and range framework to the challenges of climate change. As a result, several disciplinary projects either recommended in March 2009 or identified as priorities by FFEI were not funded. Funding cutbacks resulted in FFESC funding a variety of projects that might otherwise have been supported through Ministry budgets or longer term programs such as FIA-FSP, and there are very few partnerships with researchers outside BC. Overall, the research program has good geographic distribution (no projects north of 55^{o} latitude), and an excellent balance among the four FFESC objectives of understanding changes, forecasting impacts, developing adaptation options, and researching economic and social consequences.

References

Abbott, C.L., K.E. Bennett, K. Campbell, T.Q. Murdock and H. Swain. 2007. *Forests Pests and Climate Change: Summary Report*. Symposium Proceedings, 14-15, Oct. 2007, Pacific Climate Change Impacts Consortium, University of Victoria, Victoria, B.C. 14 p.

Adam M.C. and D. Kneeshaw. 2009. *Formulating Aboriginal Criteria and Indicator Frameworks*. Sustainable Forest Management Network, Edmonton, AB, 35 p.

Aitken, S. and T. Wang. 2009. *Potential Impacts of Climate Change on the Distribution of Ecosystems and Tree Species in British Columbia*. Unpublished Progress Report prepared for the Future Forest Ecosystem Scientific Council, Centre for Forest Conservation Genetics, University of BC, Vancouver, BC. 9 p.

Aitken, S. N., S. Yeaman, J.A. Holliday, T.Wang and S. Curtis-McLane. 2008. Adaptation, migration or extirpation: climate change outcomes for tree populations. *Evolutionary Applications* 1: 95-111.

Almuedo , P.L. 2008. Adding value… players in the climate change arena. *BC Journal of Ecosystems and Management* 9: 4-6.

Armitage, D.R., R. Plummer, F. Berkes, R.I. Arthur, A.T. Charles, A,J. Davidson-Hunt, A.P. Diduck, N.C. Doubleday, D.S. Johnson, M. Marschke, P. McConney, E.W. Pinkerton and E.K. Wollenberg. 2009. Adaptive co-management for social-ecological complexity. *Frontiers in Ecology and Environment* 7: 95–102.

Aukema, B.H., A.L. Carroll, A.L., Y. Zheng, J. Zhu, K.F. Raffa, R.D. Moore, K. Stahl and S.W. Taylor. 2008. Movement of outbreak populations of mountain pine beetle: influences of spatiotemporal patterns and climate. *Ecography* 31: 348-358.

Bai, Y., K. Broersma and D. Thompson. 2004. Landscape–level dynamics of grassland-forest transitions in British Columbia. *Journal of Range Management* 57: 66-75.

Bai, Y., N. Walsworth, B. Roddanc, D.A. Hill, K. Broersma and D. Thompson 2005. Quantifying tree cover in the forest–grassland ecotone of British Columbia using crown delineation and pattern detection. *Forest Ecology and Management* 212: 92-100.

BC Climate Exchange. 2010. Website of the British Columbia Climate Exchange, a Project of the Fraser Basin Council, Vancouver, BC. Available online at: **http://www.bcclimateexchange.ca** [accessed March 26, 2010].

Black, T.A., R.S. Jassal and A.L. Fredeen. 2008. *Carbon Sequestration in British Columbia's Forests and Management Options.* Pacific Institute for Climate Solutions, Victoria, BC. 19 p.

Burton, P.J., S.W. Taylor and G. Thandi. 2005. Challenges in defining the disturbance regimes of northern British Columbia. *BC Journal of Ecosystems and Management* 6: 119-123.

CCFM. 2008. *A Vision for Canada's Forests: 2008 and Beyond.* Canadian Council of Forest Ministers, Ottawa, ON. 15 p. Available online at: **http://www.ccmf.org/pdf/Vision_EN.pdf** [accessed March 1, 2010].

Chapin, F.S. III, G.P. Kofinas and C. Folke. (editors). 2009. *Principles of Ecosystem Stewardship: Resilience-based Natural Resource Management in a Changing World.* Springer, NY. 409 p.

Chhin, S., E.H. Hogg, V.J. Lieffers and S. Huang. 2008. Potential effects of climate change on the growth of lodgepole pine across diameter size classes and ecological regions. *Forest Ecology and Management* 256: 1692-1703.

