Management strategies for climate-change adaptation in the Nadina Forest District

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*** http://bvcentre.ca/research/project/a_multi-scale_trans-disciplinary_vulnerability_assessment/

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Summary

The table below summarizes adaptation strategies designed to address the main climate-induced ecological changes expected to affect three types of ecosystem services in the Nadina District: trees and timber; biodiversity; hydrology and aquatic systems. Most strategies presented are not novel; however, they will need to be implemented more widely and thoroughly, with the underlying goal of learning more about their effectiveness. Addressing climate change requires an adaptive management approach.

Summary Table. Climate-induced effects (bold) and adaptation strategies (bulleted) for trees and timber, biodiversity, and hydrology and aquatic resources.

Trees and Timber
Increased tree growth potential on sites with sufficient moisture
• Plant climatically-suited species and genetic stock
• Fertilize appropriate sites
• Partially-cut stands on dry sites
Increased tree disease virulence (mainly younger stands)
• Plant climatically-suited species and genetic stock
• Increase stand-scale species diversity
• Remove stumps with root disease
Increased bark beetle virulence (mainly older stands)
• Plant climatically-suited species and genetic stock
• Increase stand-scale species diversity
• Shorten rotations of susceptible stands
• Monitor and control beetle populations
Increased fire hazard (all stands)
• Control human access during high hazard times
• Reduce post-harvest fuels
• Leave fire-breaks
• Provide more and better fire-suppression equipment on site
• Improve access for fire suppression
Biodiversity
Loss of old forest habitat and connectivity due to increased tree mortality
• Create a network of reserves, corridors and wildlife tree patches; limit salvage in network
• Reduce disturbance from insects, disease and fire across the landscape
Loss of suitable microclimate and soil conditions following harvest (e.g., dry sites, brushy sites)
• Avoid harvesting sensitive sites
• Partially-cut stands on dry sites
• Retain down wood
• Rapidly reforest sites
Loss of young forest vigour and diversity due to species maladaptation to changing climate
• Retain naturally-occurring and regenerating species and plant a diverse species mix

• Use stand tending to influence successional pathways
• Plant climatically-suited species and genotypes
Increased spread of invasive species
• Minimize roads
• Minimize road use
• Minimize grazing
• Minimize site disturbance
Hydrology and aquatic ecosystems
Increased stream temperature
• Retain riparian cover
• Properly maintain ditches and properly deactivate roads
• Avoid harvesting sites with high water tables
Increased risk of landslides and surface erosion
• Avoid locating roads and cutblocks on unstable terrain
• Design roads and drainage structures to accommodate increased peak flow and bedload transport in areas likely to become wetter
Increased peak flows (western mountains)
• Limit ECA[a] to 30 to 50% of THLB

Introduction

Climate change has already affected ecosystems in the Nadina Forest District (e.g., mountain pine beetle outbreak). Irrespective of efforts to curb carbon emissions, climate change will continue to influence ecosystem function and alter services provided by ecosystems. Proactively developing approaches and plans to cope with a novel and more dynamic ecological reality can potentially reduce negative impacts and capture potential benefits of climate change.

This report presents a preliminary set of strategies for sustainable forest management in the Nadina Forest District in an era of climate change. These "adaptation strategies" address some of the major challenges presented by climate change. The challenges and solutions (i.e., strategies) are based on modelled projections of climate change, expert projections of ecological change and brainstorming sessions with forest managers[1]. Most strategies presented are not novel; however, they will need to be implemented more widely and thoroughly, with the underlying goal of learning more about their effectiveness. Addressing climate change requires an adaptive management approach.

This report is divided into three sections dealing with trees and timber, biodiversity, and hydrology and aquatic ecosystems respectively. Each section outlines potential climate-related challenges (and opportunities) and presents a table of strategies designed to address specific challenges. The report ends with a recommendation to shift the current management paradigm to better address a more dynamic climate.

[a] Equivalent Clearcut Area: percent of basin that functions hydrologically as though it were clearcut (calculation assumes hydrological recovery of disturbed sites is a function of tree height).

Trees and timber

Trees are both foundation species supporting biodiversity and an important source of wood fibre for local mills. Across a landscape, timber supply depends on the rate of volume growth within each stand and on the probability of trees and stands surviving to rotation age (Figure 1). It also depends on how much merchantable (e.g., mature) dead volume can be salvaged before it decays.

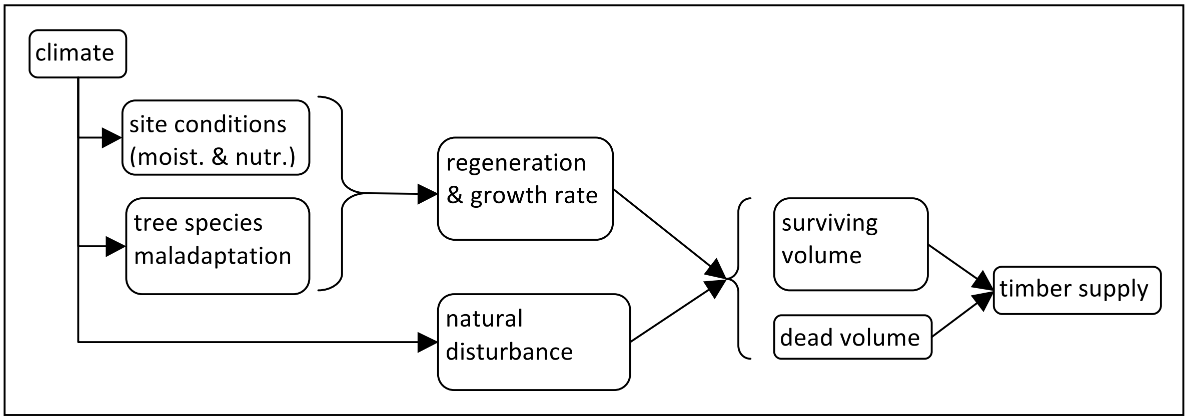

Figure 1. Simple conceptual model showing influence of climate on timber supply; many complexities are not shown. Logging influences disturbance rate; silviculture influences regeneration and growth; salvage harvesting determines contribution of dead volume to timber supply.

