Adapting forest and range management to climate change in the Skeena Region:

Considerations for practitioners and Government staff

1. About this Series

There is strong scientific evidence that climate change will significantly affect British Columbia's forests and rangelands.[1] Therefore, adapting forest and range management to climate change is necessary to foster resilient[2] ecosystems that continue to provide the services, products and benefits society relies on.

This extension note is part of a series that uses current climate change research[3] to summarize, for each region, projected climate changes, impacts to ecosystems, and potential adaptation strategies. Where regional information is limited, information is drawn from provincial-scope research.

The intent of this extension note is to inform adaptation of forest and range practices to climate change by providing **best available information**[4] to resource professionals, licensees, and Government staff engaged in: operational planning under the *Forest and Range Practices Act;* monitoring effectiveness of adaptation practices; assessing cumulative effects; and, preparing climate change action plans. Endnotes provide references and further sources of information.

2. Provincial Overview[5]

Climate: As a whole, BC has become warmer and wetter over the last century. Winter has warmed the most. Extreme rainfall and dry conditions have increased and snowpacks have decreased. Due to the effects of greenhouse gas emissions already in the atmosphere, climate scientists agree these warming trends will continue. By the end of this century, mean annual temperature in BC could be at least 1.7 to 4.6°C warmer than it was in the last few decades.[6] More winter precipitation will likely fall as rain rather than snow, resulting in lower snowpacks, earlier and more rapid snowmelt, and longer fire seasons.

Regional differences: Northern and southern interior regions of BC are expected to warm more than coastal BC and parts of central BC. Winter precipitation is expected to increase in all regions, but summer precipitation is expected to increase in northern BC and decrease in southern and coastal BC.

Impacts: ***Ecosystems*** will likely undergo both predictable and unpredictable ecological shifts. Climate envelopes (the climate associated with an ecosystem today) for subalpine and alpine areas will diminish in most locations while those for grasslands, shrub-steppe and dry forested ecosystems are expected to expand. In response, ecological communities will disassemble and reassemble—sometimes into novel combinations—as populations decline, move or adapt. Many species, including trees, will not be able to migrate quickly enough to keep pace with shifting climate. During this evolution, ecosystems will be strongly influenced by disturbances and invasive plants. ***Natural disturbance*** dynamics will change: likely changes include increased fire and drought in southern and coastal BC, increased storms and windthrow on the coast, and more frequent and extensive mortality due to bark beetles, defoliators and diseases across BC. Invasive species will increase. ***Hydrological regimes*** will shift due to increased evaporation, altered vegetation communities, increased storm frequency and magnitude, decreased snow accumulation, seasonal changes to precipitation, and accelerated ice melt followed by diminished glacier extent.

Adaptation: Many climate change adaptation strategies are similar across BC. With the exception of assisted migration, most strategies are not new, but rather are elements of ecosystem management that require broader application. Strategies to reduce risks to forest ecosystems include **promoting resilience** by maintaining or increasing diversity at all scales, **guiding ecological transformation** by maintaining landscape connectivity and assisting migration, **combating detrimental change** by controlling invasive plants and excessive disturbance, and **limiting cumulative effects** of multiple land-use activities. Strategies to reduce risks to forestry-dependent communities include **increasing monitoring** of change, **strategically harvesting** at-risk forests, managing fire in wildland-urban **interfaces**, increasing capacity of **infrastructure** to withstand extreme events, and **increasing community capacity** to respond to change (e.g., by economic diversification).

3. Description of Region

The Skeena Region is vast with varied and complex physiography, including coastal lowlands, several mountain ranges and interior plateaus. At the broadest scale, the Coast Mountains divide the region into coastal and interior portions with very different climatic regimes. Valleys associated with large river systems, including the Skeena, Nass and Stikine, cut through the mountains, allowing coastal influence to travel inland. These divisions represent enduring features that will shape ecosystems in any climate regime. A less obvious and perhaps less enduring boundary divides the northern and southern interior sub-regions.[7]

Current ecoprovince boundaries, with the Sub-boreal Interior and Central Interior zones merged, represent a reasonable division of the Skeena region into three broad climatically-relevant portions (see Figure 1, next page). At this broad scale, current forested biogeoclimatic (BEC) zones[8] match the three sections well: the **coast** sub-region is dominated by CWH and MH, the **southern interior** sub-region by SBS and ESSF, and the **northern interior** sub-region by SWB and BWBS. ICH is common in coast-interior transition zones, along the wide valleys to the east of the Coast Mountains. For more information on biogeoclimatic zones in this region, visit BEC WEB.

Because of landscape complexity, finer-scaled units that divide mountain ranges and plateaus will be useful for future work. More detailed analyses look at the Nadina District within the southern interior portion of the Skeena Region. Vulnerability assessment in the Nadina District divided the district into a western mountain zone and an eastern plateau zone. The west is mountainous, with exposed bedrock and incised streams, and is heavily influenced by the coastal climate; the eastern plateau contains many small streams and wetlands on shallow, low-relief glaciated terrain.

