# Removing multi-scale barriers to climate-change adaptation in managed forests of BC

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## Preface

This report is based on observations from a climate change vulnerability assessment conducted in the Nadina Forest District and on discussions with project leaders of vulnerability assessments conducted in the Kamloops and West Kootenay areas. The perspectives in this report, however, are those of the authors.

## Introduction

Forest managers should in theory be preparing to adapt to a changing forest environment. Anthropogenic climate change is already well underway (IPCC 2007a, Oreskes 2004). There are few signs that world leaders can reduce greenhouse gas emissions enough to prevent rapid and dangerous change (e.g., exceeding a $2^0$C increase; Schneider et al 2007), even though doing seems highly cost effective (Stern 2007). Even if greenhouse gases emissions can be stabilised, the existing build-up of greenhouse gases in the atmosphere will drive environmental change for several centuries (IPCC 2007a).

Meeting forest management objectives will become increasingly challenging as the climate changes. Climate change will alter the physical environment and increase disturbance, affecting terrestrial biodiversity, hydrology and aquatic ecosystems (Daust and Morgan 2011). Climate change adds gradually to existing stress (e.g., from development) on ecosystems and increases the probability of extreme events (Dale et al 2001, IPCC 2011). Managed forests are particularly susceptible to the impacts of climate change because they are managed over long time periods (Hallegate 2008).

For forest managers, climate change represents a dramatic increase in uncertainty about the future that complicates planning (Hallegate 2008). There are fundamental difficulties in understanding and predicting large-scale complex systems such as climate (Ludwig et al. 1993) and ecological responses to climate change are unpredictable (Spittlehouse and Stewart 2003, Suttle et al. 2007).

Below we present our observations from three climate change vulnerability assessments of managed forests in BC[1]. We outline potential management responses to climate change in BC's forests, present observations about barriers to adaptation and recommend steps to remove those barriers.

## *Potential management responses*

In the forestry context, adaptation means developing management strategies that account for expected or actual effects of climate change in order to improve chances of meeting management goals (based on definition in IPCC 2007b). Effective adaptation policy must address societal goals (Burton et al. 2002). Adaptation can be viewed as part of the risk management component of sustainable forest management (Spittlehouse and Stewart 2003).

Here, we focus on proactive or anticipatory adaptation (IPCC 2007b). Organisms, including people will react automatically to climate-change impacts, but people and organisations have the capacity to plan for expected change. Proactive adaptation is thought to be more effective than reactive adaptation (Ohlson et al. 2005, CCSP 2008). Proactive adaptation includes (1) changing current management practices and (2) making preparations to deal with future climate-related uncertainty (i.e., mainly disturbance). In some cases informed inaction is the best response (Joyce et al. 2008).

Our vulnerability assessments identified many potential management responses (Appendix). Most responses are modifications of existing strategies (e.g., higher levels of forest retention around temperature sensitive streams); some are untested (e.g., planting southern species). Management responses fall into two broad categories.

1. **Reduce risks to managed forests (change current practices):**
    a. limit anthropogenic stress (to reduce susceptibility to climate-change impacts; to facilitate autonomous adaptation of ecosystems)
        i. develop a BC-scale conservation strategy that supports both adaptation and mitigation (Pojar);
        ii. develop a regional cumulative effects assessment approach (Duinker and Greig 2006; Ohlson et al. 2005) [2] that limits total anthropogenic stress, including climate change, in a region;
        iii. develop a triage approach to deal with species at risk;

[1] FFESC-B8 - Resilience and climate change: adaptation potential for management and ecological systems in the West Kootenays, leader Rachel Holt, Veridian Consultants; FFESC-B11-A multi-scale trans-disciplinary vulnerability assessment, leader Don Morgan, Ministry of Environment, Smithers; FFESC-B12 - Validating impacts, exploring vulnerabilities, and developing robust adaptive strategies under the Kamloops Future Forest Strategy, leader Harry Nelson, UBC.