Projected impacts

Net volume production is unlikely to increase in the Nadina during this century and could likely decline. Projections of lower timber supply have also been made for BC and Canada[2]. The effects of climate change on timber supply are highly uncertain, reflecting tradeoffs between increased growth (10 to 25%), due to longer, warmer growing seasons and increased carbon dioxide concentrations, and increased unsalvaged mortality (10 to 30%) due to increased natural disturbance (see supporting rationale, page 14). Effects of tree mortality are particularly difficult to estimate for two reasons. First, gap disturbance is more difficult to identify and salvage than stand-replacing disturbance but still lowers yield. Second, the periodic nature of disturbance can overwhelm salvage capacity, but the timing of disturbance cannot be predicted or planned for. In addition, future fire disturbance rates for the Nadina are highly uncertain.

Disturbance could be worse in the short and mid-term (a transition period) as disturbance agents spread into high densities of susceptible hosts (e.g., mountain pine beetle outbreak) or, conversely, worse in the long-term as climate change becomes more pronounced.

Adaptation

Adaptation aims to capitalize on opportunities (mainly increased tree growth potential) and to reduce negative impacts (mainly increased disturbance) resulting from climate change (Table 1). Adaptation strategies have the potential to shift overall climate-induced impacts on timber supply from negative to positive. Adaptation could lead to large decreases in projected beetle mortality over the long term, modest decreases in disease and modest increases in tree growth. Large decreases in beetle mortality are partly attributable to a changing forest age class structure, however. Adaptation may have limited success in reducing fire disturbance, because effective fire control in average-weather years can be swamped by large disturbances in very dry years.

Table 1. Adaptation strategies (bullets) addressing climate-induced effects (shaded rows) on trees and timber and estimated response to adaptation[3] [4].

<table>
<tr><th>Climate-induced effects and adaptation strategies</th><th>Response to adaptation strategies[b]</th></tr>
<tr><td>Increased tree growth potential on sites with sufficient moisture</td><td>LM→M</td></tr>
<tr><td colspan="2">• Plant climatically-suited species and genetic stock
o purpose: to increase drought resistance, reduce maladaptation and increase growth
o scope: all sites, but especially dry sites
o barriers: existing seed standards; risk to free growing; expensive stock
o learning: active and passive adaptive management[c] to test survival and growth of a variety of species and genotypes

• Fertilize sites that have limited nutrients but sufficient moisture
o purpose: to increase growth in order to increase mid-term timber supply
o scope: sites without moisture limitations and with potential to contribute to mid-term timber supply or that are susceptible to mortality
o barriers: expense and limited experience
o learning: active adaptive management (e.g., to test effects of stand age and site series)

• Partially cut stands on dry sites to retain shelter and moisture
o purpose: to increase regeneration success on dry sites
o scope: dry sites
o barriers: limited experience in the Nadina
o learning: passive adaptive management to assess regeneration success</td></tr>
<tr><td>Increased disease-related mortality (mainly younger stands)</td><td>MH→M</td></tr>
<tr><td colspan="2">• Plant climatically suited species and genetic stock (i.e., facilitated migration)
o purpose: to reduce climate-stress, increasing resistance to insects and disease
o scope: all sites, but especially sites facing increased moisture stress and areas shifting to wetter climate
o barriers: existing seed standards; risk to free growing; expensive stock
o learning: passive adaptive management (monitoring disease)

• Increase stand-scale species diversity (e.g., retain and plant a variety of species, including broadleaf)
o purpose: to reduce stand-scale mortality from any one disease or insect and to reduce spread of insects and disease within the stand
o scope: all sites, especially naturally diverse ones
o barriers: risk to free growing; uncertain impact on yield
o learning: active adaptive management to assess effects on growth rate and disease incidence
• Remove stumps on productive sites with root disease after harvest
o purpose: to reduce spread of root disease to regenerating stand
o scope: productive sites with root disease
o barriers: expense</td></tr>
</table>

[b] The first code shows the projected approx. magnitude of the climate-induced effect, given current management. The arrow leads to the second code that shows the potential effect of climate change plus all adaptation strategies. Magnitude of effect is represented by five classes: **L**ow, **M**edium, **H**igh and intermediate combinations. Most adaptation strategies aim to reduce climate-induced effects, except for the case of increased tree growth.

[c] Passive adaptive management involves applying a recommended strategy and monitoring results; active adaptive management involves applying different strategies in a manner that tests the merits of each.

Climate-induced effects and adaptation strategies	Response to adaptation strategies[b]

- monitoring: passive adaptive management to assess growth

Mechanical damage from wind / snow and from animals may also increase.

Increased beetle-related mortality (mainly mature/old stands)	H→LM

- See first two strategies addressing disease-related mortality

- Shorten rotations
  - purpose: to reduce exposure of merchantable timber to natural disturbance; but, consider potential loss of mean annual increment and piece size.
  - scope: especially relatively productive sites (with larger piece sizes) and especially stands most susceptible to disturbance
  - barriers: limited market demand for small wood
  - learning: active adaptive management to measure loss of MAI and piece size; research to quantify disturbance rates

- Monitor and control beetle population sources (e.g., sanitation harvesting)
  - purpose: to reduce beetle spread
  - scope: stands where benefit of control outweighs cost to non-timber values
  - barriers: expense of monitoring and control; non-timber values
  - learning: active adaptive management to assess efficacy of control (provincial-scale study); document expense of alternative beetle monitoring options

Note that disturbances such as harvesting, beetles and fire reduce the proportion of older forest, susceptible to beetles, without management intervention.

Increased fire hazard (all stand ages)	H→H?

- Control human access during fire season (e.g., via gates)
  - purpose: to reduce ignition risk
  - scope: areas that people use and that face high risk
  - barriers: lack of public support
  - learning: post-fire analysis

- Reduce post-harvest fuels (e.g., broadcast burning, pile and burn, mulching, chipping)
  - purpose: to reduce risk of spread
  - scope: stands with abundant slash
  - barriers: limited public support for burning; expense
  - learning: post-fire analysis

- Leave fire-breaks (e.g., deciduous strips)
  - purpose: to reduce risk of spread
  - scope: sites that have low flammability
  - barriers: loss of some harvestable timber
  - learning: post-fire analysis

- Provide more and better fire-suppression equipment at logging sites
  - purpose: more effective fire control
  - scope: all active logging sites, during high fire hazard periods
  - barriers: expense
  - learning: post-fire analysis

Climate-induced effects and adaptation strategies	Response to adaptation strategies[b]
• Improve access to support suppression ○ purpose: more effective fire control ○ scope: timber harvesting land base ○ barriers: impacts to non-timber values; expense ○ learning: post-fire analysis Managing fire around communities is an important strategy to protect lives and property that is not considered here.	