Coastal Communities Project. 2008. Website of the Coastal Communities Project, Sociology Department, University of British Columbia, Vancouver, BC. Available online at: **http://coastalcommunitiesproject.ca/** [accessed March 2, 2010].

Coates, K.D., C.D. Canham, M. Beaudet, D.L. Sachs and C. Messier. 2003. Use of a spatially explicit individual-tree model (SORTIE/BC) to explore the implications of patchiness in complex forests. *Forest Ecology and Management* 186: 297-310.

Cohen, S. and T. Neale (editors). 2006. *Participatory integrated assessment of water management and climate change in the Okanagan Basin, British Columbia.* Environment Canada and University of British Columbia, Vancouver, BC. Available online at: **http://www.forestry.ubc.ca/Portals/97/docs/OKPIA_2004-06_FinalReport_HiRes.pdf** [accessed March 25, 2010].

CPAWS. 2010. *Atlin-Taku in an Era of Climate Change*. Webpage of the Canadian Parks and Wilderness Society, British Columbia Chapter, Vancouver, BC. Available online at: **http://www.cpawsbc.org/campaigns/atlintaku.php** [accessed March 30, 2010].

Davidson-Hunt, I. and F. Berkes. 2003. Learning as you journey: Anishinaabe perception of social-ecological environments and adaptive learning. *Conservation Ecol.* 8: 5. Available online at: **http://www.consecol.org/vol8/iss1/art5/** [accessed February 25, 2010].

Dawson, R.J., A.T. Werner and T.Q. Murdock. 2008. *Preliminary Analysis of Climate Change in the Cariboo-Chilcotin Area of British Columbia.* Pacific Climate Impacts Consortium, University of Victoria, and BC Ministry of Agriculture and Lands, Victoria, BC. 49 p.

Duinker, P.N. and L.A. Greig. 2007. Scenario analysis in environmental impact assessment: improving explorations of the future. *Environmental Impact Assessment Review* 27: 206-219.

Duchesneau, R. 2005. *A Compendium of Sustainable Forest Management Network Computer Simulation Modeling.* Sustainable Forest Management Network, Edmonton, Alberta. 56 p.

Eddington, M.M., J.L. Innes, A.E. McHugh and A.C. Smith. 2009. *Monitoring Forest and Rangeland Species and Ecological Processes to Anticipate and Respond to Climate Change.* Forest and Range Evaluation Program, BC Ministry of Forests and Range, FREP Report #20. Victoria, BC. 41 p.

Farnden, C. (editor). 2010. Aldern, *Newsletter of the FFESC Project 2009-006: Red Alder Adaptation Strategy*. BC Ministry of Forests and Range and Future Forest Ecosystem Scientific Council, Victoria, BC. 7 p. Available online at: **http://www.for.gov.bc.ca/ftp/hts/external/!publish/web/ffesc/newsletter/Aldern-March-2010.pdf** [accessed April 1, 2010].

Fagre, D.B. and C.W. Charles (lead authors). 2009. *Thresholds of Climate Change in Ecosystems*. U.S. Climate Change Science Program, Synthesis and Assessment Product 4.2, Wash. DC. Available online at: **http://www.climatescience.gov/Library/sap/sap4-2/final-report/default.htm** [accessed January 6, 2010].

Feix, C., A. Nagel, J. Schulz and T. Stratenwerth, (editors). 2009. *Combating Climate Change: The German Adaptation Strategy*. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Berlin, Germany. Available online at: **http://www.bmu.de/files/pdfs/allgemein/application/pdf/broschuere_dem_klimawandel_begegnen_en.pdf** [accessed January 6, 2010].

FFESC. 2009a. *Interdisciplinary Climate Change Adaptation Research for Forest and Rangeland Ecosystems: 2009 Program Overview*. Unpublished Progress Report. Future Forest Ecosystem Scientific Council, Victoria, BC. 7 p. Available online at: **http://www.for.gov.bc.ca/ftp/hts/external/!publish/web/ffesc/FFESC_2009ProgramOverview.pdf** [accessed March 31, 2010].