[2] Any reasonable approach that does not omit important variables (e.g., climate change) will suffice.

iv. use a precautionary approach (Gollier and Treich 2003) to development that recognizes uncertainty (e.g., increased redundancy in conservation design);

b. promote ecological diversity (e.g., age, species, structure) that contributes to resilience, across multiple spatial and temporal scales;
c. guide ecological transformation (e.g., plant climatically-suited tree species, limit spread of invasive species [but see Schlaepfer et al. 2011], alter successional pathways);
d. increase capacity of infrastructure to withstand extreme events;
e. preferentially harvest susceptible timber (e.g., during a mountain pine-beetle outbreak).

2. **Increase the capacity of the forestry community to respond (prepare for the future):**
    a. increase monitoring and detection of undesirable change and hence efficacy of control (e.g., improve basic knowledge, monitor climate trends, monitor insect and disease populations, monitor stream flow and risk to infrastructure);
    b. increase emergency response capability (e.g., fire suppression, salvage harvesting);
    c. increase diversity and flexibility of timber processing facilities (e.g., develop pellet plants; use a greater variety of fibre sources).

Forest-dependent communities will be affected by changes to forest ecosystems and by changes to the forest sector.

While our projects identified potential responses to climate change, we did not assess costs and benefits across the range of forest values or examine the practicality of implementation in detail.

## Barriers to adaptation

Barriers limit the identification and implementation of climate-savvy management strategies and preparations for future disturbance. Some barriers are insurmountable: existing knowledge is insufficient to identity feasible, beneficial responses. Below we present surmountable barriers observed in one or more of the vulnerability assessments.

In our vulnerability assessments, we identified lack of mandate and resources as the largest barrier to adaptation at the regional scale (Table 1), followed by restrictive legislation and policy and then by planning capacity. Although knowledge about future conditions under climate change is limited, we did not find it to be a substantial barrier, at least in the short-term.

Table 1. Observed importance (0 to 3 Xs show nil, low, medium and high) of different types of surmountable barriers (based on CSSP 2008 and Glick et al. 2009)

| Barrier | Importance rating |
|---|---|
| 1. Lack of concern | — |
| 2. Lack of knowledge expertise | X |
| 3. Lack of planning capacity | XX |
| 4. Lack of mandate/resources* | XXX |
| 5. Restrictive legislation and policy** | X to XXX |
| 6. Lack of political will | Assume causes lack of mandate/resources |

*we assume that resources should accompany mandate.
**moves from a X to XXX when publicly-defined management objectives are included.

1. In the vulnerability assessments, regional-scale forest managers expressed concern about and interest in climate change and wanted to find out more about climate change in general and about impacts on forests specifically. Disbelief in climate change does not appear to be a barrier to adaptation.

2. Forest managers did not have ready access to the knowledge and expertise that would support adaptation, prior to vulnerability assessments. Relevant knowledge is scattered among disciplines. The process of assembling basic knowledge for the vulnerability assessments required effort but was not onerous, thus we do not believe it is a major barrier. In the Nadina, regional research staff with the Ministry of Forests Lands and Natural Resource Operations (FLNRO) provided most of the information and expertise. In the Kamloops and West Kootenays, research staff with academia and the Canadian Forest Service also contributed. Consultants were primarily responsible for synthesis. Assembled knowledge is uncertain and based in part on expert opinion, but is often adequate to estimate the direction and approximate magnitude of biophysical change and to serve as a basis for climate-savvy planning.

3. Lack of planning capacity can hinder adaptation. Planning for multiple publically-defined values over long time frames is complex. Forest managers have already invested substantially in existing plans and are reluctant start over. Integrating climate-savvy strategies with existing forest management plans will not be trivial for several reasons:
   - there are multiple plans to update;
   - the costs and benefits of potential climate-savvy strategies have not been assessed across all values;
   - in some cases, operational trials are needed to demonstrate implementation feasibility.

4. At the regional scale, forest managers lack the mandate and resources to undertake adaptation:
   - Without research-oriented vulnerability assessments, forest managers would not have assembled information about potential impacts and identified potential responses.