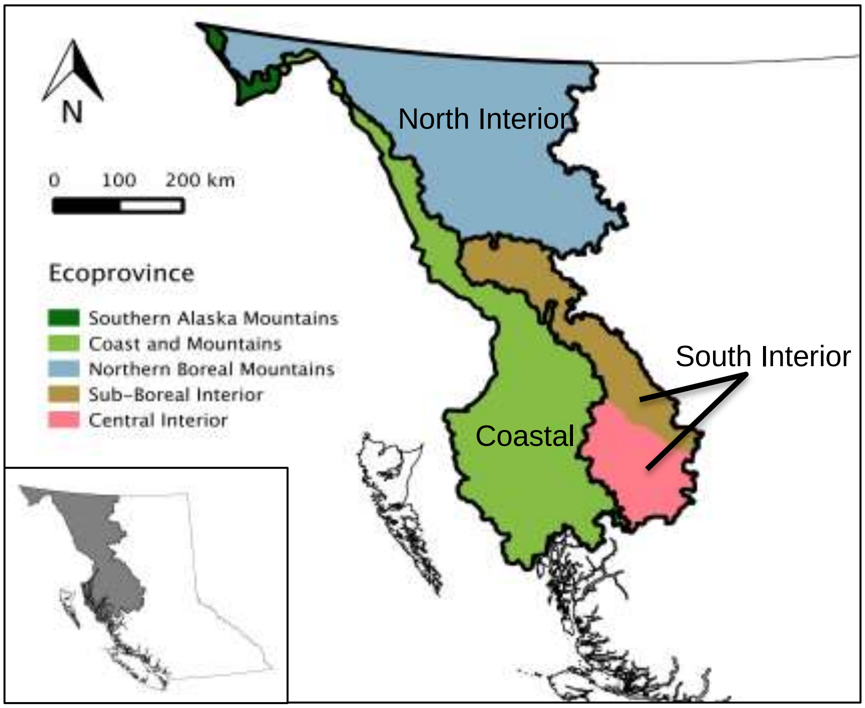

Figure 1. Climatically-relevant sub-regions within the Skeena Region. The South Interior sub-region includes both Central Interior and Sub-boreal Interior ecoprovinces.

4. Climate Change Projections

Our understanding of climate change is improving continually as models are improved with new research and methods. Projections in this document are derived from the Pacific Climate Impacts Consortium's regional climate summary for the Skeena Region, its Plan2Adapt tool for projecting future climate conditions, and ClimateBC.[9]

The climate in the Skeena Region has changed over the past century and is expected to continue to change. Averaged across the region, almost 2°C of warming has occurred during the 20th century, with most warming occurring in winter. Projections suggest the region may warm, on average, an additional 1.5 to 4.3°C by the end of this century, similar to moving from Smithers to Kelowna or Prince Rupert to Vancouver (3.8° and 3.3°C warmer respectively).

Significance of Increasing Temperatures

While it is normal for temperatures to vary considerably between seasons or from day to night, even a fraction of a degree rise in temperatures, when averaged over decades, is significant for ecosystems. For example, the mountain pine beetle epidemic was triggered by a series of warm winters that accompanied an increase in average temperature of less than one degree over a century. Climate is changing an order of magnitude faster than Canada's tree species can migrate or adapt.[10]

Precipitation trends are more complex and vary considerably across the region; current winter precipitation varies by an order of magnitude from the coast to interior rain-shadow areas. Over the entire Skeena Region, annual precipitation has increased over the past century, but has decreased from 1951 – 2009. Winter precipitation is projected to increase (in common with the entire province), but projections for summer precipitation are highly uncertain, with potential increases or decreases. Uncertainty about whether future summers will be wetter or drier is particularly high in the coast-interior transition area: in general, it is likely that more westerly, mountainous areas will be wetter and interior plateaus drier, but different climate models shift the location of the boundary between the two.

Summary of climate projections for the Skeena for the 2050s*

Climate variable	Change in Skeena	Variation within region
Temperature		
Mean (°C)	+1.8 (1.1 to 2.5)	Less increase on coast
Summer (°C)	+1.7	Fairly consistent
Winter (°C)	+1.9 (0 to 3)	Biggest increase in north; lower on coast
Precipitation (%)		
Annual	+7 (3 to 13)	Fairly consistent
Summer	+2 (-5 to 11)	Increase in north; decrease on coast and parts of interior
Winter	+9 (-1 to 16)	Fairly consistent
Snowfall (%)		
Winter	-6 (-12 to 7)	High variation: increase in north (8%); big decrease on coast (-40%)
Spring	-56 (-68 to -10)	Fairly consistent: between -50 and -58% across sub-regions
Snowpack	Decrease	Biggest decrease on coast; little change in north[11]
Frost-free days	+22 (12 to 34)	Greater increase in lower elevations than higher elevations and southern vs. northern areas
Growing Degree Days	+226 (142 to 353)	Greater increase in lower elevations than higher elevations and southern vs. northern areas
Extreme weather	More heat waves, summer drought, heavy precipitation and windstorms[12]	Storms more likely on coast; heat waves more likely in southern interior sub-region

*Based on 1961-1990 baseline. Projected changes in temperature continue to increase past 2050. Source: PCIC Plan2Adapt tool. Projections are based on a combination of A2 and B1 emissions scenarios, where A2 represents roughly business as usual and B1 represents a more optimistic scenario with about ½ of emissions of business as usual. Median of 30 projections with range (in brackets) showing the 10th to 90th percentile of projected changes.[13]

Increased Variability and Extremes: Focusing on mean changes in temperature and precipitation can obscure important changes in climate variability and extremes. Climate projections are based on mean temperature and precipitation per season and do not reflect potentially large changes in variability. Even with constant variability, the frequency of extreme events will increase much more than a small change in mean temperature or precipitation would suggest.

Climate Variability and Extreme Events

Seemingly small increases in mean values of climate variables can substantially increase the probability of an extreme event. For example, increasing the mean by one standard deviation can lead to a more than 10-fold increase in extremes so that a 1 in 100 year event (e.g. flood) can become a 1 in 10 year event.[14]

5. Impacts to Ecosystems

Ecosystem Climate Envelopes

Climate envelopes describe the climatic conditions associated with currently mapped biogeoclimatic (BEC) subzone/variants.[15] These envelopes help scientists and resource professionals integrate climate variables and visualise the potential extent and implications of climate change, but they **do not** predict what future ecosystems will look like for several reasons. First, ecosystems do not move as a unit; second, current climate projections are based on average climate values, ignoring the extreme events that can shape ecosystem structure and composition; third, climate envelopes do not capture site-scale shifts well. **Nonetheless, projections can help estimate the relative stress that climate change poses to an ecosystem and its potential to recover to a new functional state.**

Climate envelopes are projected to shift upslope and northward across BC.[16] By the 2050s, climate envelopes for current Skeena BEC zones are predicted to shift about 60 – 300 m upward in elevation and 10 - 170 km northward (Figure 2). High elevation BEC zones across the Skeena will likely experience the highest stress, with MH, ESSF and SWB all projected to lose over two-thirds of their current area by the 2050s. Conversely, the CWH and ICH climate envelopes are projected to lose little current area and to expand inland and upslope. The southern interior sub-region of the Skeena may see the most change. The ESSF and SBS BEC zones currently dominate this sub-region. At a smaller scale, projections for the Nadina District suggest the ESSF climate envelope will be almost gone from the area by 2050 and the SBS envelope will be mostly gone by 2080. Between now and 2080, the current ESSF zone may be replaced by some combination of ICH, CWH, SBS and IDF zones, with drier zones in the eastern plateau and wetter zones in the western mountains. IDF and ICH climate envelopes will move into the location of the current SBS zone. The proportion of IDF or ICH envelopes varies substantially by model run.