FFESC. 2009b. *Summary of FFESC Climate Change Adaptation Research Projects*. Unpublished Summary Report. Future Forest Ecosystem Scientific Council, Victoria, BC. Available online at: **http://www.for.gov.bc.ca/hts/future_forests/council/index.htm** [accessed March 31, 2010].

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16: 253-267.

Forest Communities Program. 2008. Website of the Canadian Forest Service, Forest Communities Program. Natural Resources Canada, Ottawa, ON. Available online at: **http://cfs.nrcan.gc.ca/subsite/forest-communities** [accessed March 1, 2010].

Fraser Basin Council. 2010. Website of the Fraser Basin Council, Vancouver, BC. Available online at: **http://www.fraserbasin.bc.ca/** [accessed March 26, 2010].

Freedman, B., G. Stinson and P. Lacoul. 2009. Carbon credits and the conservation of natural areas. *Environmental Reviews* 17: 1-19.

Gardiner, B., K. Byrne, S. Hale, K. Kamimura, S.J. Mitchell, H. Peltola and J.-C. Ruel. 2008. A review of mechanistic modelling of wind damage risk to forests. *Forestry* 81: 447-463.

Grant, R.F., A.G. Barr, T.A, Black, H.A. Margolis, A.L. Dunn, J. Metsaranta, S. Wang, J.H. McCaughey and C.S. Bourque. 2009. Interannual variation in net ecosystem productivity of Canadian forests as affected by regional weather patterns - A Fluxnet-Canada synthesis. *Agricultural and Forest Meteorology*: 149: 2022-2039.

Hall, C. and E. Higgs. 2010. *Summary of Resilient Ecosystems Workshop: Possible Ideas for A Solutions-Focused Research Agenda*. Pacific Institute for Climate Solutions, Victoria, BC 35 p.

Hamann, A. and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. *Ecology* 87: 2773–2786.

Harford, D., C. Vanderwill and A. Church. 2008. *Climate Change Adaptation: Planning for BC.* Pacific Institute for Climate Solutions, Victoria, BC.

Hilborn, R.C. 2004. Sea gulls, butterflies, and grasshoppers: A brief history of the butterfly effect in nonlinear dynamics. *American Journal of Physics* 72: 425-427.

Hogg, E.H., J.P. Brandt and B. Kochtubajda. 2005. Factors affecting interannual variation in growth of western Canadian aspen forests during 1951–2000. *Can. J. For. Res.* 35: 610-622.

Hogg, E.H., J.P. Brandt and M. Michaelian. 2008. Impacts of a regional drought on the productivity, dieback, and biomass of western Canadian aspen forests. *Canadian Journal of Forest Research* 38: 1373-1384.

Hunt, S., J. Newman and G. Otis. 2006. *Threats and Impacts of Exotic Pests under Climate Change: Implications for Canada's Forest Ecosystems and Carbon Stocks*. BIOCAP Canada. 57 p.

Johnston, M., T. Williamson, D. Price, D. Spittlehouse, A. Wellstead, P. Gray, D. Scott, S. Askew and S. Webber. 2006. *Adapting forest management to the impacts of climate in Canada.* BIOCAP Canada. 96 p. Available online at: **http://www.biocap.ca/rif/report/Johnston_M.pdf** [accessed March 1, 2010].

Johnston, M. 2009. *Vulnerability of Canada's Tree Species to Climate Change and Management Options for Adaption: An Overview for Policy Makers and Practitioners*. Canadian Council of Forest Ministers, Ottawa, ON. 40 p.

Julius, S.H. and J.M. West (editors). 2008. *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency, Washington, DC, USA, 873 p.

Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson and F.L. Toth, 2007: Inter-relationships between adaptation and mitigation. *In* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK, pp. 745-777.

Kneeshaw, D.D., A. Leduc, P. Drapeau, S. Gauthier, D. Pare and R. Carignan. 2000. Development of integrated ecological standards of sustainable forest management at an operational scale. *Forestry Chronicle* 76: 481–493.

Koot, C. 2007. *Performance of Ponderosa Pine and Western Larch planted north of natural ranges*. RP#05-03. Unpublished Technical Report, Forestry Investment Account Land Base Investment Program Projects 4638002 and 4655007. University of BC, Alex Fraser Research Forest.