- Company forest managers expressed an unwillingness to take implementation steps that increase costs (e.g., expensive planting stock) or risks (e.g., longer time to free growing) without short-term benefit. Under a corporate model, benefits that occur in the mid- to long-term are subject to substantial discounting. Also, under volume-based tenures, future benefits are not secure: they may accrue to a competing company. Overall, the motivation for companies to undertake proactive adaptation is limited.
- Government managers do not feel they have the primary responsibility for developing climate-savvy strategies. Government forest managers are not directly responsible for developing and implementing management strategies, rather their main role is to ensure that company-developed strategies meet publically-defined management objectives.

Thus, despite the recognition that existing management strategies should be improved to address climate change, no forest manager feels that he/she has the primary responsibility for adaptation. One could argue that government managers could demand climate-savvy strategies, but few strategies are certain to the extent that they would support such a demand.

5. Legislation and policy can directly prevent adaptation or can increase the risks associated with adaptation. For example, legislation restricts planting of tree species found further south and the level of deciduous tree retention. Even where more climatically-suited species are allowed, companies will plant species that are most likely to quickly achieve free-growing status to reduce their liability.

   Most importantly, policies based on publically-defined management objectives[3] (e.g., from Land and Resource Management Plans) no longer adequately reflect public concerns because past planning did not account for climate change. For example, the public may wish to place greater emphasis on ecosystem resilience and migration corridors.

6. The lack of mandate and resources to address climate change observed at the regional scale suggests to us that provincial interest in supporting climate change adaptation is weak. The status of provincial programs supporting climate change adaptation (e.g., Future Forest Ecosystems Science Council) is unclear. Government research staff in the regions do however have the flexibility to study climate change and one provincial-level forest manager did participate in the Kamloops project.

## Steps to increase adaptive capacity

Adaptive capacity can be improved in several ways: by increasing the awareness of provincial leaders, by improving regional knowledge, by updating resource

[3] Broad public direction is included under policy rather than planning.

management policy (goals), by improving and land and resource planning, by motivating private enterprise and by removing restrictive legislation

1. Increase awareness of provincial-scale forest managers of the need to support climate change adaptation

This step is similar to one recommended for the US Forest Service—providing appropriate climate change information to the multiple actors that influence forestry decision-making (Joyce et al. 2008)—but focuses on provincial decision-makers. This first step is critical because the remaining recommendations require a mandate and resources from provincial leaders. Forest managers and researchers that are already aware of risks posed by climate change are ultimately responsible for spreading information. Ideally, the Association of BC Forest Professionals should develop a stance and guidance on climate change adaptation. Professional associations can influence members to pay greater attention to climate change and can raise the awareness of provincial leaders (Gage 2011).

It is difficult for governments to act without public support, however, a recent poll suggests that the Canadian public believes climate change is happening and is a serious concern that is worthy of government action (Borick et al. 2011).

2. Develop regional learning programs to improve knowledge and support decision-making

A substantial number of papers addressing climate change call for adaptive management as a means of dealing with the uncertainty created by climate change (e.g., Glick et al. 2009, CCSP 2008). Here we use the term "regional learning program" to avoid pre-conceived notions of adaptive management. Learning is intended to be broad in scope and methodology and can take a variety of forms:

- synthesize the latest knowledge (e.g., tree species responses to climate change, hydrological models);
- improve inventories needed for climate-change planning (e.g., soils maps);
- monitor climate trends (e.g., is the region becoming wetter or drier in the summer?);
- monitor ecological response (e.g., is tree disease increasing?);
- conduct research to understand ecological responses (e.g., how does provenance influence susceptibility to disease?);
- monitor responses to management (e.g., has disease incidence decreased in plantations?);
- test management alternatives (e.g., which provenance reduces disease and grows fastest?).

Steps to create a learning program include:

- build on existing regional strengths (i.e., mainly government research staff);
- create a regional climate-change adaptation research/extension position;

- create a framework for recording and disseminating knowledge and for identifying knowledge gaps that can survive staff turnover and institutional restructuring (e.g., Babine Watershed Monitoring Trust[4], Price and Daust 2009);
- create formal and informal channels for sharing information among external researchers, regional researchers, regional and provincial forest managers and interested community members (e.g., articles, conferences, collaborative projects).