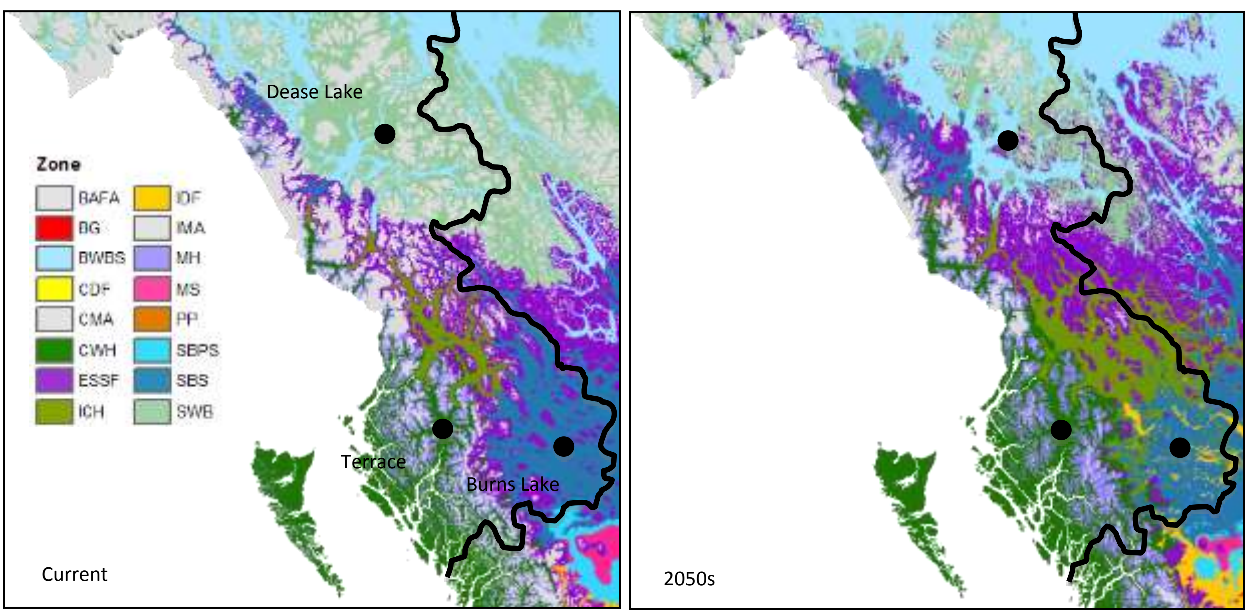

Figure 2. Current BEC zone locations (based on BEC8) and projected future (2041-2070) BEC zone locations. Future map shows consensus of multiple projections. Maps retrieved from ClimateBC.

At a smaller scale, the wettest and driest ecosystems may also experience regime shifts. For example, bogs in the southern interior of the Skeena may become forested with drier summers, and dry ecosystems may no longer be able to support forests and may transition to shrub or grasslands.

Natural Disturbance

The most profound changes to BC's forests in this century are expected to be the result of more frequent and severe natural disturbances.[17] Changes in **climatic conditions** support range expansion of forest pests that are currently limited by climate. Skeena ecosystems are already undergoing massive shifts due to loss of mature lodgepole pine to the mountain pine beetle, loss of young planted pine to hard pine stem rust species or *Dothistroma* needle blight, loss of aspen to the aspen leaf-miner, and loss of willows to the willow borer. The limited number of tree species in the region means ecosystems may be more sensitive to pest outbreaks than more diverse ecosystems.

Changes in **extreme weather events** lead to increased abiotic and biotic disturbances. For example, in the coastal sub-region, increased storms will influence flooding, landslides and windthrow. Although the Skeena is less likely to experience severe heat waves than southern portions of the province, periods of relative drought projected for some sub-regions will influence fire hazard and drought stress, making trees more susceptible to insects and disease. Less extreme cold events will occur to inhibit insect outbreaks.

The increased prevalence of disturbance will vary by climatic sub-region, elevation and forest type.

Disturbance	Projected changes
Fire and drought	• **Fires and drought** may **increase** in **coastal areas** and in the most southerly areas of the **interior plateau** due to decreased summer precipitation (increase in mean severity rating of 2 in Coast Mountain Ecoregion and 1 in Central Interior Ecoregion). • **Fire patterns** (e.g., size distribution) and variability among years may **change**.
Wind and mechanical damage	• **Windstorms** may damage ecosystems in **coastal** and **northern** portions of the Skeena (~15% increase in speed of high-wind events projected). • **Damage** to trees from **ice and snow** may increase with increased storms and increased freeze-thaw events.
Hydrogeomorphic (flooding and mass wasting)	• Increased **peak flows** and **sediment delivery** may **affect aquatic** ecosystems and **fish** habitat, and may damage infrastructure. Uncertainty is high and some snowmelt-dominated systems may have reduced peak flows due to mid-winter melting. • **Increased** seasonal **soil moisture** due to snowmelt and rainfall may increase **mass movement.** • **Loss of forest cover** (due to disturbances) may **increase** chance of **mass wasting**. • **Increased storm surge** events on the coast may affect coastal ecosystems. • **Loss of snow and ice** at high elevation may **increase mass wasting** from increasing freeze-thaw of exposed rock.
Insects and disease	• **Mountain pine beetle** outbreaks may expand into the **northern portion** of the Skeena. • **Spruce beetles** may increase throughout the **Skeena Region.** • ***Dothistroma* needle blight** could expand into much of BC's **northern interior** and shift to include mature pine hosts. Even-aged **lodgepole pine** plantations will be especially **vulnerable** to a wide range of foliar diseases and stem rusts.