Kurz, W.A., C.C. Dymond, G. Stinson, G.J. Rampley, E.T. Neilson, A.L. Carroll, T. Ebata and L. Safranyik. 2008. Mountain pine beetle and forest carbon feedback to climate change. *Nature* 452: 987-990.

Kurz, W.A., C.C. Dymond, T.M. White, G. Stinson, C.H. Shaw, G.J. Rampley, C. Smyth, B.N. Simpson, E.T. Neilson, J.A. Trofymow, J. Metsaranta and M.J. Apps. 2009. CBM-CFS3: a model of carbon-dynamics in forestry and land-use change implementing IPCC standards. *Ecological Modelling* 220: 480-504.

Leake, N.L., V. Adamowicz and P. Boxall. 2002. *An examination of economic sustainability indicators in forest-dependent communities in Canada.* Sustainable Forest Management Network, Edmonton, AB. 55 p.

Leith, R.M.M. and P.H. Whitfield. 1998. Evidence of climate change effects on the hydrology of streams in south-central BC. *Canadian Water Resources Journal* 23: 219-230.

Lemmen, D.S., F.J. Warren, J. Lacroix and E. Bush, (editors). 2008. *From Impacts to Adaptation: Canada in a Changing Climate 2007;* Government of Canada, Ottawa, ON, 448 p.

Lemprière, T.C., P.Y. Bernier, A.L. Carroll, M.D. Flannigan, R.P. Gilsenan, D.W. McKenney, E.H. Hogg, J.H. Pedlar and D. Blain. 2008. *The Importance of Forest Sector Adaptation to Climate Change*. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-416E. 78 p.

Martell, D.W., K. Hirsch, J. Malcolm, R. McAlpine, A. Weintraub, M. Acuna, W. Cui, A. Espinoza, J. Johnson and C. Palma. 2004. *A FireSmart Approach to Integrated Fire and Forest Management in the Boreal Forest Region of Canada*. Sustainable Forest Management Network Project Report , University of Alberta, Edmonton, AB. 17p.

McLachlan, J.S., J.J. Hellmann and M.W. Schwartz. 2007. A framework for debate of assisted migration in an era of climate change. *Conservation Biol.* 21: 297-302.

MEA. 2005a. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC. Available online at: **http://www.millenniumassessment.org/documents/document.356.aspx.pdf** [accessed March 31, 2010].

MFR. 2009. *Climate Change and Fire Management Research Strategy* . BC Ministry of Forests and Range, Wildfire Management Branch, Victoria, BC. 24 p. Available online at: **http://bcwildfire.ca/Weather/Climate/docs/Climate%20change%20forum%20report_final.pdf** [accessed March 31, 2010].

Morgan, D., K. Swift and P. Diunker. 2008. Scenario planning being used to evaluate uncertain future supply of ecosystem services. *Link* 10: 10-12.

Morgan, D., J. Feick, D. Lewis, R. Pike, L. McAuley, E. Campbell, J. Burleigh and M. Kranabetter. 2009a. *Interdisciplinary Assessment of the Implications of Climate Change on British Columbia's Forest andRrange Ecosystems and theirSstewardship*. Year 1 Final Report, FFEI Vulnerability Assessment Working Group, BC Ministry of Forests and Range, Victoria, BC. Available online at: **http://www.for.gov.bc.ca/hts/future_forests/index.htm** [accessed January 6, 2010].

Morgan, M.G., H. Dowlatabadi, M. Henrion, D. Keith, R. Lempert, S. McBride, M. Small and T. Wilbanks. 2009b. *Best Practice Approaches for Characterizing,Communicating and Incorporating Scientific Uncertainty in Climate Decision-Making*. Synthesis and Assessment Product 5.2. U.S. Climate Change Science Program. Wash. DC. 87p.

Murdock, T.Q. and A. Flower. 2009. *Development and Analysis of Forest Health Databases, Models, and Economic impacts for BC: Spruce Bark Beetle & Spruce; Western Spruce Budworm and Douglas- fir.* Final Technical Report, Forest Science Program Project # Y093061. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC. 43 p.

Neilsen, D., C.A.S Smith, G. Frank, W.O. Koch and P. Parchomchuk. 2000. Impact of climate change on crop water demand in the Okanagan Valley, B.C., Canada. Technical Bulletin 01-15. Pacific Agri-Food Research Centre, Summerland, BC. 32 p.