In addition to providing data and knowledge, a learning program can also cultivate collaboration, partnerships and human capital (recommended for the USFS in Joyce et al. 2008). It could also contribute to the awareness and education of provincial leaders.

The regional scale (e.g., one or more Forest Districts) seems the most appropriate scale for focussed learning because adaptation varies by region, and because regional investments can build adaptive capacity (Walker Sydneysmith 2008). Steps to build adaptive capacity should be locally relevant and build on existing programs and community attributes. In the Nadina area, the core of a learning program already exists: a strong research community (e.g., Bulkley Valley Research Centre[5] and regional FLNRO research staff) and a functioning example of a framework for managing knowledge (e.g., Babine Watershed Monitoring Trust).

3) Review and revise forest management objectives (policy)

Broad direction for land and resource management (e.g., Land and Resource Management Plans) was developed largely without consideration of climate change; it should be updated. For example, the role of forests in climate change mitigation and in supporting autonomous ecological adaptation should be considered. Goals for biodiversity may need to be reframed to recognize that climate change brings extinction risk and to incorporate concepts such as ecosystem function (Bunnell et al. 2011) and resilience. Goals to maintain timber supply may need to be modified to account for increased variability in the supply of dead and damaged trees, as well as for maintaining ecosystem resilience.

Revising such broad policy requires collaboration of provincial and First Nations governments and meaningful public involvement.

4. Review and revise forest management plans

Implementing new objectives for mitigation and resilience will require a provincial-scale land management strategy (e.g., Pojar 2011). Existing planning approaches should be improved to better address climate change (see also recommendations in Williamson et al 2009):

[4] www.babinetrust.ca
[5] www.bvcentre.ca

a) Use a structured decision-making approach (Ohlson et al. 2005) that separates knowledge from values (Price and Daust 2009). Isolating knowledge allows planners to better cope with the continuously evolving knowledge about climate impacts and the effectiveness of management.

b) Develop a regional cumulative effects assessment approach that ensures that all resource development decisions consider climate change and uncertainty (see discussion in Duinker and Greig 2006). To manage sustainably, policies must account for uncertainty. Principles of decision-making under uncertainty are mainly common sense (Ludwig et al. 1993):

- consider a variety of plausible hypotheses about future conditions
- consider a variety of possible strategies
    - favour actions that are robust to uncertainties
    - favour actions that are reversible
    - favour a variety of actions (hedge)
    - favour actions that are informative (probe and experiment; monitor)
- update assessments and modify policies

Similarly, the precautionary principle—err on the side of caution when uncertainty exists—provides a foundation for decision-making, provided that uncertainty can be resolved over time (Gollier and Treich 2001).

c) Develop a triage approach (Joyce et al. 2008) to deal with the expected increase in species-at- risk due to climate change (Thomas et al 2004). The current rating system (e.g., rare, threatened, endangered; COSEWIC) and management response treats species as likely to recover if threats are removed. Climate change may invalidate this assumption. A triage approach must be developed with care so that triage does not become an excuse for less conservation effort.

<u>5. Create incentives for companies to adapt.</u>

The benefits and costs of adaptation to climate change depend on perspective. Companies representing shareholders have different goals and time-frames than governments representing the public. Private enterprise can be encouraged to undertake adaptation that benefits the broader public with incentives (e.g., taxes, subsidies, regulations) and extension (e.g., technology transfer, education), depending on the situation (Figure 1). In the early stages of adaptation, collaborative projects, involving forest managers and researchers from various organizations, may be useful for developing and testing climate-savvy management strategies.

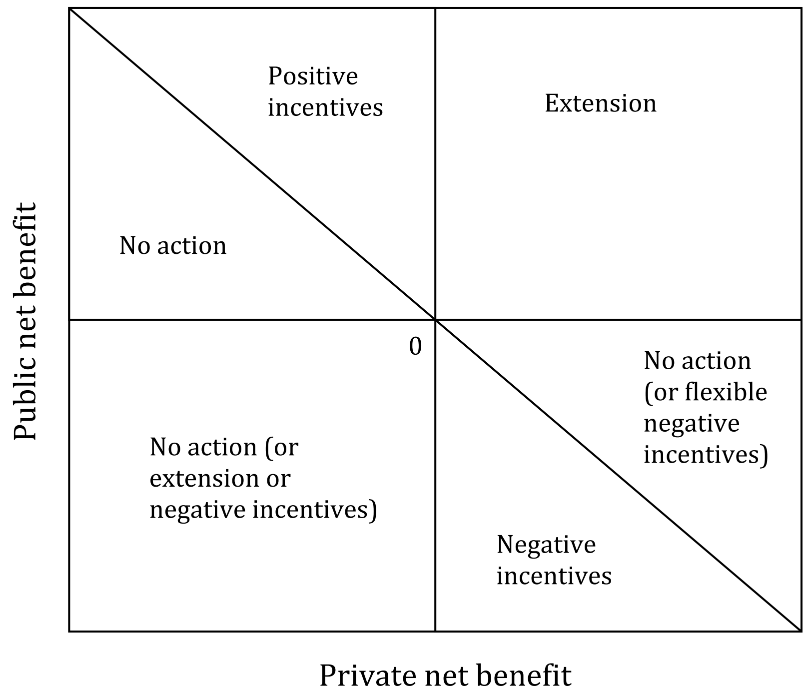


Figure 1. Suggested classes of policy tools for different levels of public and private benefits (from Pannell 2009).

<u>6. Remove legislative and policy barriers</u>

Removal of legislative and policy barriers requires careful consideration. Legislation and policy can constrain adaptation, but also protects forest values by providing minimum performance standards. The costs and benefits of each change need to be weighed. Increasing flexibility in legislation for the purposes of research trials, provides one means of advancing climate change adaptation without substantially increasing risk.

## Discussion

Our vulnerability assessments suggest that identifying potential responses to climate change is possible, but implementation is challenging. Similarly, many climate-savvy management strategies have been identified in the literature, but few have been implemented (Hallegate 2008).

Translating ideas to practice is hindered fundamentally by a lack of mandate and resources and by a lack of clear responsibility among forest managers. It is also hindered by the inertia of the status quo:

- Existing policies that are based on outdated public objectives
- Existing management plans that are difficult to revise
- Existing legislation that prevents adaptation
- Lack of incentive for private enterprise to create public benefit

Addressing these barriers requires committing personnel and funding to tackle each barrier. In the United States, significant investments in capacity will be required at federal, state, and local scales to support adaptation (Glick et al 2008). In BC, where forest land is publically held, the provincial government should lead this process because it holds primary responsibility for forest management. Partnerships with academia (e.g., collaborative adaptation research), industry (e.g., operational trials under the Forest Investment Account) and non-government organisations are possible and desirable. Recently, foundations have shown interest in supporting region-based research and monitoring that contributes to wise resource management[6].

Responding to climate change requires a coherent, coordinated response from forest managers at all levels (e.g., provincial policy-makers, District Managers, field foresters) that influence a region. Resources should be concentrated at the regional scale, however, because adaptation will vary by region and because strong regional institutions can contribute to resilience and adaptive capacity (Lemmen et al 2008)

While knowledge does not appear to be a substantial barrier to identifying potential climate-savvy strategies, at least in the short term, we suggest that regional learning programs will be needed to support implementation (e.g., analyses of costs and benefits, operational trials, assessing effectiveness), to detect biophysical change and to foster collaboration among managers and researchers. We recommend a low-budget approach, (e.g., starting with hiring climate-change, research-extension specialists) until adaptation needs are better defined. Regional learning programs can also provide information to provincial leaders.

Several authors suggest that planning for adaptation should treat uncertainty and apply risk management principles (e.g., Lemmen et al. 2008, Joyce et al. 2008). We agree, but think there two more basic needs:

- clarify societal goals for managed forests under climate change
- revise existing plans to roughly account for climate change.

Recommendations for the United States Forest Service include a rapid assessment of plans to determine level of preparedness for climate change (Joyce et al. 2008).

Ultimately failure to adapt proactively to climate change reflects a broader societal barrier: our inability to manage resources sustainably. Sustained yield estimates are optimistic and overexploitation is common (Ludwig et al. 1993). Hypothesized contributing factors include greed coupled with political influence, and inappropriate treatment of uncertainty. Harvest levels are also subject to the ratchet effect: increased resource use is easily rationalized, but proposed decreases face appeals to governments to protect investments and jobs (Burton 2011). Managers tend to defer economically unpopular decisions to conserve species at risk until the

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[6] e.g., the Moore Foundation supports projects addressing climate change in the context of conservation.

threat is certain and imminent (e.g., fisheries collapse[7]). When the crisis is reached, sudden changes in access to resources leads to hardship for companies and communities and substantial investment is required to develop and implement recovery plans.

Biodiversity can be viewed as an ecosystem service in its own right, or as a necessary condition underpinning the long-term provision of other services (citations in Joyce et al. 2008). Conserving biodiversity and maintaining ecosystem resilience will require greater restraint on economic activity under a changing climate than before. Reducing greenhouse gases requires similar restraint and is a necessary complement to climate-change adaptation because adaptation will only work when ecological and social impacts remain within limits. Whether society is willing to restrain economic activity remains to be seen.

While Canada (and other wealthy countries) seems to have high adaptive capacity (knowledge, skills and resources to support adaptation; Lemmen et al. 2008), we may be missing the mindset to adapt. Adaptive capacity is only as strong as the weakest link.

[7] Summarized in Overstall 2011. Bringing principle and transparency to the setting of wild salmon policy benchmarks. A Submission to the Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River. Burri, Overstall Barristers and Solicitors, Smithers, BC.

## Literature Cited

Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit and K. Takahashi, 2007: Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 717-743.

Borick, C., E. Lachapelle and B. Rabe. Climate compared: public opinion on climate change in the United States and Canada. University of Michingan. 9 pp.

Bunnell, F.L., L.L. Kremsater and R.W. Wells. 2011. Global weirding in British Columbia: climate change and the habitat of terrestrial vertebrates. BC Journal of Ecosystems and Management 12(2): 21-38.

Burton, I., S. Huq, B. Lim, O. Pilifosova and E.M. Schipper. 2002. From impacts assessment to adaptation priorities: the shaping of adaptation policy. Climate Policy. 2: 145-159.

Burton, P.J. 2010. Striving for sustainability and resilience in the face of unprecedented change: the case of the mountain pine beetle outbreak in British Columbia. Sustainability 2: 2403-2423.

CCSP. 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. [Julius, S.H., J.M. West (eds.), J.S. Baron, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA, 873 pp.

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, AND B.M. Wotton 2001. Climate change and forest disturbances. BioScience 51 (9): 723-734.

Daust, D. and D. Morgan. 2011. Management strategies for climate-change adaptation in the Nadina Forest District. Unpublished report available at [http://bvcentre.ca/research/project/a_multi-scale_trans-disciplinary_vulnerability_assessment/](http://bvcentre.ca/research/project/a_multi-scale_trans-disciplinary_vulnerability_assessment/)

Duinker, P.N. and Greig, L.A. 2006. The impotence of cumulative effects assessment in Canada: ailments and ideas for redeployment. Environmental Management 37:153-161

Gage, A. 2011. Professionals and climate change: how professional associations can get serious about global warming. West Coast Environmental Law. 23 pp.

Glick, P., A. Staudt and B. Stein. 2009. A new era for conservation: review of climate change and adaptation literature. National Wildlife Federation.

Gollier, C. and N. Treich. 2003. Decision-making under scientific uncertainty: the economics of the precautionary principle. Journal of Risk and Uncertainty. 27(1): 77-103.

Hallegate, S. 2009. Strategies to adapt to an uncertain climate change. Global Environmental Change. 19: 240-247.

IPCC, 2007a: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on

Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2007b: Appendix I: Glossary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2011. IPCC special report on managing the risks of extreme events and disasters to advance climate change adaptation: fact sheet.

Joyce, L.A., G.M. Blate, J.S. Littell, S.G. McNulty, C.I. Millar, S.C. Moser, R.P. Neilson, K. O'Halloran, and D.L. Peterson, 2008: National Forests. In: *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 [Julius, S.H., J.M. West (eds.), J.S. Baron, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA, pp. 3-1 to 3-127.

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.

Ludwig, D., R. Hilborn and C. Walters. 1993. Uncertainty, resource exploitation and conservation: lessons from history. Science. 260: 17, 36.

Ohlson, D.W., G.A. McKinnon and K.G. Hirsch. 2005. A structured decision-making approach to climate change adaptation in the forest sector. Forestry Chronicle. 81(1): 97-103.

Oreskes, N. 2004. The scientific consensus on climate change. Science. 306:1686.

Pannell, D.J. (2009). Technology change as a policy response to promote changes in land management for environmental benefits, Agricultural Economics 40(1), 95-102. (DOI:10.1111/j.1574-0862.2008.00362.x)

Pojar J. 2011. A new climate for conservation: nature, carbon and climate change in British Columbia. Commissioned by the Working Group on Biodiversity, Forests and Climate. http://www.forestethics.ca/new-climate-for-conservation-report

Price, K. and D. Daust. 2009. Making monitoring manageable: a framework to guide learning. Canadian Journal of Forest Research. 39: 1881-1892.

Schlaepfer, M.A., D.F. Sax and J.D. Olden. 2011. The potential conservation value of non-native species. Conservation Biology. 25: 428-437.

Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez and F. Yamin, 2007: Assessing key vulnerabilities and the risk from climate change. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 779-810.

Spittlehouse, D.L. and R.B Stewart. 2003. Adaptation to climate change in forest management. BC Journal of Ecosystems and Management. 4(1): 1-11. Online at http://www.forrex.org/jem/2003/vol4/no1/art1.pdf

Stern, N. 2007. The Economics of Climate Change: The Stern Review. Cambridge, UK: Cambridge University Press, online at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm.

Suttle, K.B., M.A. Thompsen, and M.E. Power, 2007: Species interactions reverse grassland responses to changing climates. Science, 315, 640-642.

Thomas, C.D., A Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, MF de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips and S.E. Williams. 2004. Extinction risk from climate change. Nature 427(8): 145-148

Walker, I.J. and Sydneysmith, R. (2008): British Columbia; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 329-386.

Williamson, T.B.; Colombo, S.J.; Duinker, P.N.; Gray, P.A.; Hennessey, R.J.; Houle, D.; Johnston, M.H.; Ogden, A.E.; Spittlehouse, D.L. 2009. Climate change and Canada's forests: from impacts to adaptation. Sustain. For. Manag. Netw. and Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. 104 p.

# Appendix: Table of management issues and responses

Table. Management issues, resulting from ecological responses to climate change, and potential management responses.

| Management issue (bold) due to ecological response (•) to climate change (○) | Management response (adaptation) |
|---|---|
| **Loss or degradation of old forest ecosystems and focal species' habitat**<br>• Increased stand-replacing and stand-opening disturbance<br>o warmer mean temperatures increase pests and fire hazard<br>• Changing species assemblages<br>o altered microclimate and soil moisture affects some species more than others<br>• Uncertain changes in snowpack, snow condition and winter severity<br>o warmer winters may increase or reduce snowfall<br>o reduced forest cover will increase snow accumulation<br>o altered freeze-thaw cycles will affect snow crusts<br>o mean winter temperature will decrease but climatic variability will increase leading to uncertain winter severity<br>• Increased invasive species<br>o warmer winters favour exotic and southern species<br>o intense fires and salvage harvesting increase soil disturbance | • Maintain a connected network of reserves, corridors, focal habitats and WTPs<br>• Increase redundancy of reserves and habitat units<br>• Allow flexibility to move habitat reserves<br>• Reduce hunting and control predators of ungulates<br>• Increase unroaded area to limit invasive species spread<br>• Control invasive species |
| **Potential extirpation of culturally important plants**<br>• Changing species assemblages (see above)<br>• Reduced seed banks<br>o intense disturbance can damage seed banks | • Avoid harvesting sensitive sites to maintain inertia (N)<br>• Use silviculture to create site conditions that favour threatened plants |
| **Reduced timber supply (growing stock and yield/ha)**<br>• Increased stand-replacing and stand-opening disturbance (see above)<br>• Increased growth rate (but likely less than mortality)<br>o longer, warmer growing seasons increase growth, subject to available moisture<br>o increased $CO_2$ increases efficiency of water use and photosynthesis | • Control insects, disease and fire, where possible<br>• Preferentially harvest susceptible stands<br>• Shorten rotations to reduce risk of loss<br>• Fertilize to reduce harvest age<br>• Regenerate diverse stands of climatically-suited species/stock that resist insects and disease |
| **Loss of productive forest landbase to grassland (or shrubs or human use)**<br>• Changing species assemblages (see above)<br>• Warmer climate may lead to increased human habitation | • Avoid harvesting sensitive sites to maintain inertia (N)<br>• Partially-cut stands on dry sites to retain shelter (N)<br>• Promote rapid site recovery (e.g., reforestation of dry sites; retain deciduous trees on moist sites) (N) |
| **Increased plantation failures**<br>• Increased stand-replacing and stand-opening disturbance (see above)<br>• Changing species assemblages (see above) | • Retain downed wood to store moisture on dry sites (N)<br>• Regenerate diverse, resilient stands of climatically-suited species/stock<br>• Use stand tending to influence successional pathways |

| Management issue (bold) due to ecological response (•) to climate change (○) | Management response (adaptation) |
|---|---|
| **Reduced water quality**<br>• Increased peak flows, stream flashiness and scour and increased landslides and surface erosion<br>o Increased spring, winter and fall precipitation<br>o Increased winter rain/snow ratio and rain on snow events<br>o Increased frequency and magnitude of storm events<br>o Increased ECA due to disturbance reduces capacity of landscape to buffer rainfall events, leading to rapid (flashy) changes in streamflow | • Limit ECA to 30 to 50% of THLB<br>• Avoid locating roads and cutblocks on unstable terrain<br>• Design roads and drainage structures to accommodate increased peak flow and bedload transport in areas likely to become wetter |
| **Infrastructure damage**<br>• Increased peak flows, flashiness and scour and increased landslides and surface erosion (see above) | • As above |
| **Degraded fish habitat**<br>• Increased peak flows, flashiness and scour and increased landslides and surface erosion (see above), increases scour and sedimentation of spawning gravel<br>• Reduced summer low flows (that isolate fish)<br>o warmer summer temperatures increase evapotransipiration<br>o summer precipitation may decline (southern Kamloops, eastern Nadina)<br>o possible declining snowpacks lead to smaller and earlier recession, creating longer low flow period<br>o declining snowpacks reduce late summer drainage feeding streams<br>o but glacier melt increases summer flows (Nadina)<br>o compounded by human water use<br>• Also see shift of stream ecosystem below (flow continuity affects habitat) | • As above<br>• Limit human water use |
| **Shift of stream ecosystem from perennial to intermittent or ephemeral (affects aquatic community and isolates fish)**<br>• Reduced summer low flows (see above) | • Limit human water use<br>• Limit ECA |
| **Possible lethal temperatures for salmonids (low elevation streams)**<br>• Increased stream temperature<br>o warmer annual temperature increases water temperature<br>o reduced snowpacks provide less cool water<br>o reduced summer flows (see above) are easier to heat<br>o but glacial meltwater cools streams<br><br>Note that high elevation streams may become more productive (however many of these streams have isolated fish populations) | • Retain riparian cover<br>• Manage warm water sources (e.g., ditches; deactivated roads)<br>• Avoid harvesting sites with high water tables |