Biodiversity

Biodiversity is the variety of life. Interacting species generate the broader ecological functions (e.g., decomposition and nutrient release) that create characteristic ecological patterns (e.g., site series) and that produce ecosystem services. Biodiversity confers ecological resilience, but is also valued directly by society.

Each species needs habitat to survive. At a coarse level, key elements of forest habitat include site type, seral stage and climate (Figure 2). Climate affects species directly because species tolerate a limited range of climatic conditions (e.g., temperature and precipitation). Climate also affects the moisture status and ultimately the nutrient status of a site, which affects plant species, species that use plants, and soil organisms. Climate affects disturbance rates and successional pathways, which affect seral stage. All these changes affect species interactions (e.g., competition for resources).

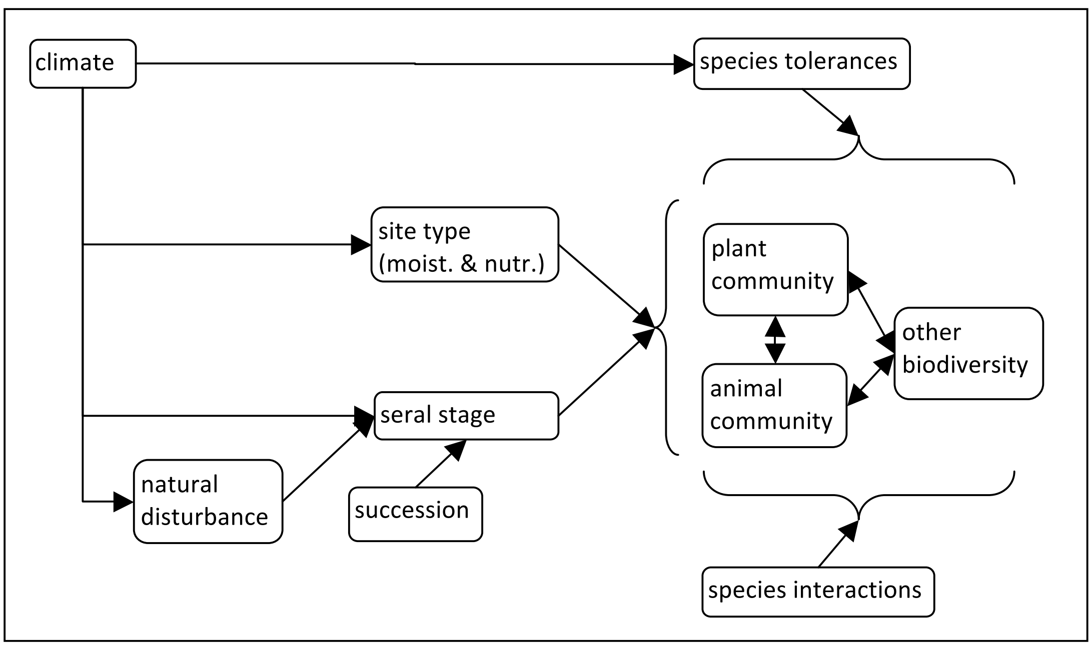

Figure 2. Simple conceptual model showing the pathway by which climate influences plants and animals (and more generally biodiversity). Logging influences disturbance rate; silviculture influences the post-harvest plant community; roads and landings facilitate spread of invasive species, impacting biodiversity.

Projected impacts

Species strongly associated with the ESSF and SBS climate envelopes face high extirpation risk from the Nadina in the latter half of this century as their climate envelopes disappear (see supporting rationale, page 16). Loss of species from the Nadina (extirpation) or changes in the relative abundance of species can affect community structure and function and consequently ecological resilience.

Due to increased disturbance related to climate change, the area of old seral forest could decline to roughly 15% to 60% of historic "natural" abundance (i.e., abundance prior to industrial development; see supporting rationale, page 16). Species strongly associated with old forest face an uncertain chance of extirpation, ranging from low (at 60% of natural old forest remaining) to high (at 15% of natural old forest remaining). Species strongly associated with old forest and a particular climate envelope face compounded risk.

Only the "strongly-associated" portion of the species that occur in a particular climate envelope or seral stage will face extirpation as climatically-suitable and mature/old habitats are lost. Many species will be able to survive in similar climate envelopes or seral stages, but the relative abundance of each species is likely to change. The ultimate effect on ecosystem function depends on which species are lost or decimated and on which species become dominant. Ecological consequences are highly uncertain, but in general, efforts to retain existing habitats and to support immigration of climatically-suited species can limit ecological upheaval.

Adaptation

In the context of biodiversity conservation, adaptation consists mainly of reducing anthropogenic pressures that compound the negative effects of climate change (e.g., reducing harvesting and road access) and of generally promoting diversity at stand and landscape scales (Table 2). Strategies address old forest conservation, harvesting and reforestation practices and soil disturbance. In alpine ecosystems, tree ingress could be controlled.

Table 2. Adaptation strategies (bullets) addressing climate-induced effects (shaded rows) on biodiversity and estimated response to adaptation[5] [4].

<table>
<tr><th>Climate-induced effects and adaptation strategies</th><th>Response to adaptation strategies[b]</th></tr>
<tr><td>Loss of old forest habitat and connectivity, due to increased tree mortality.</td><td>H→M in SBS
MH→LM in ESSF</td></tr>
<tr><td colspan="2">

Create a network of reserves, corridors and wildlife tree patches

purpose: to retain enough old forest habitat to support old forest species, accounting for increased disturbance; to retain age class diversity at stand and landscape scales; to facilitate dispersal of old forest species; ultimately to increase ecosystem resilience
barriers: reduced short- and mid-term timber supply
learning: watershed-scale adaptive management to determine area to reserve (provincial-scale study)
Scope for reserve network

Include riparian areas in reserves

they are productive and diverse
they form naturally connected networks
they may have a relatively resistant microclimate
they may be relatively resistant to disturbance

Include corridors crossing elevation gradients

to facilitate dispersal among climate zones

Include habitat for specialized species and communities at risk

Limit salvage in reserve network (e.g., partial cut or avoid harvest)

purpose: retain old forest structure; reduce road access and soil disturbance
scope: particularly where stands buffer microclimate or provide large structure

</td></tr>
</table>

Climate-induced effects and adaptation strategies	Response to adaptation strategies[b]
o barriers: reduced short- and mid-term timber supply o learning: active adaptive management examining salvage options • Reduce disturbance from insects, disease and fire using strategies outlined in timber section	
Loss of suitable microclimate and soil conditions following harvest due to changing climate	**MH→M**
• Avoid harvesting sensitive sites o purpose: to maintain stand inertia (e.g., tree survival is easier than establishment) and microclimate (e.g., reduced exposure to sun and wind) o scope: bogs and low nutrient “remnant boreal” sites, dry sites o barriers: lack of mapped sensitivity; minor loss of timber supply o learning: inventory of sensitive sites; monitor mortality of intact sensitive sites • Partially-cut stands on dry sites (i.e., retain partial overstory shelter) o see partial cutting in timber section • Retain downed wood o purpose: to store moisture on dry sites o scope: drier sites o barriers: waste and residue limits o learning: active adaptive management to test benefits • Promote rapid site recovery (e.g., reforestation of dry sites; retain deciduous trees on moist sites) o purpose: to reduce direct exposure of site to climate o scope: particularly drier sites o barriers: already standard practice but could have plantation failures o learning: microclimate studies if warranted	
Loss of young forest vigour and diversity due to species maladaptation to changing climate	**MH→M**
• Retain naturally-occurring and regenerating species (including deciduous trees and shrubs) and plant a diverse species mix o purpose: to reduce impact of catastrophic loss of any one species; to retain successional options; to increase stand-scale biodiversity o scope: all sites o barriers: stocking standards; free growing standards o learning: active adaptive management examining biodiversity and tree growth • Use stand tending to influence successional pathways o purpose: to facilitate shift to climatically-suitable species o scope: sites with high-risk successional trajectories o barriers: expense; uncertainty about best pathway o learning: identify candidate sites; passive adaptive management • Plant climatically-suited species and genotypes (i.e., facilitated migration) o see trees and timber section	
Increased spread of invasive species	**H→H?**
• Minimize roads o purpose: to reduce exposure of soil in ditches and cut/fill banks	

Climate-induced effects and adaptation strategies	Response to adaptation strategies[b]
○ scope: entire area, especially currently unroaded areas ○ barriers: loss of timber supply; increased planning and harvesting costs ○ learning: monitoring of roads for invasive species • Minimize road use (e.g., gates) ○ purpose: to reduce spread of seed via vehicles ○ scope: entire area ○ barriers: lack of public support ○ learning: active adaptive management to test effectiveness of gates • Minimize grazing ○ purpose: to reduce spread of seed via cattle ○ scope: near susceptible sites ○ barriers: existing range tenures ○ learning: active adaptive management to test long-term benefit of exclusion • Minimize site disturbance, particularly multiple disturbances (also summer logging) ○ purpose: to reduce exposure of disturbed soil seedbeds ○ scope: particularly susceptible sites (e.g., dry, grassy sites) ○ barriers: loss of timber supply ○ learning: identify high risk sites SBSdk already has many invasive species.	

Hydrology and aquatic ecosystems

Aquatic ecosystems contribute to biodiversity and ecological integrity. They provide fish habitat and clean water. Impacts to aquatic ecosystems arise from climate-induced changes to hydrological regimes (e.g., changes in the amount and timing of peak flows and low flows) and from industrial development, in combination (Figure 3). The main impacts, in approximate order of importance, include increased stream temperatures, increased erosion (scour) and increased risk of landslides. Erosion and landslides can add sediment to streams, affecting aquatic communities and spawning beds. Increased peak flows and landslides also pose risk to infrastructure.

Projected impacts

Estimating the magnitude of change to hydrology and aquatic systems in the Nadina is beyond the scope of this report, however, we suggest that changes in stream temperature could be the most ecologically important. In the Nadina, some salmon stocks and bull trout are particularly sensitive to increased water temperature [6]. Studies of the Fraser River system indicate that increased water temperatures could pose a significant risk to salmon before the end of this century [7].

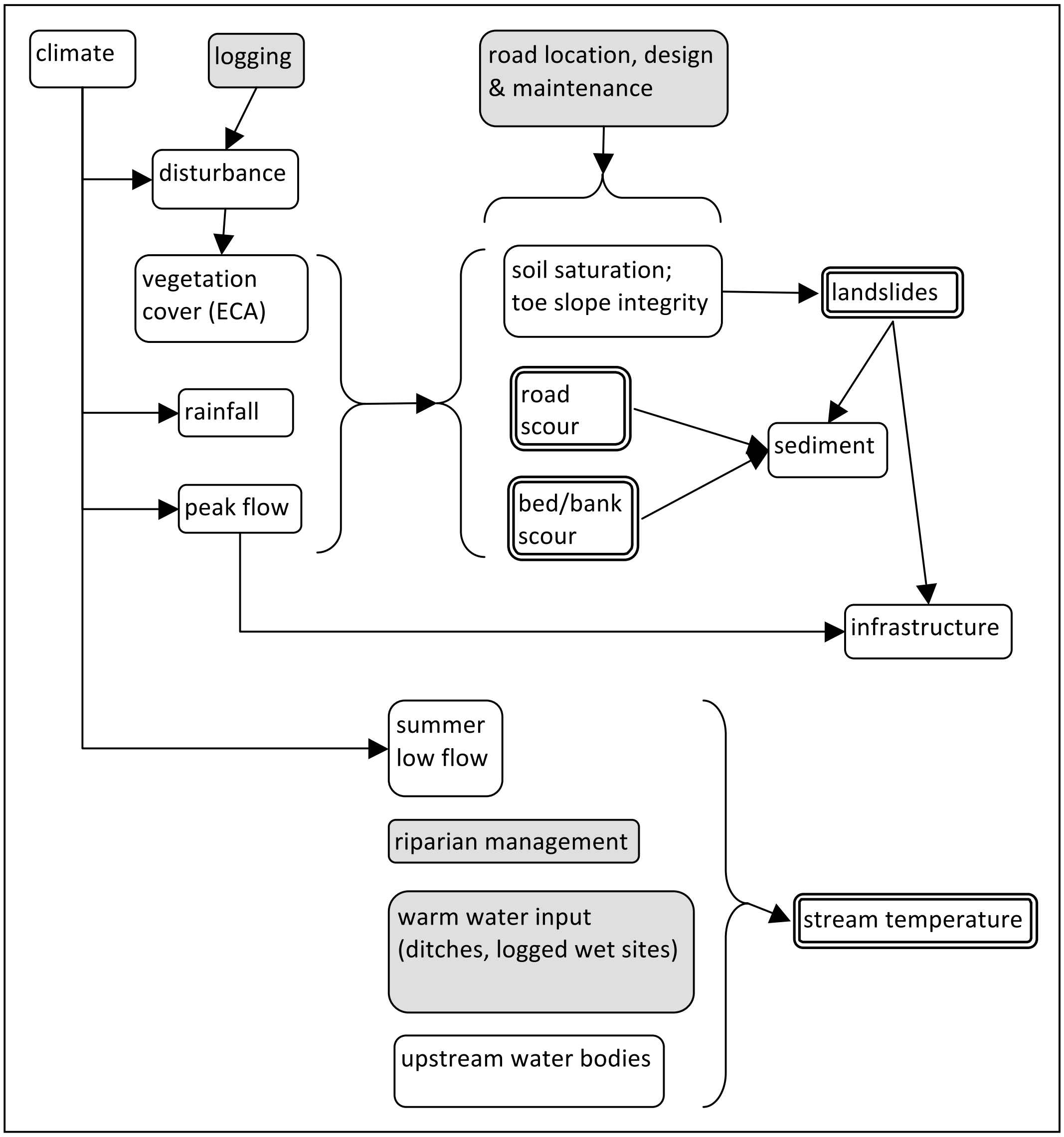

Figure 3. Simple conceptual model showing the influence of climate on hydrology and aquatic ecosystems. Grey boxes show management influence. Double-lined boxes show main impacts.

Adaptation

To protect aquatic ecosystems and infrastructure near watercourses, adaptation consists of limiting increases in stream temperature, limiting sediment input, via surface erosion and landslides, and limiting increases in peak flows (Table 3).

Table 3. Adaptation strategies (bullets) addressing climate-induced effects (shaded rows) on hydrology and aquatic ecosystems and estimated response to adaptation[6 4].

Climate-induced effects and adaptation strategies	Response to adaptation strategies[b]
Increased stream temperature	**H→H?[d]**
• Retain riparian cover ○ purpose: shade stream and upstream sources to limit stream heating ○ scope: particularly temperature sensitive watersheds	

[d] Strategies will not help if air temperature increases too much.

<table>
<tr><th>Climate-induced effects and adaptation strategies</th><th>Response to adaptation strategies[b]</th></tr>
<tr><td colspan="2">o barriers: minor loss of timber supply; increased planning effort
o learning: identify temperature sensitive watersheds; test alternative riparian management standards

• Properly maintain ditches and properly deactivate roads
o purpose: prevent pooling of water to reduce input of warm water to streams
o scope: sites that feed streams; particularly temperature sensitive watersheds
o barriers: increased road maintenance cost
o learning: identify temperature sensitive watersheds; monitor road drainage

• Avoid harvesting sites with high water tables
o purpose: reduce input of warm water to streams
o scope: sites with a high water table that feed streams; particularly temperature sensitive watersheds
o barriers: minor loss of timber supply
o learning: identify temperature sensitive watersheds; inventory potential warm water sources; determine aquifer volumes</td></tr>
<tr><td>Increased risk of landslides and surface erosion (that affect streams or infrastructure)</td><td>LM→L</td></tr>
<tr><td colspan="2">• Avoid locating roads and cutblocks on unstable terrain
o purpose: to reduce risk of landslides and earthflows that deliver large sediment wedges to streams or that affect infrastructure
o scope: roads that cross toe slopes and other unstable terrain; cutblocks above unstable terrain
o barriers: expense, specialized expertise
o learning: inventory potentially unstable terrain; monitor precipitation and runoff patterns

• Design roads and drainage structures to accommodate increased peak flow and bedload transport in areas that are likely to become wetter: e.g., surface high hazard roads; seed erodible cut slopes; build adequate ditches; replace selected culverts with bridges; limit road density in erosion-prone areas
o purpose: to reduce surface erosion from roads and drainage structures that influence streams and to reduce risk to infrastructure
o scope: roads with erodible soils in high rainfall or runoff areas; roads and drainage structures influenced by watercourses
o barriers: expense
o learning: identify “flashy” watersheds and plan accordingly; monitor erosion related to ditches, culverts and bridges</td></tr>
<tr><td>Increased peak flows (western mountains)</td><td>MH→M</td></tr>
<tr><td colspan="2">• Limit Equivalent Clearcut Area (ECA) to 30 to 50% of THLB in western mountains
o purpose: to retain forest to intercept and transpire precipitation and thus reduce peak flows, in order to limit erosion and risk to infrastructure
o scope: watersheds in western mountains
o barriers: minor loss of timber supply and operational flexibility
o learning: assess each watershed to determine appropriate management</td></tr>
</table>

Towards a new management paradigm

This document has described the potential effects of climate change and outlined potential adaptation strategies. It has presented rough estimates of the magnitude of climate-induced effects before and after adaptation, because such estimates should inform management decisions and priority setting. The estimates are a starting point to guide adaptation, but clearly need to be improved. Implementing the strategies outlined above in a meaningful way will require a revised management approach, including

- additional investment in learning;
- additional investment in relatively expensive management strategies;
- relatively precautionary management (e.g., accepting variable and likely reduced timber supply), to limit cumulative effects of development and climate change on biodiversity and aquatic ecosystems;
- collaboration that brings together necessary expertise from diverse disciplines and that shares information widely among managers.

Existing institutional structures and management paradigms do not adequately support learning or collaboration, nor do they provide adequate incentives to invest in adaptation, including especially precautionary management. Future work related to climate change should aim to identify institutional structures that facilitate learning, collaboration and investment.

Efforts to promote adaptation should be aligned with efforts to promote mitigation.

Supporting rationale: estimated impacts on trees and timber

The effects of climate change on timber supply reflect tradeoffs between increased growth (10 to 25%), due to longer warmer growing seasons and increased carbon dioxide concentrations, and increased unsalvaged mortality (10 to 30%) due to increased natural disturbance (Table 4).

Considering possible increases in fire, disease, storm damage and drought, roughly 20 (based mainly on disease) to 60% (based mainly on disease and fire) of young stands (e.g., < 60 to 80 yr) may not reach merchantable age prior to stand-replacing disturbance. Mortality of pre-merchantable stands represents a direct loss of timber volume. In young stands, volume losses depend on the age of the stand at the time of disturbance and on reforestation policies. The actual volume in the stand is less relevant than the increased time required to produce a merchantable stand. Assuming that all young stands are about equally susceptible and reforestation is prompt, the proportion of AAC lost might be about half of the proportion of stands disturbed (i.e., 10 to 30%).

Mortality in young stands may become a greater concern in the future. Higher disturbance rates (i.e., including natural disturbance and harvesting) increase the proportion of young forest on the landscape. Thus, increased disturbance rates both increase the chance that a young hectare is disturbed and the total area of young forest that faces this chance.

Considering possible increases in fire (0 – 100%) and beetle mortality (50 – 100%; Table 4), volume losses in merchantable stands could be similar to losses in younger stands (10 to 30% of AAC). For example, a 100-year disturbance return interval disturbs about 15% of the forest between age 80 and 120 (typical harvest window). Because increasing rates of mortality leave less old forest on the landscape, the average area of merchantable forest killed per year is relatively stable across disturbance regimes (i.e., a higher rate applies to a smaller area). Transition periods can bring very high tree mortality for several decades, however, and overwhelm salvage capacity (e.g., due to increased mountain pine beetle virulence and abundant susceptible pine left by historic disturbance). Estimated impacts on merchantable stands are highly uncertain because they depend on mature forest area and on salvage policies. Even with aggressive salvage policies, only a proportion of original stand volume can be salvaged. Volume can be damaged during disturbance, can decay or can be inaccessible or too expensive to harvest.

The area disturbed by multiple disturbance agents is not straightforward to calculate. It must account for the area susceptible to each disturbance agent. For example, bark beetles mainly affect mature and old trees, but different beetle species select different tree species; disease tends to affect younger stands and mainly pine to date; fire disturbs young and old forest, but can also affect stands killed by beetles and disease. Susceptible area changes in response to disturbance.

Doubling the natural disturbance rate does not double the rate of mortality prior to merchantable age; rather this latter rate depends on the proportion of the forest that is pre-merchantable, on the susceptibility of these young stands to disturbance, relative to older stands, and on the historic rate of disturbance. For example, stands in a landscape with a 200-year disturbance return interval face a 33% chance of mortality prior to age 80; stands in landscape with a 100 year interval face a 47% chance of mortality prior to age 80 (given indiscriminant disturbance).

Table 4. Projected changes in factors affecting timber supply and supporting considerations.

<table>
<tr><th>Factor</th><th>Projection</th></tr>
<tr><td>Growth (m^3), species and site</td><td>10 to 25% increased growth</td></tr>
<tr><td colspan="2">
• Increased temperatures and longer growing seasons could increase tree growth by 10 to 25% by 2050, without efforts to improve reforestation practices[8].
• Increased $C0_2$ can increase growth (e.g., by 50%) even in older trees provided moisture and nutrients are not limiting[9].
• Increased temperatures and changing precipitation patterns and seasonal temperatures can cause trees to be maladapted to their environment (e.g., leading to frost damage, aborted vegetative buds, moisture stress)[9]. Maladaptation may be particularly important on drier sites where drought can kill trees and on brushy sites where crop trees may become relatively less competitive with shrubs.
• A shortage of available nitrogen often limits tree growth in northern forests, but nutrient availability may increase if rising surface and soil temperatures stimulate decomposition of soil organic matter[9].
• In the Nadina, summer temperatures are expected to increase while precipitation may remain relatively constant[10], leading to increased evapotranspiration and summer moisture deficits that may limit growth on some sites, however, increased $C0_2$ leads to increased water use efficiency and some species can respond to increased evapotranspiration by increasing root growth[9].
</td></tr>
<tr><td>Disease disturbance (younger stands)</td><td>5 to 10x historic rate
~ 25 to 50% of stands disturbed</td></tr>
<tr><td colspan="2">
• Climate change could increase disease virulence and lead to high mortality (poor stocking) in 25 to 50% of early seral stands by 2080[8]. About 1/3 of these disturbances could be considered stand replacing; remaining disturbances reduce stocking and stand-scale growth rate. Diseases (e.g., Commandra, Dothestroma) are most prevalent in lodgepole pine plantations.
</td></tr>
<tr><td>Beetle disturbance (mature and old stands)</td><td>1.5 to 2x historic rate</td></tr>
<tr><td colspan="2">
• Climate change could double mortality rates in older stands from pine, spruce and balsam bark beetles[8]. Insect virulence is expected to increase due to longer, warmer summers that favour population growth and a reduced frequency of extreme cold periods that cause high mortality; trees stressed by climate change are more susceptible to insects and disease[11].
</td></tr>
</table>

Fire disturbance (all stands ages)	1 to 2x historic rate
• Projected shifts in BEC envelopes from ESSF to SBS and from SBS to IDF (more likely in the eastern plateau) suggest an approximate doubling in the natural stand-replacing disturbance rate[10]. Shifts from SBS to ICH (more likely in the western mountains) could reduce stand-replacing disturbance. Note that disturbance estimates may include both fire and beetle disturbance, depending on method used to calculate disturbance. • Estimates of the effects of climate change on fire vary. Fire disturbance in Canada could double due to climate change[12]. Shifts in BEC envelopes support this finding for the eastern plateau portion of the Nadina[10], however, Burton[13] projects that fire disturbance may increase slightly (southern BC) or decrease (northern BC).	
Unfavourable site conditions—drought	5 to 10% loss of THLB
• The proportion of dry sites with marginal timber production may double from about 5% (current proportion of forest area) to 10% due to increased evapotranspiration and increased climate variability[8]. • Warm temperatures can cause drought stress and lead to regional scale die-offs for some species[9]. • Brush competition may affect tree establishment on some sites[14].	

Supporting rationale: estimated impacts on biodiversity

Climate change may lead to changes in the relative abundance of species which will affect community structure, ecosystem function and resilience; it may lead to extirpation of some species from the Nadina. The Nadina is too small an area to assess extinction risk for most species, because most species have distributions that extend beyond the Nadina.

Species that are strongly associated with particular habitats begin to face extirpation risk when habitat declines to 60% of historic area; extirpation risk becomes high when habitat declines below 30%[15].

This section roughly estimates extirpation risk from loss of climatically-suitable habitat (including climatic influences on site moisture and nutrient status) and from loss of old seral habitat. It examines potential changes in community structure. Invasive species will also affect biodiversity in the Nadina, but the magnitude of impact is difficult to determine (Table 5).

Extirpation due to shifting climate envelopes

Across BC, the climatic conditions historically associated with major forest types ("BEC climate envelopes") are expected to shift substantially over this century[16].

Species strongly associated with the ESSF climate envelope (i.e., relatively specialized species) face high extirpation risk from the Nadina circa 2050, when less than 10% of climatically-suitable habitat remains (Table 5; Figure 4). Species strongly associated with the SBS have a more uncertain near future (at 2050); two of three projections suggest less than 10% of climatically suitable SBS habitat will remain. Extirpation will likely lag behind climate change because current species are well established and because immigrating species will need time to establish and dominate.

Table 5. Projected changes in factors affecting biodiversity and supporting considerations.

<table>
<tr><th>Factor</th><th>Projection</th></tr>
<tr><td>Loss of historically-suitable climate envelopes (percent of original area remaining in 2050)
(Affects microclimate, soil conditions and maladaptation)</td><td>1 to 10% of ESSF remaining
1 to 90% of SBS remaining</td></tr>
<tr><td colspan="2">• Loss of current climate envelopes is based on three climate models, each using a different emissions scenario; the three projections cover a representative range of future emissions scenarios[17].
• Current climate envelopes continue to decline past 2050 (Figure 4).
• Replacement envelopes include IDF (eastern Nadina), ICH (west) and CWH (west) (Figure 5 and Figure 6).
• Site moisture and nutrient regimes depend on climate and topography.
• Broad patterns of vegetation (e.g., leading tree species) correlate with climate envelopes.
• Loss of ecological function and resilience may occur as the relative abundance of species changes, even without extirpation[18].</td></tr>
<tr><td>Loss of old forest (percent of historic natural remaining circa 2050)</td><td>15 to 60% of historic natural old forest remaining</td></tr>
<tr><td colspan="2">• Historic natural disturbance frequency is about 1/200 in the ESSF, leaving about 29% of the forest older than 250 yr, and about 1/125 in the SBS, leaving about 33% of the forest older than 140 yr[19]. Old forest area was calculated using e(-t/b) where e is the natural logarithm, t is the starting age of old forest and b is the disturbance return interval.
• Diseases in young stands could cause 25 to 50% of young stands to be disturbed before maturity (a 5 to 10 fold increase over historic disturbance)[8]. This increased disturbance rate roughly correlates with a 100 to 250 year disturbance return interval (assuming randomly located disturbance of stands < 70 yr), ignoring other disturbance agents.
• Beetle disturbance rates could increase by 50 to 100% in mature and older stands[8].
• Disease and beetles cause partial disturbance of stands, leaving a mixed-age stand; older mixed-age stands with less than 50% mortality may retain substantial old forest functionality[8].
• Fire disturbance rates could increase by 0 to 100% (see fire disturbance in Table 4).
• Based on trends in beetle, insect and fire disturbance, the overall increase in disturbance ranges from roughly 50% to 150% (some disturbances overlap and others add; some disturbances are less intense and retain old forest function)</td></tr>
<tr><td>Increase in invasive species</td><td>Likely but uncertain magnitude</td></tr>
<tr><td colspan="2">• When invasive species spread beyond their historic range, they escape from ecological relationships that control their population[18].
• Increased temperatures and reduced continentality associated with climate change will favour the spread of exotic invasive species into the Nadina[18].
• Native BC species that occur further south can also become invasive in Nadina[18].</td></tr>
</table>

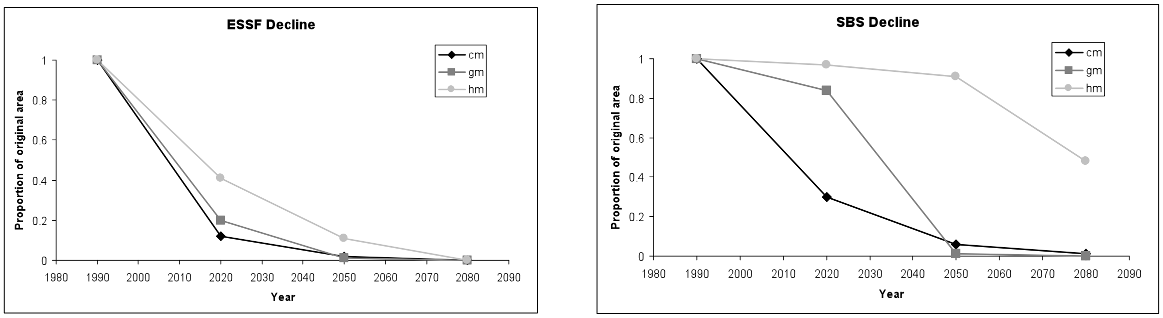

Figure 4. Decline in Nadina ESSF and SBS climate envelopes (proportion of 1990 region still covered) over time predicted by three different climate model projections (cm, gm, hm)[10].

The number of species facing extirpation depends in part on the degree to which species are specialized to existing climatic conditions. We defined specialized species as those that occur in the retreating envelope but not in the advancing envelope. Current projections suggest that retreating ESSF envelopes could be dominated by ICH and CWH envelopes and that retreating SBS envelopes could be dominated by either IDF or ICH envelopes (Figure 5 and Figure 6). A complete analysis of species overlap among BEC zones is beyond the scope of this report, however, preliminary analysis suggests that some species (e.g., 10%) in the SBS and ESSF are not found in projected climate envelopes.

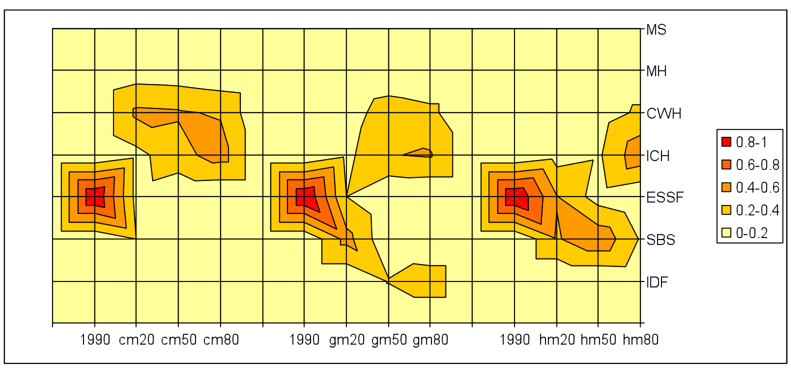

Figure 5. Proportion (shown by contour bands) of the 1990 Nadina ESSF zone covered by different climate envelopes (y-axis) versus time (1990, 2020, 2050 and 2080) for different model runs (cm, gm, hm)[10].

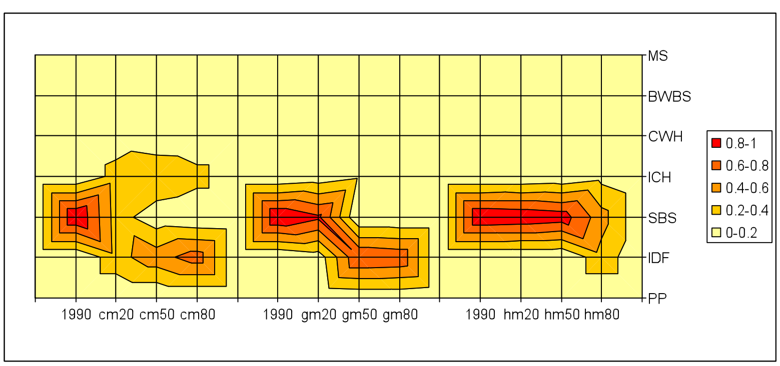

Figure 6. Proportion (shown by contour bands) of the 1990 Nadina SBS zone covered by different climate envelopes (y-axis) versus time (1990, 2020, 2050 and 2080) for different model runs (cm, gm, hm)[10].

Extirpation due to loss of older forest

Of all the seral stages, old forest faces the highest risk of decline due to increased disturbance related to climate change. Old forest area could decline to 15 to 60% of historic "natural" abundance (Table 5). Species strongly associated with old forest face an uncertain chance of extirpation, ranging from low (at 60% of natural old forest remaining) to high (at 15% of natural old forest remaining). About ¼ of vertebrate species in the SBS are strongly associated with mature and old forest[20]. Those relying more on old forest structure could face extirpation. Species strongly associated with old forest and a particular climate envelope face compounded risk.

Changing plant communities due to shifting climate envelopes

Ecosystem function and resilience depends on the relative abundance of different species as well as on species richness. As the climate changes, plant species associated with different old forest plant communities will change in abundance in response to changing environmental conditions and altered species interactions (e.g., competition). The similarity of plant communities associated with retreating and advancing climate envelopes (in a given topographic location) gives an estimate of how much ecological disruption and loss of function might occur as the climate changes. Where plant communities are very dissimilar, species associated with retreating climate envelopes may be overrun by generalist species. For example, if a SBSdk climate shifts to an ICHmc2 climate, four SBSdk site series would face climate and site conditions that support dissimilar tree and shrub communities (Table 6). Unlike the shift to ICHmc2, if SBSdk shifted to IDFdk, then dry sites and floodplain sites show the least similarity, although a less pronounced difference occurs in the shrub layer. A complete analysis of dissimilarity is beyond the scope of this report, so only selected examples have been presented. The consequences to community structure and ecosystem function of shifts towards dissimilar plant communities requires further research.

Table 6. Similarity of tree and shrub layers in SBSdk to those in the IDFdk and ICHmc2, by SBSdk site series. Similarity score ranges from 0 to 100% for each layer[21]. The SBSdk sites that are subjectively least similar to the IDFdk and to the ICHmc2 and are shaded grey.

	Similarity to SBSdk communities (each X represents a quartile)			
SBSdk	**IDFdk Trees**	**IDFdk Shrubs**	**ICHmc2 Trees**	**ICHmc2 Shrubs**
01	XX	XX	X	X
02	X	XX	XXXX	X
03	X	XX	X	X
04	XXXX	XX	X	X
05	XXX	XX	X	X
06	XXX	XXX	X	XX
07	XXX	XX	X	XX
08	X	XX	XXX	XXX
09/10	XX	XX	XXX	XXX

Notes

[1] see project reports at http://bvcentre.ca/research/project/a_multi-scale_trans-disciplinary_vulnerability_assessment/

[2] Canada National Round Table on the Environment and the Economy. (2011). Paying the Price: The Economic Impacts of Climate Change for Canada. Available at http://nrtee-trnee.ca/wp-content/uploads/2011/09/paying-the-price.pdf

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[4] Strategies and their estimated effectiveness based on a workshop: Daust, D., D. Morgan and K. Zielke. 2011. Workshop summary: adapting Nadina forest management to climate change. Available at http://bvcentre.ca/research/project/a_multi-scale_trans-disciplinary_vulnerability_assessment/

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