Nitschke, C. and J. Innes. 2008a. A tree and climate assessment tool for modelling ecosystem response to climate change. *Ecol. Modelling* 210: 263-277.

Nitschke, C. and J. Innes. 2008b. Climatic change and fire potential in South-Central British Columbia, Canada. *Global Change Biology*. 14: 841–855.

NRCan. 2010. *British Columbia Regional Adaptation Collaborative: Preparing for Climate Change: Securing BC's Water Future*. News Release prepared by Natural Resources Canada, Ottawa, ON. Available online at: **http://www.nrcan-rncan.gc.ca/media/newcom/2010/201004a-eng.php?PHPSESSID=3a9f885309ceb4574f466c1af00df6bb** [accessed March 25, 2010].

NSERC. 2010. Webpage of the Healthy Environment and Ecosystems target area, Strategic Project Grants program, Natural Sciences and Engineering Research Council of Canada, Ottawa, ON. Available online at: **http://www.nserc-crsng.gc.ca/Professors-Professeurs/RPP-PP/SPGTargetAreas-SPSDomainesCibles_eng.asp#EnvEcosyst** [accessed March 2, 2010].

O'Neill, G.A., A. Hamann and T. Wang. 2008. Accounting for population variation improves estimates of the impact of climate change on species' growth and distribution. *Journal of Applied Ecology* 45: 1040-1049.

Parry, M., O. Canziani, J. Palutikof, P. van der Linden and C. Hanson. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press. Cambridge, UK.

Penman, J., M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe and F. Wagner, (editors). 2003a. *Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegatation of Other Vegetation Types.* IPCC Special Report, Institute for Global Environmental Strategies, Kanagawa, Japan. 32 p.

Penman, J., M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe and F. Wagner (editors) . 2003b. *Practice Guidance for Land Use, Land-Use Change and Forestry* IPCC Special Report. Institute for Global Environmental Strategies, Kanagawa, Japan. 347 p.

Picketts, I.M., A.T. Werner and T.Q. Murdock. 2009. *Climate Change in Prince George: Summary of Past Trends and Future Projections.* University of Northern BC, Prince George, BC and Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC. 48 p.

Pojar, J. 2010. *A New Climate for Conservation: Nature, Carbon and Climate Change in British Columbia*. The Working Group on Biodiversity, Forests and Climate, Vancouver, BC.

Rehfeldt, G.E., C.C. Ying, D.L. Spittlehouse and D.A. Hamilton, Jr. 1999. Genetic responses to climate in *Pinus contorta:* niche breadth, climate change and reforestation. *Ecological Monographs* 69:375-407.

Resilient Communities Project. 2006. Website of the Resilient Communities Project, Department of Sociology, University of British Columbia, Vancouver, BC. Available online at: **http://www.resilientcommunities.ca/** [accessed March 2, 2010].

Resources North. 2010. Website of the Resources North Association, Prince George, BC. Available online at: **http://www.resourcesnorth.org/rna** [accessed January 7, 2010].

Robinson, J. , T. Berkhout, S. Burch, E.-J. Davis, N. Dusyk, A. Shaw, S. Sheppard and J. Tansey. 2008. *Infrastructure & Communities: The Path to Sustainable Communities.* Pacific Institute for Climate Solutions, Victoria, BC. 18p.

Rodenhuis, D., K.E. Bennett, A.T. Werner, T.Q. Murdock and D. Bronaugh. 2009. *Climate Overview 2007: Hydro-climatology and Future Climate Impacts in British Columbia*. Revised version. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC. 132 p.

Rose, N.-A. and P.J. Burton. 2009. Using bioclimatic envelopes to identify temporal corridors in support of conservation planning in a changing climate. *Forest Ecology and Management* 258S: S64–S74.

SFMN. 2009b. *Envisioning Tomorrow's Forests: Knowledge Networking for Sustainability.* Proceedings of Sustainable Forest Management Network 5th National Conference, April 21-23, 2009, Gatineau, QC. Available online at: **http://www.sfmnetwork.ca/html/conference_2009_e.html** [accessed March 1, 2010].