Hydrology

The Skeena Region is expected to follow projected provincial trends in hydrology.[18] In the Skeena's interior sub-regions, increased winter temperatures, increased precipitation, and reduced snowfall in spring (i.e., more rain) will likely shift the hydrological regime from snowmelt-driven to hybrid rain/snow-driven, leading to more frequent rain-on-snow events and smaller spring snowpacks. These changes will affect peak flows, sediment loads, and channel stability, and will reduce summer low flows and increase the duration of low-flow periods, with consequent increased risk to fish. On the coast, systems may shift from hybrid to rain-driven, changing flow timing and magnitude. Earlier thaws and changed peaks pose hazards to infrastructure, including winter roads and bridges. Streams in the Skeena are already experiencing changes in hydrological regime.[19]

Loss of vegetation through natural or anthropogenic disturbance, combined with climate change, will cause cumulative effects. These cumulative effects may decrease the capacity of a landscape to buffer rainfall, increasing streamflow flashiness and increase potentially increasing sediment delivery and channel instability.

Cumulative Effects

Cumulative effects are defined as changes to an ecosystem over time caused by a combination of **human activities**, **natural variability** and **climate change**. Assessment of cumulative effects integrates the effects of past, present and foreseeable future events and processes. FLNR has a framework in place to guide assessment of the cumulative effects of resource management and climate change. Such a framework provides the context for informed decisions about which management actions are most likely to succeed.

Feature	Projected changes
Hydrological regime	• **Glaciers** and **permafrost** will **thaw**; uncertainty is higher for some glaciers in the northwest of the region (towards Alaska). • **Shift** from **snowmelt-driven** to **hybrid rain/snow**-driven in **interior**, with more rain-on-snow events. • **Shift** from **hybrid rain/snow** regime towards **rain-driven** on **coast.** • **Altered timing** of peak and low **flows**. Spring freshets are already earlier in the Skeena.
Peak flows	• Spring **peak discharge** will **change**; in some areas and years, particularly with shifts to rain-driven regimes, it may be earlier and lower; at other times and places it may be higher, due to added winter precipitation. The outcome is difficult to predict at specific sites. • Shift to hybrid regime could lead to **more frequent high flows** during fall and winter. • More frequent, higher magnitude flows could disturb streambeds and spawning habitat.
Spring recession	• Loss of snow-driven regime could **reduce** the **spring recession** (a relatively stable period of moderate flow and temperature following the spring peak), affecting the sorting and deposition of sediment and profoundly impacting aquatic habitat.
Low flows	• **Smaller spring snowpack** and **earlier** spring **freshet** will **lower** summer **low flows**, **lengthen** the low-flow **period**, and **decrease groundwater storage**. Skeena streams are already experiencing declining summer flows. • Loss of **glacial meltwater** over the long term will reduce summer low flows (e.g. Morice

Feature	Projected changes
	headwaters). Most glaciated basins in the Skeena are already experiencing reduced August flows. • **Temperature** may **increase** in some streams and lakes, posing **risk to temperature-sensitive fish** (e.g. interior race of sockeye salmon, including Babine stock).
Variability	• Variability in peak flow frequency and magnitude will likely increase, leading to **unstable stream morphology.**

Flood Return Intervals

Small changes in mean climate can cause large changes in flooding frequency and magnitude. For example, current 50-year floods may become 5-year events and future 50-year floods might be what we now consider a 1,000-year flood.[20]

Biodiversity

Climate shapes species distributions and ecological communities.[21] Populations faced with a changed environment can die out, move, be displaced by encroaching species, or adapt to the new conditions. Many species that are adapted to projected future climates currently live several hundred kilometres distant from that area; only the fastest dispersers will be able to keep up with the pace of change. Most invasive plants and generalist weedy species are well-adapted for broad movement. For some ecosystems, potentially irreversible regime shifts may follow intense disturbances, particularly if invasive plants colonise and block historical successional paths.

Mountain ranges are particularly important for conservation of biodiversity. Relative to gentle terrain, mountains accommodate more climatic zones within close proximity; thus, as the climate changes, populations in lower elevation zones may find suitable climatic conditions by migrating upwards.

Feature	Projected changes
Cumulative effects	• Past human activities have altered, degraded and **fragmented habitat**, making **dispersal** in response to climate-related disturbance more **difficult** for **specialist species**. • Human response to increased disturbance (e.g. extensive **salvage harvest** following insect infestations and fire) can **exacerbate impacts** of climate change. • **Old forest** will **decline** due to disturbance and harvesting, threatening associated species. • Without management intervention, climate change will exacerbate the effects of **over-grazing** and **trampling,** which impact **grasslands** and **forest understory** by changing the plant community, destroying the biological crust and opening soil to invasive plants.
Communities	• **Communities** will **reassemble**, often into new combinations, as some established species decline or disappear, new species colonise, and interactions change. • Some ecosystems may undergo **regime shifts** (e.g. from **forest to shrubs or grassland**). • Analyses in the Nadina District suggest communities of **plant and lichen species** in current versus projected climate envelopes **may differ by 80%** at the site level in the **wettest and driest sites**, and by up to 65% at the variant scale[22].
Interactions	• **Ecological processes** and **relationships** among species (e.g. predation, pollination, mutualism) may **uncouple** as the timing of events changes and becomes more variable (e.g., if migration depends on day length, but prey abundance depends on temperature).

Feature	Projected changes
Invasive species	• **Invasive species** (plants and other organisms) are expected to **increase** as temperatures and disturbance increase. • Current **indigenous species** may be **less competitive** in the new climate and disturbance conditions, facilitating invasive plant population expansion. • Some ecosystems in the Skeena (e.g., parts of the **SBSdk,** roadsides) already have many invasive plant species. These areas will be increasingly vulnerable to **invasive plants** following disturbance, facilitating **regime shifts**.
Wildlife[23]	• Wildlife and trophic interactions (e.g., **predation**) will be particularly **affected** by **changes** in **snowpack** and **freeze-thaw** regimes. Impacts vary by species. • **Biting insects** and **disease** may **increase** in response to milder weather; for example, **winter ticks** may increase impacts to **moose**. • In the northern sub-region, **later green-up** timing could **increase mortality** of young **sheep and goats.** • **Increased fire** could **affect caribou** habitat **negatively** and **moose** habitat **positively**.

Trees

Tree species distributions will shift gradually in response to climate change due to physiological tolerances, natural disturbance, and competition.[24] There are few tree species in the Skeena, hence low ecological redundancy. Although most tree species will be unable to migrate quickly enough to follow the climate envelopes to which they are adapted, the future climate may be able to support a greater diversity of tree species.

Feature	Projected changes
Physiological tolerance	• Most species in the Skeena seem physiologically resilient. • In **coastal ecosystems**, small changes in mean temperature around the rain-snow threshold have already led to a precipitous **decline in yellow-cedar** following the loss of a protective snow blanket. • **Interior spruce** on **dry sites within the SBS** plateau may be **vulnerable** to **moisture stress**.
Productivity	• **Tree growth** will likely **increase** in some areas due to elevated CO_2 coupled with wetter summers and warmer temperatures. • **Growth potential**, however, may **not be realised** because of **limited moisture** or nutrients, because populations are not adapted to changed seasonality and increased **extreme events**, or because **maladaptation** increases susceptibility to insects and disease. Provenances are adapted to even narrower climatic conditions than species.
Natural disturbance	• **Insect and disease outbreaks** could **increase mortality,** even in healthy rapidly-growing trees. • **Stressed trees** are more **susceptible** to insects and pathogens. • Several **deciduous and coniferous** species, including the aspen, lodgepole pine and interior spruce that have defined the Skeena's interior sub-regions, may **decline** substantially due to **outbreaks**.
Competition	• **Migrating species** may **not** be able to **out-compete established** species. • Competitive interactions among trees and other plants will change in unexpected ways, leading to **shifts in species dominance**; for example, **shrubs** may be **favoured** in some cases following natural disturbance.

Uncertainty about climate projection leads to uncertainty about which trees may be best-suited to changing conditions, particularly in the coast/interior transition. In the Nadina District, for example, a warmer and wetter scenario may create opportunities for western hemlock and western redcedar, while a much warmer scenario would be potentially suitable for Douglas-fir, western larch or ponderosa pine.[25] Suitable trees at any given point in time may become maladapted by rotation age, creating additional uncertainty and complexity for management.

Ecological Surprises

Current vulnerability modelling does not include ecological surprises or complex climate-ecological relationships. The decline of yellow-cedar in some regions is a good example of the unpredictability of impacts: yellow-cedars are essentially freezing due to warmer winters as snowpack declines and allows frost to damage roots.[26] Simplistic predictions in complex systems cannot replace long-term interdisciplinary research and monitoring.

Range

Grassland ecosystems will also shift in response to climate change due to increased drought, loss of forest due to disturbance, and competition. Earlier spring plant growth and a longer growing season may translate into a longer grazing season for livestock. Grasslands are projected to increase in the region, but community composition will likely change and, without dedicated management intervention, may be overcome by invasive plant species in some areas.[27]

6. Adaptation—modifying management to account for climate change

It is necessary to modify management activities – planning, practices, and monitoring - to address the impacts of climate change on ecosystems. Adaptation strategies will vary depending on the ecosystem, the direction of climatic variables, the degree of certainty in projected changes, the urgency (risk and vulnerability), and the likelihood of adaptation practices achieving desired outcomes. Hence, management activities under a changing climate will need to be flexible and proactive.

This section includes potential adaptation strategies that may help address the current and anticipated impacts to ecosystems described above. These strategies reflect regionally-important **best available information** drawn from research and the input of regional specialists**.** Resource professionals, licensees and Government staff should consider these adaptation strategies as **voluntary non-legal guidance** to inform operational planning and practices.

Almost all of these adaptation strategies are existing elements of good forest and range management that require broader application. ***As such, they are generally supported by current policy guidance***. Because we manage for multiple resource values, some adaptation strategies may conflict with each other (e.g., maintaining downed wood to sustain biodiversity may conflict with minimizing forest fuels to reduce catastrophic wildfire risks). This will require decisions that balance the benefits and risks to resource values, depending on the priorities for the area in question.

Although some of these adaptation strategies may be perceived as incurring incremental costs or land base constraints, the long-term economic benefits of adaptation to the productivity of timber, forage and other resource values are predicted to outweigh short-term costs. For example, studies in Central BC indicate the economic benefits of diversifying managed forests to reduce forest health risks and increase resilience.[28] And, designing and maintaining roads and bridges to a higher standard will likely minimize repair and compensation costs after flood events. Some adaptation strategies are also potential climate change mitigation or carbon storage strategies (e.g., retention networks, retaining downed wood).

Potential adaptation strategies in this section reference supporting policy guidance, information or tools.

Planning Considerations

Climate change poses at least three broad challenges for practitioners:

- Existing management ***objectives*** may be inappropriate because they were developed without considering climate change and do not generally include objectives for mitigation or adaptation.
- Existing management ***strategies*** are unlikely to achieve existing objectives under a changing climate.
- ***Uncertainty*** about the effectiveness of management strategies will increase.

In addition, slow regulatory or administrative change may pose a challenge to implementing timely management responses to changing conditions. At a broader scale, market forces may pose barriers.

Uncertainty[29]

The impacts of climate change are already present on the landscape and there is substantial scientific evidence that this trend will continue. However, projecting the impacts of climate change into the future is fraught with uncertainty due to the limitations of ecological and climate models, and to alternative plausible emissions scenarios. Ecological processes that reflect multiple interactions (e.g. shifting species distributions) are more uncertain than processes that correlate strongly with a single variable (e.g. fire hazard and temperature).

Managing in the face of uncertainty requires:

- Recognition of uncertainty (known and unknown sources)
- Information gathering (via monitoring) to reduce uncertainty where possible
- Recognition that uncertainty increases with time span considered
- Acceptance that uncertainty will remain and a decision to either use precaution to maintain a desired value or to put a value at risk

Adaptation requires planning that includes new objectives, new strategies and increased consideration of uncertainty. For example, objectives to maintain biodiversity or timber could be modified to maintain ecological resilience, and strategies to mitigate flood impacts should take into account the higher probability of flooding associated with climate change plus climate oscillations. Practitioners may need more flexibility to handle regime shifts (e.g., if forested ecosystems lose viability). Best management practices for ecosystem management[30] provide an excellent resource.

Practice Considerations

Hydrology

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

Potential adaptation strategies	Supporting policy guidance, information or tools
Projected ecosystem change: Increased stream temperature	
• Retain adequate riparian cover next to streams and wetlands ○ Particularly important in temperature sensitive watersheds and along headwater areas	• Watershed monitoring[31]
• Maintain ditches and culverts on active roads and deactivate roads to restore natural drainage as soon as possible ○ Important to prevent water warming on sites that feed streams, particularly in temperature sensitive watersheds	
• Avoid harvesting sites with high water tables ○ Important for sites with high water tables that feed streams, particularly in temperature sensitive watersheds	
Projected ecosystem change: Increased risk of landslides and surface erosion (that affect streams or infrastructure)	
• Avoid locating roads and cutblocks on or above unstable terrain • Design and maintain roads and drainage structures to accommodate increased peak flow and sediment transport in areas likely to become wetter: e.g., improve surface on high hazard roads; seed erodible cut slopes; build adequate ditches; replace selected culverts with bridges; limit road density in erosion-prone areas • Manage grazing to maintain functional riparian ecosystems; maintain sufficient riparian vegetation to control grazing	• Watershed assessment[32], [33] • Gentle-over-steep terrain[34] • Water quality evaluation[35] • Forest road engineering guidebook • Guidelines for managing terrain stability • Water quality and livestock grazing BMPs
Projected ecosystem change: Increased peak flows	
• Limit Equivalent Clearcut Area (ECA) to 30 to 50% of THLB ○ Important in watersheds in western mountains of Nadina • Anticipate increased natural disturbance and manage harvest to stay within ECA limits ○ Evaluate hydrological implications of salvaging stands disturbed by insects ○ Account for increased runoff from burned sites in ECA calculations • Assess flood risk and increase design criteria for infrastructure • Limit development on known floodplains	• Watershed assessment (see above) • Post disturbance watershed effects[36] • Practice guidelines for flood assessment

Biodiversity

Adaptation strategies for biodiversity are designed to achieve two objectives: (1) reduce the existing anthropogenic pressures that compound the negative effects of climate change on biodiversity (e.g., minimize harvesting and road access in sensitive areas), and (2) promote resilient ecosystems at stand and landscape scales.

Potential adaptation strategies	Supporting policy guidance, information or tools
Projected ecosystem change: Loss of old forest habitat and connectivity, due to increased tree mortality	

• Create a network of retention areas and corridors at multiple scales
  ○ Include riparian areas, wildlife tree patches, and old growth management areas in retention areas
  ○ Include corridors crossing elevation gradients
  ○ Include habitat for specialized species and communities at risk
	• Biodiversity Guidebook

• Limit salvage in retention network (e.g., partial cut or avoid harvest) ○ Particularly important where stands buffer microclimate or provide large structure	• Chief Forester's retention guidance • Post-disturbance biodiversity management[37]
Projected ecosystem change: Loss of suitable microclimate and soil conditions to re-establish historic ecosystems following harvest (e.g., potential regime shift from forest to grassland)	
• Avoid harvesting sensitive sites ○ Particularly important in bogs, low nutrient "remnant boreal" sites, and dry sites • Partially-cut stands (i.e., retain partial overstory for shelter) on dry sites[38]	• Drought risk assessment tool • Enhancing biodiversity through partial cutting
• Retain large downed wood ○ Particularly important on drier sites	• Wildlife trees and coarse woody debris policies • FREP CWD backgrounder • CWD management • Morice operational trials
• Promote rapid site recovery to appropriate species (e.g., reforest dry sites; retain deciduous trees on moist sites) ○ Particularly important on drier sites	• See Trees section
Projected ecosystem change: Loss of diversity and vigour in young and maturing forests due to maladaptation to changing climate	
• Plant climatically-suited species and genotypes (i.e., facilitate migration)	• See Trees section
• Retain naturally-occurring and regenerating species (including deciduous trees and shrubs) and plant a diverse species mix	• Climate change stocking standards[39]
• Use stand tending to influence succession	• See Trees section
Projected ecosystem change: Increased spread of invasive plants following disturbance	
• Minimize roads ○ Especially important in currently unroaded areas and susceptible ecosystems	• Invasive plant management practices • Invasive species council of BC • Invasive species working group;

Potential adaptation strategies	Supporting policy guidance, information or tools
• Minimize road use (e.g., use gates, deactivate) • Establish competitive vegetation in ditches, on side slopes and other disturbed soil as soon as possible • Wash equipment to remove seeds/plants prior to moving into new areas • Follow best management practices for invasive plants	IAPP Map, E-Flora BC

• Manage grazing to maintain late seral vegetation communities
  ○ Adjust stocking rates and distribution
  ○ Particularly important near susceptible ecosystems (e.g. grass ecosystems in SBSdk)
	• Managing rangeland invasive plants

• Minimize site disturbance, especially multiple disturbances ○ Especially important on susceptible (e.g., dry, grassy) sites • Minimize summer logging on susceptible sites (e.g., dry, grassy sites) • Account for invasive plants in site plans • SBSdk already has many invasive plants	

Trees

Adaptation strategies for trees are designed to increase establishment success, survival and growth potential, and to reduce the negative impacts of natural disturbance resulting from climate change. Adaptation strategies have the potential to shift overall climate-induced impacts on timber supply from negative to positive or neutral.

Adaptation could lead to large decreases in projected beetle-related tree mortality over the long term, modest decreases in disease, and modest increases in tree growth. Large decreases in beetle mortality are, however, partly attributable to a changing forest age class structure as old stands decrease.

Adaptation may have limited success in reducing fire disturbance because effective fire control in average-weather years can be negated by large fires in very dry years. Landscape fire management planning is aimed at reducing these losses as much as possible.

Potential adaptation strategies	Supporting policy guidance, information or tools
Projected ecosystem change: Increased tree growth potential on sites with sufficient moisture	
• Plant climatically-suited species and genetic stock ○ Especially on dry sites or sites facing drought • Monitor select plantations and establish operational trials to test survival and growth	• Tree species selection tool • FFT assisted species migration guidance • Chief Forester standards for seed use[40] • Climate-based seed transfer interim policy measures • Seed zone maps
• Fertilize sites that have limited nutrients but sufficient moisture	
• Partially cut stands on dry sites to retain shelter and moisture and increase fire resiliency	• Drought risk assessment tool

Potential adaptation strategies	Supporting policy guidance, information or tools
Projected ecosystem change: Increased disease-related mortality (mainly younger stands)	
• Plant climatically suited species and genetic stock ○ Especially on sites facing drought and areas shifting to wetter climate	• Forest health and species selection • Regional & TSA forest health strategies
• Increase stand-scale species diversity (e.g., retain and plant a variety of species, including broadleaf; expand breadth of "acceptable" species in young stands) • Increase landscape-scale species diversity by planning retention and reforestation at the landscape level; vary species mix and density	• Long-term forest health and stocking standards • Guidance on species composition • Guidance on broadleaves • Guidance for FSP stocking standards • Mixed species options for FFT • Successional responses[41] • Stocking standards reference guide • Climate change stocking standards
• Plant higher initial densities to account for losses to biotic (and abiotic) damage; i.e. build in redundancy	• Nadina FSP stocking standards • Regional & TSA forest health strategies
• Minimize mechanical damage from wind, snow and ice	• BCTS windthrow manual
Projected ecosystem change: Increased beetle-related mortality (mainly mature/old stands)	
• Plant climatically-suited species and stock	• See above
• Increase stand-scale diversity	• See above
• Shorten rotations ○ Especially for relatively productive sites most susceptible to disturbance	
• Monitor and control beetle population sources (e.g., sanitation harvesting) ○ Focus on stands where benefit of control outweighs cost to non-timber values	• Regional & TSA forest health strategies • Provincial bark beetle management strategy • Mountain pine beetle action plan • Chief Forester's retention guidance
Projected ecosystem change: Increased fire hazard (all stand ages)	
• Increase fire resilience at the landscape level by creating strategic fuel breaks (e.g., deciduous stands), prescribing fire, and allowing ecologically appropriate fires in suitable locations to burn under appropriate conditions ○ Work with range managers to create fire breaks	• Landscape fire management planning

• Increase fire resilience at the stand level by managing surface fuels, species composition, density, crown base height, crown bulk density and age-class of forest stands
• Reduce post-harvest fuels as necessary (e.g., biomass recovery, broadcast burning, pile and burn, mulching, chipping)
  ○ Choose appropriate season and weather for fuel-reduction
  ○ Consider using grazing to manage fine fuels
  ○ Consider trade-offs with strategies to maintain
	• Landscape fire management planning
	• Fire management stocking standards[42]
	• Fire and fuel management guidelines[43]

Potential adaptation strategies	Supporting policy guidance, information or tools
resilience for biodiversity	
• Reduce human-caused fires	• Wildfire Management Branch prevention strategy
• Manage fire hazard around communities • Reduce risk to structures in interface areas	• Strategic wildfire prevention initiative[44] • Fuel hazard assessment and abatement • FireSmart program • FireSmart communities

Assisted Migration

When trees are harvested 60-120 years after they are planted, the climate could be 3-5 degrees warmer, exposing the trees to maladaptation and health risks. Moving populations of trees today (assisting migration) from their current location is one potential solution; growth and health are better when seeds are transferred to match the climate in which they evolved. However, trees have complex symbiotic relationships with many ectomychorrizal fungal species in the soil and in some cases these bonds are tightly linked to local nutrient and climate conditions.[45] Improved understanding of these interactions in specific ecosystems may increase success. Government is leading a large, long-term Assisted Migration Adaptation Trial to understand tree species' climate tolerances. Findings are helping inform Climate Based Seed Transfer policy and tree species selection guidance.

Range

Adaptation strategies for rangelands[46] aim to capitalize on opportunities (e.g., longer grazing season) and to reduce the negative impacts (e.g., increased invasive plants and drought stress) of climate change. Steps towards adaptation include revising expectations for rangelands to include climate dynamics, expecting higher variability in productivity, maintaining late seral native perennial grass species on existing grassland sites, adjusting stocking rates to reflect changing productivity, and considering the need for new water developments to sustain livestock drinking water.

Monitoring

To develop adaptation strategies that are more likely to achieve management objectives, practitioners and decision-makers need to understand changes in climatic variables and key ecological responses at relevant spatial scales. In the Skeena, trend monitoring should include:

- Climate: temperature, precipitation, snowpack, glacial melt and extreme weather.
- Hydrology: stream flow by watershed, channel stability, forest cover, water temperature, erosion, suspended sediment.
- Disturbance: mass earth movements, insect and disease prevalence by seral stage, soil moisture, fire weather index and wildfire.[47]
- Tree growth and health.
- Range: plant communities and conditions.

- Biodiversity: regime shifts, seral stage, habitat supply, species health, invasive plant species and distribution shifts.

Some of these data are already collected, but are not analysed regularly. A climate network that covers sub-regional variability with sufficient weather monitoring stations will be important.

Moving Forward

Successful regional adaptation will require innovation and collaboration. Shared learning among practitioners, decision-makers and communities has the best potential for developing suitable adaptation strategies for the Skeena Region that foster resilient ecosystems and sustain natural resources into the future. This document could be a helpful catalyst in collaborative efforts.

Contact for More Information

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2. Provincial specialist – Kathy Hopkins, Technical Advisor, Climate Change, Competitiveness and Innovation Branch, kathy.hopkins@gov.bc.ca (250-387-2112).

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[1] Message from the Chief Forester, Future Forest Ecosystems Initiative Strategic Plan (2008)

[2] Ecological resilience is the capacity of an ecosystem to absorb, recover from and adapt to disturbance or stress caused by agents of change (such as climate change and natural resource management); this 'desired outcome' was established under the Future Forest Ecosystems Initiative (FFEI) in 2008, and is further explained in FFEI's scientific foundation (2009)

[3] Current research outcomes are primarily derived from projects under the Future Forest Ecosystems Scientific Council (FFESC) research program, but also including related regionally-relevant research

[4] Adaptation strategies in this extension note are derived from research and do **not** constitute new Government policy, standards, or regulations; they represent best available information and voluntary non-legal guidance for the consideration of resource professionals and decision-makers; where helpful, adaptation strategies include hyperlinks to supporting policy guidance, information or tools

[5] See the report *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests* (Morgan and Daust et al, 2013) for more insight into how climate change is expected to impact BC's forest ecosystems

[6] Projections are based on a combination of A2 and B1 emissions scenarios, where A2 represents roughly business as usual and B1 represents a more optimistic scenario with about ½ of emissions of business as usual (Trevor Murdock, Pacific Climate Impacts Consortium)

[7] For information on how topography and weather systems influence regional climatic variations, see Moore et al, Chapter 3 (Weather and Climate), Compendium of Forest Hydrology and Geomorphology in British Columbia

[8] BEC zone acronyms: CWH = Coastal Western Hemlock; MH = Mountain Hemlock; SBS = Sub-boreal Spruce; ESSF = Engelmann Spruce Subalpine Fir; SWB = Spruce Willow Birch; BWBS = Boreal White and Black Spruce; ICH = Interior Cedar Hemlock

[9] The sites provide definitions and calculation details for indices

[10] Johnston et al (for Canadian Council of Forest Ministers), Vulnerability of Canada's Tree Species to Climate Change and Management Options for Adaptation (2009)

[11] Rodenuis et al, Hydro-climatology and future climate impacts in British Columbia (2009)

[12] Based on trends for all of BC

[13] Details of the ensemble PCIC30 are given in Murdock and Spittlehouse, Selecting and using climate change scenarios for British Columbia (2011)

[14] Wigley, The effect of changing climate on the frequency of absolute extreme events (2009) (Climatic Change 97:67-76; DOI 10.1007/s10584-009-9654-7) gives a theoretical analysis; Kharin et al, Changes in temperature and precipitation extremes in the CMIP5 ensemble (2013) (Climatic Change 119:345-357; DOI10.1007/s10584-013-0705-8) gives an analysis based on global climate models

[15] BECWeb includes information on BEC and climate change

[16] Wang et al, Projecting future distributions of ecosystem climate niches: uncertainties and management implications (2012)

[17] For more information, see Chapter 2c (Natural Disturbance) of *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests*

[18] For more information, see summary in Chapter 2b (Hydrology and Aquatic Ecosystems) of *A Climate Change Vulnerability Assessment for British Columbia's Managed* Forests, and Chapter 19 (Climate Change Effects on Watershed Processes in BC) in the Compendium of Forest Hydrology and Geomorphology

[19] See Jackson, Streamflow trends in the Skeena Region (2014)

[20] See Footnote 14

[21] For more information, see Chapter 2e (Forested Ecosystems) of *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests*

[22] Price and Daust, Development of a Climate Change Index of Stress Using Future Projected BEC: Proof of Concept for the Nadina TSA (2013)

[23] For more information, see Chapter 2f (Wildlife) of *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests*

[24] For more information, see Hamann and Wang, Potential effects of climate change on ecosystem and tree species distribution in British Columbia (2006)

[25] See Footnote 21

[26] Hennon et al, Shifting climate, altered niche, and a dynamic conservation strategy for yellow-cedar in the North Pacific coastal rainforest (2012)

[27] For more information, see Climate Change and BC Range

[28] Dymond et al, Diversifying managed forests to increase resilience (2014)

[29] Fletcher, *Towards a framework to support working with uncertainty in natural resource management (a discussion paper)* (2015)

[30] For example, see Leech et al, Ecosystem management: A practitioners' guide (2009)

[31] Wilford and Lalonde, A framework for effective watershed monitoring (2004)

[32] Interior and Coastal watershed assessment procedure guidebooks

[33] Bulkley TSA watershed-based risk analysis (available from Skeena Region)

[34] Grainger, Terrain stability field assessments in "gentle over steep" terrain of the Southern Interior of British Columbia (2001)

[35] FREP water quality effectiveness evaluation indicators and protocols; stream quality crossing index

[36] Redding et al, Natural disturbance and post-disturbance management effects on selected watershed values (2012)

[37] Gayton and Almuedo, Post-disturbance management of biodiversity in BC forests (2012)

[38] Clearcutting may exacerbate adverse environmental conditions for regeneration associated with microclimate (frost, drying winds, and extreme temperatures), soil (lack of soil moisture), etc.

[39] Updates to the Chief Forester's reference guide for FDP stocking standards based on climate change projections (2014)

[40] Refer to Section 8, Page 15

[41] Swift & Ran, Successional Responses to Natural Disturbance, Forest Management, and Climate Change in British Columbia's Forests (2012)

[42] Guidance for designing fire management stocking standards is anticipated for release in December 2015

[43] Silvicultural regimes for fuel management; Interim guidelines for fire and fuel management (ABCFP, 2013)

[44] This web site includes guidance for Community Wildfire Protection Plans, Fuels Management Prescriptions, and Operation Fuel Treatments

[45] Recent research shows effects in coastal ecosystems. Kranabetter, Stoehr, and O'Neill, Ectomycorrhizal fungal maladaptation and growth reductions associated with assisted migration of Douglas-fir (2015)

[46] For more information on managing the effects of climate change on BC rangelands, refer to: (i) Newman et al, Managing for the ecological and socioeconomic effects of climate change on BC rangelands: developing strategic Range Use Plans, Range Stewardship Plans, and range management strategic documents (2013); and, (ii) Range Branch's *Range Management Responses to Climate Change* (to be published in summer 2015)

[47] Provincial fire research and monitoring needs