SFMN KETE Subcommittee. 2006. *Knowledge Exchange and Technology Extension strategy* (2005 – 2009). Sustainable Forest Management Network, Edmonton AB. 27 p.

Spittlehouse, D. L. and Stewart, R.B. 2003. Adaptation to climate change in forest management. *BC Journal of Ecosystems and Management* 4:1-11.

SSHRC. 2010a. Webpage of the Canadian Environmental Issues—Special Call, Community University Research Alliances (CURAs), Social Sciences and Humanities Research Council of Canada, Ottawa, ON. Available online at: **http://www.sshrc.ca/site/apply-demande/program_descriptions-descriptions_de_programmes/environment_cura-environnement_aruc-eng.aspx** [accessed March 2, 2010].

SSHRC. 2010b. *Successful Programs in Community-University Research Alliances—Formal* Proposal. Social Sciences and Humanities Research Council of Canada, Ottawa, ON. Available online at: **http://www.sshrc.ca/site/winning-recherche_subventionnee/results-resultats/2010/cura-aruc_eng.pdf** [accessed March 2, 2010].

Steffen, W., A. Burbidge, L. Hughes, R. Kitching, D. Lindenmayer, W. Musgrave, M. Stafford Smith and P.a Werner 2009. *Australia's Biodiversity and Climate Change.* Australian Government, Department of Climate Change, Canberra, ACT. 160p.

Stevenson, M.G. and D. Natcher, (editors). 2009. *Changing the Culture of Forestry in Canada: Building Effective Institutions for Aboriginal Engagement in Sustainable Forest Management.* Canadian Circumpolar Institute Press and Sustainable Forest Management Network. University of Alberta, Edmonton, AB. CCI Occasional Publication Series No. 60. 226 p.

Sturtevant, B.R., A. Fall, D.D. Kneeshaw, N.P.P. Simon, M.J. Papaik, K. Berninger, F. Doyon, D.G. Morgan and C. Messier. 2007. A toolkit modeling approach for sustainable forest management planning: achieving balance between science and local needs. *Ecology and Society* 12(2): 7.

van Mantgem, P.J., Stephenson, N.L., Byrne, J.C., Daniels, L.D., Franklin, J.F., Fulé, P.Z., Harmon, M.E., Larson, A.J., Smith, J.M., Taylor, A.H., Veblen, T.T. 2009. Widespread increase of tree mortality rates in the western United States. *Science* 323: 521-523.

Wainwright, C. and K. Zimmerman, (compilers). 2006. *Communities and Climate Change: Planning for Impacts and Adaptations.* Proceedings of a Workshop, May 17, 2006, McGregor Model Forest Association, Prince George, BC. 27 p.

Watson, R.T, I.R. Noble, B.Bolin, N.H. Ravindranath, D.J. Verado and D.J. Dokken. (eds.) 2000. *Land Use, Land-Use Change, and Forestry.* Special Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK. 375 p.

Wellstead, A.M., D.J. Davidson and R.C. Stedman. 2006. Assessing approaches to climate-change-related policy formulation in British Columbia's forest sector: The case of the mountain pine beetle epidemic. 2006. *BC Journal of Ecosystems and Management* 7: 1-10.

Williamson, T.B., D.T. Price, J.L. Beverly, P.M. Bothwell, J.R. Parkins, M.N. Patriquin, C.V. Pearce, R.C. Stedman and W.J.A. Volney. 2007. *A Framework for Assessing Vulnerability of Forest-Based Communities to Climate Change*. Nat. Resources Canada, Canadian Forest Service, Northern Forestry Centre, Inf. Rept. NOR-X-414.40p.

Williamson, T.B., D.T. Price, J. Beverly, P.M. Bothwell, B. Frenkel, J. Park and M.N. Patriquin. 2008. *Assessing Potential Biophysical and Socioeconomic Impacts of Climate Change on Forest-Based Communities: A Methodological Case Study*. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-415E. 136 p.

Williamson, T.B., S. Colombo, P. Duinker, P. Gray, R. Hennessey, D. Houle, M. Johnston, A. Ogden and D. Spittlehouse. 2009. *Climate Change and Canada's Forests: From Impacts to Adaptation*. Sustainable Forest Management Network, University of Alberta and Natural

Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, AB. 104 p.

List of abbreviations

with links to each organization's website [accessed September 27, 2010]

Abbreviation	Full Name
AIRD	Adaptation and Impacts Research Division, Environment Canada
AR4	Fourth Assessment Report (2007) of the IPCC
AR5	Fifth Assessment Report (2013-2014) of the IPCC
BEC	Biogeoclimatic Ecosystem Classification program of MFR
BIOCAP	The BIOCAP Canada Foundation (no longer in operation)
BVRC	Bulkley Valley Research Centre, Smithers, BC
CAS	Province of British Columbia, Climate Action Secretariat
CAT	Province of British Columbia, Climate Action Team
CBM-CFS3	Carbon Budget Model of the Canadian Forest Service (version 3)
CCCSN	Canadian Climate Change Scenarios Network, Environment Canada (archives)
CCFM	Canadian Council of Forest Ministers
CCIAD	Climate Change Impacts and Adaptation Division, Natural Resources Canada
C-CIARD	Canadian Climate Impacts and Adaptation Research Network
CCP	Canadian Carbon Program, formerly Fluxnet-Canada
CFCAS	Canadian Foundation for Climate and Atmospheric Sciences
CFS	Canadian Forest Service
CICS	Canadian Institute for Climate Studies at UVic, now the PCIC secretariat
CIHR	Canadian Institutes of Health Reserch
CMI	Columbia Mountains Institute for Applied Ecology, Revelstoke, BC
CPAWS	Canadian Parks and Wilderness Society
CSN	Climate Solutions Network, a PICS-run database of climate change specialists
CURA	Community University Research Alliance, SSHRC
ENGO	Environmental Non-Governmental Organization
FFEI	Future Forest Ecosystem Initiative
FFESC	Future Forest Ecosystem Scientific Council of British Columbia (not active)
FIA-FSP	Forest Investment Account, Forest Science Program of MFR (not active)
FORREX	Forum for Research and Extension in Natural Resources (not active)
IDRC	International Development Research Centre
ILMB	Integrated Land Management Bureau of MFR (not active)
IPCC	Intergovernmental Panel on Climate Change
IRES	Institute for Resources, Environment and Sustainability
IRIACC	International Research Initiative on Adaptation to Climate Change
MEA	Millennium Ecosystem Assessment
MFR	BC Ministry of Forests and Range
NCCN	Northern Climate Change Network of Resources North Association (not active)
NCE	Networks of Centres of Excellence of Canada
NRCan	Natural Resources Canada
NRES Institute	Natural Resources and Environmental Studies Institute
NSERC	Natural Sciences and Engineering Research Council of Canada
PCIC	Pacific Climate Impacts Consortium
PCT	Pacific Carbon Trust, a British Columbia Crown corporation (not active)
PICS	Pacific Institute for Climate Solutions
RAC	Regional Adaptation Collaboratives program of Natural Resources Canada (not active)
SFMN	Sustainable Forest Management Network (legacy archives)
SSHRC	Social Sciences and Humanities Research Council of Canada
TRU	Thompson Rivers University, Kamloops BC
UBC	University of British Columbia, Vancouver, BC
UNBC	University of Northern British Columbia, Prince George, BC
UNEP	United Nations Environment Programme
USGCRP	United States Global Change Research Program
UVic	University of Victoria, Victoria, BC
WC^2N	Western Canadian Cryospheric Network

Glossary

Definitions used by the IPCC 4th Assessment Report and MEA

Adaptation: Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.

Adaptive capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Climate change: Any change in climate over time, whether due to natural variability or as a result of human activity.

Ecosystem services: The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other non-material benefits.

Impacts: The direct and indirect effects of anthropogenic climate change on ecological and social systems.

Mitigation: A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Resilience: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change.

Scenario: A plausible, challenging and relevant story about how the future might unfold based on an internally consistent set of assumptions about key driving forces (e.g., rate of technology change, prices) and relationships. Scenarios can be told in words (narrative-based) or numbers (modeling-based). They are not forecasts, projections, predictions or recommendations. They are about envisioning future pathways and accounting for critical uncertainties. Scenarios reflect the modern worldview that the future is not preordained but rather is subject to human actions and choices.

Vulnerability: The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes.