Adapting natural resource management to climate change in the Cariboo 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 ecosystems.[1] Therefore, adapting natural resource 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 natural resource planning and practices to climate change by providing **best available information**[4] to resource professionals, licensees, and Government staff engaged in: operational planning and practices under the *Forest and Range Practices Act* and other natural resource legislation*;* 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

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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 capacity** to respond to change (e.g., by economic diversification).

3. Description of Region

The Cariboo Region includes the Fraser Plateau nestled between the Coast Mountains to the southwest and Columbia Mountains to the northeast. Precipitation is highest in the mountains and lowest in the rainshadow of the Coast Mountains. At the broadest scale, the physiography divides the region into three portions with different climatic regimes. These divisions represent enduring features that will shape ecosystems in any climate regime. Valleys associated with large river systems, including the Fraser, Chilcotin and Quesnel, cut through the plateau.[7]

Current ecoregion boundaries represent a reasonable division of the Cariboo region into three climatically-relevant portions, with the mountains on each side of the central plateau (see Figure 1). Ecosystems vary tremendously over the region, with eight biogeoclimatic (BEC) zones[8] represented. At the broad scale, current BEC zones match the three sections reasonably well: the **Plateau** sub-region is dominated by IDF in the south, with BG along the Fraser Canyon, and by SBPS, MS and SBS in the north; the mountainous **Chilcotin Ranges** sub-region is mostly MS and ESSF with IDF in the valleys, and the wetter **Columbia Highlands** sub-region is mostly ESSF with ICH in the valleys. Alpine ecosystems are present at high elevations. For more information on BEC zones in this region, visit BEC WEB.

Because of landscape complexity, finer-scaled units that divide mountain ranges and plateaus might be useful for future work.

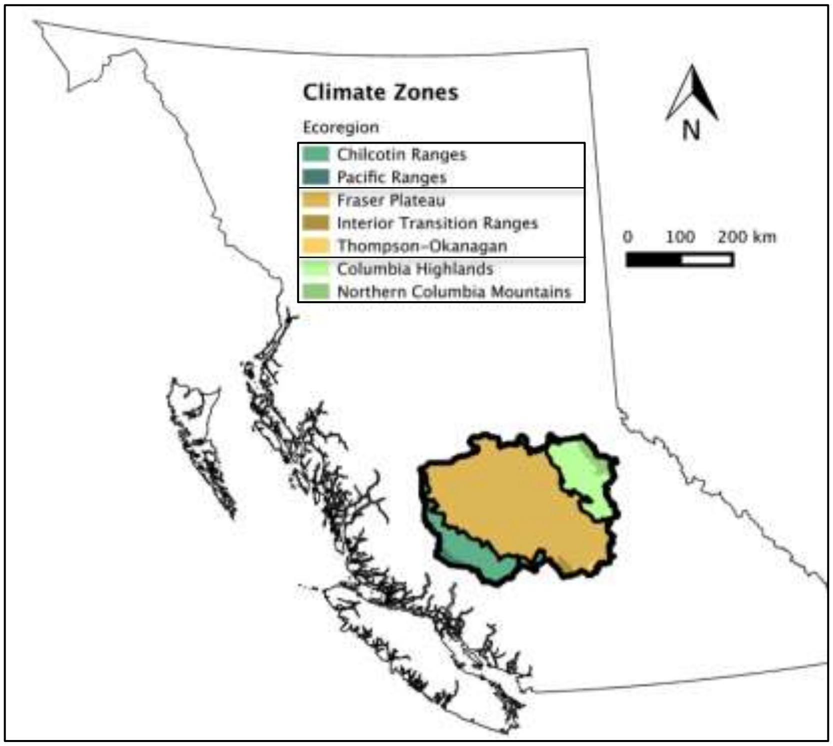

Figure 1. Three climatically-relevant sub-regions within the Cariboo Region based on groups of Ecoregions. Spatial data from DataBC.

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 Cariboo Region, its Plan2Adapt tool for projecting future climate conditions, and ClimateBC.[9]

The climate in the Cariboo Region has changed over the past century and is expected to continue to change. Averaged across the region, over 1°C of warming has occurred during the 20th century, with most since 1950. Projections suggest the region may warm, on average, an additional 1.6 to 4.3°C by the end of this century, similar to moving from Quesnel to Merritt (2.3° warmer).

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 between plateau and mountainous sub-regions. Over the entire Cariboo Region, annual precipitation has increased slightly over the past century, although winter precipitation has decreased from 1951 – 2009. Precipitation is projected to increase modestly in all seasons but summer where it is predicted to decrease.

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

Climate variable	Change in Cariboo	Variation within region
Temperature		
Mean (°C)	+1.8 (1.1 to 2.6)	Fairly consistent
Winter (°C)	+1.7 (0.6 to 2.8)	Fairly consistent
Summer (°C)	+1.8 (1.3 to 2.6)	Fairly consistent
Precipitation (%)		
Annual	+6 (-1 to 13)	Fairly consistent
Winter	+7 (-15 to 5)	Fairly consistent
Summer	-7 (-3 to 14)	Less decrease in Columbia Highlands
Snowfall (%)		
Winter	-8 (-15 to 3)	Less decrease in Columbia Highlands
Spring	-54 (-74 to -12)	Consistent
Snowpack	Decrease	Consistent, except may be no change or slight increase in Chilcotin Ranges[11]
Frost-free days	+23 (13 to 34)	Greater increase in lower elevations
Growing Degree Days	+283 (162 to 444)	Greater increase in lower elevations
Extreme weather	More heat waves, summer drought, wildfires, heavy precipitation[12]	

*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. By the 2050s, climate envelopes for current Cariboo BEC zones are predicted to shift about 100 – 250 m upward in elevation and up to 175 km northward (Figure 2). The cold, dry SBPS and high elevation MS and ESSF will likely experience the highest stress: all are projected to lose over two-thirds of their current area by the 2050s.[16] Conversely, the IDF, BG and ICH climate envelopes are projected to lose little current area and to expand inland and upslope. More detailed analyses in the Thompson-Okanagan region to the south suggest that some ICH subzones may come to resemble a combination of IDF and ICH, that dry sites may shift to shrubby or grassland ecosystems, and that the current MS zone could shift to a new state comprised of a variety of communities.[17]

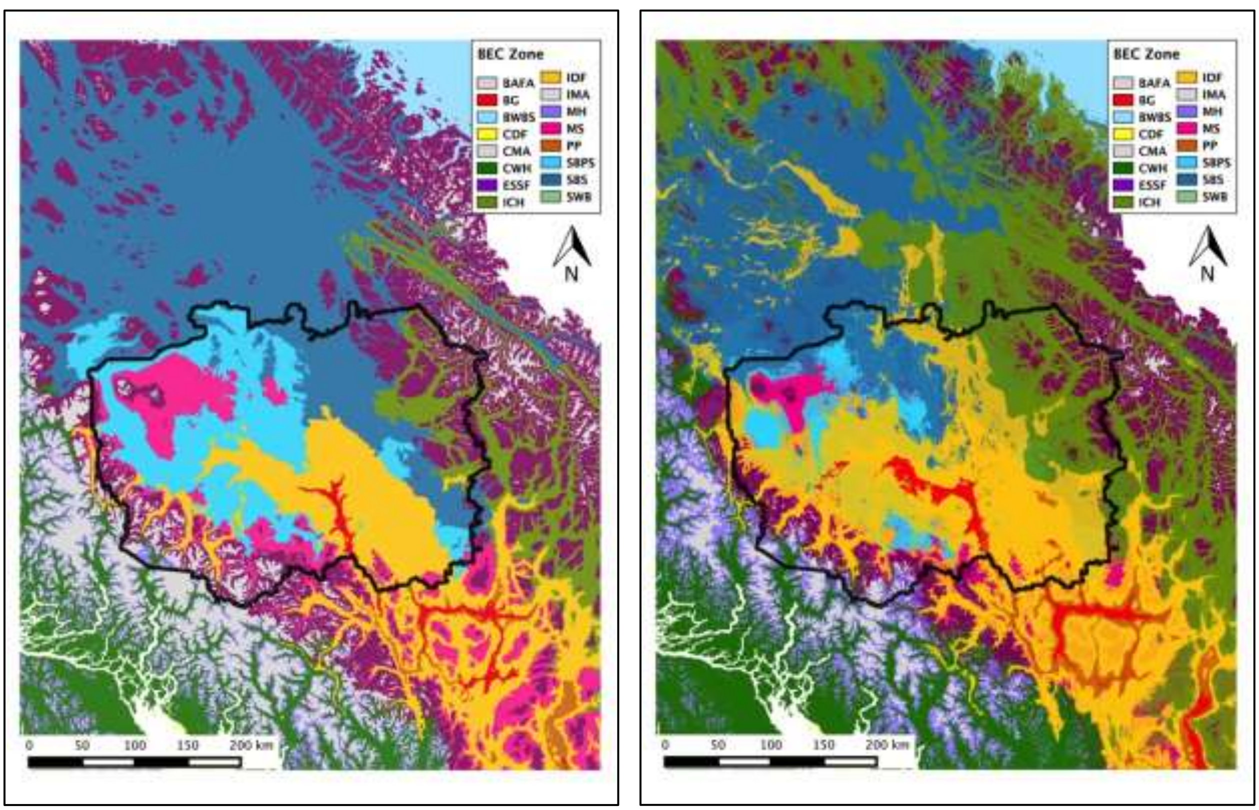

Figure 2. Current BEC zone locations (based on BEC8) and projected future (2041-2070) BEC zone locations. Future map shows consensus of multiple projections. Maps retrieved from ClimateBC.

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.[18] In the Cariboo, drought, fire and insects are expected to cause the most disturbances. Disturbances can cascade as, for example, drought-stressed trees are more susceptible to insects and disease, leading to increased mortality and relatively open stands with ladder fuels that support large wildfires. Changes in climatic conditions support range expansion of forest pests that are currently limited by climate. Fewer extreme cold events will occur to inhibit insect outbreaks. Cariboo ecosystems are already undergoing massive shifts due to loss of mature lodgepole pine to the mountain pine beetle. Douglas-fir will likely experience continued and increased mortality from the tussock moth, the Douglas-fir bark beetle and the Western spruce budworm.

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

Disturbance	Projected changes
Fire and drought	• **Drought** will **increase** in all but the coolest, wettest subzones; drought is expected to cause **mortality** to **Douglas-fir**, **spruce** and **subalpine fir**. • **Fire** size and intensity will **increase**, particularly in the southerly areas of the **plateau**, due to decreased summer precipitation.
Mass wasting	• **Increased** seasonal **soil moisture** due to snowmelt and rainfall may increase **mass movement in steep terrain**. • **Loss of forest cover** (due to fire or drought) may increase chance of **mass wasting**. • **Loss of snow and ice** at high elevation may increase mass wasting from increasing freeze-thaw of exposed rock.
Insects and disease	• **Mountain pine beetles** have already caused substantial mortality in pine in dry subzones and in the plateau subzones. • **Western spruce budworm** will continue to **expand** to the north of the region. • **Douglas-fir beetles** may **increase** with increased fire frequency and severity. • **Douglas-fir tussock moths** may **expand** northward. • **Stem rusts** may **increase** in young pines depending on changes in precipitation.

Hydrology and Fish

The Cariboo Region is expected to follow projected provincial trends in hydrology, although the effects will vary with location, elevation and aspect.[19] Hydrology in the region will be substantially influenced by warmer annual temperatures with increased evaporative demand, wetter winters with less snow and more rain, wetter springs and falls, and drier summers, combined with more frequent and severe extreme weather events. Smaller winter snowpacks that melt more rapidly will reduce late summer stream flow over most of the region. In wet cool subzones within the region, increased peak flows due to increased winter precipitation in some high-elevation watersheds could lead to increased scour, sediment transport and mass wasting. Annual water flows are expected to decline in the south of the region. Altered flow patterns could disrupt seasonal habitat use by fish. As well, earlier thaws and changed peaks pose hazards to infrastructure.

In southern parts of the plateau, domestic and agricultural water use is expected to grow. Competition for limited water resources will increase as seasonal water flow decreases.

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 potentially increasing sediment delivery and channel instability. Snow accumulation and melt patterns are projected to change considerably following moderately severe fires, but little following unsalvaged mountain pine beetle outbreak. Effects are difficult to predict, however, given projections for less snow.

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.

Increased water temperatures, reflecting warmer summer air and reduced flows, can impact salmonid populations. In addition, smaller snowpacks in the ESSF may contribute less cool water to stream systems.

Feature	Projected changes
Hydrological regime	• Projections include **earlier onset of spring peak** and **reduced late summer/fall flows**, particularly in drier subzones. • Flows may vary more across sub-regions depending on changes to late winter rains.
Peak flows	• Spring **peak discharge will change**; within the region, in wet, cool northern subzones, peaks will likely increase; in drier, southern subzones, peaks may decline. • **Shift** from **snow-driven to hybrid rain/snow-driven** regime could lead to **more frequent and flashy** high flows during fall. • These flows could disturb the streambed and spawning habitat.
Spring recession	• **Decreased snowpack** could **reduce** the magnitude and duration of the **spring recession** (a relatively stable period of moderate flow and temperature), affecting the sorting and deposition of sediment and profoundly impacting aquatic habitat.
Low flows[20]	• **Smaller spring snowpack** and **earlie**r spring **freshet** will **lower** summer **low flows**, **lengthen** the low-flow **period**, and **decrease groundwater storage**. • Some **perennial streams** may **become intermittent** or ephemeral. • **Loss** of **glacial meltwater** over the long term will reduce summer low flows. • **Temperature** will **increase** in some streams and lakes, posing **risk** to **temperature sensitive fish**; many **low elevation streams** in warm subzones could reach **lethal temperatures** for salmonids.
Variability	• Variability in peak flow will likely increase, leading to **unstable stream morphology** in some systems. • **Mid-winter melt** events will likely increase.

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. Southern parts of the Cariboo are particularly vulnerable to such regime shifts.

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 harvesting** 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. • Ecosystems may undergo **regime shifts** (e.g. from **forest to shrubs or grassland**).
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).
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. • Parts of the Cariboo already have many invasive plant species. **Grasslands and dry forest** types are particularly impacted and will be increasingly vulnerable to **invasive plants** following disturbance, facilitating **regime shifts**.
Wildlife[22]	• Wildlife and trophic interactions (e.g. **predation**) will be particularly **affected** by **changes** in **snowpack and freeze-thaw** regimes. Impacts vary by species. • **Increased fire** could impact **caribou habitat negatively** and **moose habitat positively**. • **Increased disturbance** (and salvage harvesting) of old-growth management areas will result in **decline** of **old seral forest** and affect the **character** of **reserved areas**. • **Wildlife tree patches** face increased **risk of tree mortality** that will affect their value.

Trees

Tree species distributions will shift gradually in response to climate change due to physiological tolerances, natural disturbance, and competition.[23] Fires and harvesting will shift the age-class distribution towards younger stands. Most tree species (and populations) will be unable to migrate quickly enough to follow the climate envelopes to which they are adapted.

Uncertainty about climate projections leads to uncertainty about which trees may be best-suited to changing conditions, particularly in the coast/interior transition at the west of the region. Suitable trees at any given point in time may become maladapted by rotation age, creating additional uncertainty and complexity for management.

Feature	Projected changes
Physiological tolerance	• Some **tree species**, including interior spruce, lodgepole pine, Douglas-fir, ponderosa pine and Western red cedar, will face **drought stress** and **regeneration challenges** in drier ecosystems. • In dry subzones, young stands with abundant **lodgepole pine** have **high vulnerability**. • The landscape may become climatically **suitable** for **grand fir** and **western white pine**.
Productivity	• **Tree growth** will likely **increase** in **moister, cooler** areas due to elevated CO_2 coupled with warmer temperatures. • **Growth potential**, however, may **not be realised** because of **limited nutrients**, because populations are not adapted to increased **extreme events**, or because **maladaptation** increases susceptibility to insects and disease.
Natural disturbance	• **Fires** and **drought stress** will cause **increased tree mortality**. Pulses of mortality will coincide with warmer, drier climatic cycles and follow insect and disease outbreaks. • **Insect and pathogen outbreaks** could **increase mortality,** even in healthy rapidly-growing trees. • **Stressed trees** are **more susceptible** to insects and pathogens. • Tree mortality in **transitional subzones** will be heightened by warmer, seasonally drier conditions. • Several **deciduous and coniferous** species will likely suffer **diebacks**.
Competition	• Competition will occur after natural disturbance; **shrubs** may be **favoured.**

Range

Grassland ecosystems will also shift in response to climate change due to increased drought, loss of forest due to disturbance, and competition. Grasslands are projected to increase in the region, but community composition will likely be low in native grassland diversity and, without dedicated management intervention, may be overcome by invasive plant species in some areas.[24] Cumulative effects of increased invasive species and decreased precipitation could decrease the chance of recovery.

Forage supply could increase in the IDF as the forest canopy thins. Earlier spring plant growth and a longer growing season will translate into a longer grazing season.

Feature	Projected changes
Productivity	• At lower elevations, productivity will depend on the plant community, with deep-rooted **perennial grasses performing best**. **Early seral communities** dominated by shallow-rooted grasses, annual grasses, and invasive forbs will have **lower productivity** due to drought, particularly if grazing levels remain unchanged. • **Productivity** will **increase** at **higher elevations**. • Frequent **drought** may lead to **fluctuating herd sizes**.
Competition	• Many **desirable species**, including bunchgrass and rough fescue, may be unable to migrate quickly enough to follow the climate envelopes to which they are adapted, and will **not out-compete** faster-dispersing **invasive plants** such as cheatgrass. **Needlegrasses** and some warm season (C4) grasses are **better adapted** to rapid migration. • **Invasive plants** may be particularly **favoured following fire** in forests with little understory.
Water	• **Dispersed surface water** sources available for livestock will **decrease** with reduced snowpack and spring snowfall.
Infrastructure	• **Fencing and water** developments may need to be **relocated** to realign with a **shifting forage resource**.

Ecological Surprises

Current vulnerability modelling does not include ecological surprises or complex climate-ecological relationships. For example, in a warmer climate, decreased snowpack might increase susceptibility of some tree species to late frosts (similar to yellow cedar on the Coast). Simplistic predictions in complex systems cannot replace long-term interdisciplinary research and monitoring.

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 resource 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 the Alex Fraser Research Forest, and in the Merritt and Kamloops TSAs, indicate the economic benefits of diversifying managed forests to reduce forest health risks and increase resilience.[25] 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[26]

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 should take into account the higher vulnerability of monocultures.

Practitioners may need more flexibility to handle regime shifts (e.g., if forested ecosystems lose viability). Best management practices for ecosystem management[27] provide an excellent resource.

Practice Considerations

Hydrology

To protect aquatic ecosystems and infrastructure near watercourses, adaptation consists of managing water removal to ensure sufficient flow in areas with drought, limiting increases in stream temperature, limiting sediment input (from surface erosion, streambank collapse and landslides), and limiting increases in peak flows where they are projected. Strategies vary with latitude and elevation.

Potential adaptation strategies	Supporting policy guidance, information and tools
Projected ecosystem change: Decreased flow in summer and longer low-flow period	
• Manage water allocations/use to maintain water supply during low flow periods • Maintain diversity in stand composition and age-classes across watersheds to vary snow accumulation and loss and desynchronise run-off • Retain sufficient riparian cover to maintain stream flow • Minimize establishment of invasive species in riparian areas • Manage level of livestock grazing	• Drought guidance[28] • Water quality and livestock grazing BMPs
Projected ecosystem change: Increased stream temperature	
• Retain adequate riparian vegetation next to streams and wetlands ○ Particularly important in temperature sensitive watersheds and along headwater areas	Watershed monitoring[29]
• Maintain ditches and culverts on active roads and deactivate roads to restore drainage as soon as possible ○ Important on segments that discharge directly into 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	• Interior watershed assessment • Gentle-over-steep terrain[30] • Water quality evaluation[31] • Forest road engineering guidebook • Guidelines for managing terrain stability • Water quality and livestock grazing BMPs

Potential adaptation strategies	Supporting policy guidance, information and tools
Projected ecosystem change: Increased peak flows and flashiness	

• Maintain diversity in stand composition and age-classes across watersheds to vary snow accumulation and loss and desynchronise run-off
• Consider limiting the Equivalent Clearcut Area (ECA) to 30 to 50% of THLB
• Anticipate increased natural disturbance and manage harvest to stay within ECA limits
  ○ Evaluate hydrological implications of salvaging disturbed stands
  ○ Account for increased runoff from burned sites in ECA calculations
• Assess flood risk and increase design criteria for infrastructure
• Manage roads to minimise impacts to flow
• Protect stream sources (springs, seepages) from timber harvesting and compaction by livestock and machinery
• Leave live standing vegetation and debris barriers next to all riparian features including seepages, non-classified drainages and S6 streams
	• Interior watershed assessment
	• Post disturbance watershed effects[32]
	• Landscape fire management planning
	• Guidance on natural range barriers

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., reduce harvesting and road access where sensitive values exist, and (2) promote resilient ecosystems at stand and landscape scales (e.g. manage grazing to maintain or achieve late seral plant communities).

Potential adaptation strategies	Supporting policy guidance, information and 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, communities at risk
  ○ Manage OGMAs flexibly to address changing conditions and to maintain adjacent old forest retention
	• Biodiversity Guidebook

• Limit salvage in reserve 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[33]

Potential adaptation strategies	Supporting policy guidance, information and tools
Projected ecosystem change: Loss of suitable microclimate and soil conditions to re-establish historic ecosystem following harvest (e.g., potential regime shift from forest to grassland)	
• Avoid harvesting sensitive sites ○ Particularly important on dry sites • Partially-cut stands (i.e., retain partial overstory for shelter) on dry sites[34] • Adjust stocking standards for dry, vulnerable sites where reforestation may be a challenge	• Drought risk assessment tool • Enhancing biodiversity through partial cutting

• Retain large downed wood
    ○ Particularly important on drier sites and in riparian ecosystems
    ○ Particularly important to reduce vulnerability of saproxylic (wood-feeding) species to harvesting combined with climate change
	• Wildlife trees and coarse woody debris policies
	• FREP CWD backgrounder
	• CWD management

• Promote rapid site recovery to appropriate species (e.g., reforest dry sites; retain deciduous trees on moist sites) ○ Particularly important on dry 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) • Preserve phenotypic and genetic diversity in regenerating stands to facilitate natural selection and to take advantage of phenotypic plasiticity	• See Trees section

• Retain naturally-occurring and regenerating species (including deciduous trees and shrubs) and plant a diverse species mix. Avoid monocultures.
• Encourage deciduous trees
    ○ Avoid removing aspen in dry and transition subzones
    ○ Maintain broadleaves in moist transition subzones
	• Climate change stocking standards[35]

• Use stand tending to influence successional pathways	• See Trees section
Projected ecosystem change: Increased spread of invasive plants following disturbance	
• Minimize roads ○ Especially important in currently unroaded areas and susceptible ecosystems • Minimize road use (e.g., use gates, deactivate) • Rehabilitate abandoned roads • Establish competitive vegetation in ditches, on side slopes and other disturbed soil as soon as possible • Wash equipment to remove seeds and plants prior to moving into new areas • Follow best management practices for invasive plants	• Invasive plant management practices • Invasive species council of BC • Invasive species working group; IAPP Map, E-Flora BC
• Manage grazing (appropriate level, time, duration and distribution of use, planned rest and recovery time) to maintain late seral grasslands and improve resilience ○ Adjust stocking rates and distribution	• Managing rangeland invasive plants

Potential adaptation strategies	Supporting policy guidance, information and tools
○ Particularly important near susceptible ecosystems (e.g. grass and parkland ecosystems and riparian areas)	
• Minimize site disturbance, especially multiple disturbances ○ Particularly important on susceptible (e.g., dry, grassy) sites ○ Minimize off-road vehicle access in harvested areas • Minimize summer logging on susceptible sites (e.g. dry, grassy sites) • Account for invasive plants in site plans	
• Weed-proof existing stands ○ Promote forest stands with weed-resistant understory plant communities ○ Maintain the integrity of mycorrhizal networks to resist invasion, minimize soil disturbance, and maintain high C/N ratio environments where they exist	

Trees

Adaptation strategies for trees are designed to increase tree 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.

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 • Adjust stocking standards to reflect site capabilities • Establish operational trials to test survival and growth	• Tree species selection tool • FFT assisted species migration guidance • Chief Forester standards for seed use[36] • Climate-based seed transfer interim policy measures • Seed zone maps
• Fertilize sites that have limited nutrients but sufficient moisture ○ Consider risks of increased invasive species	
• 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 drought stress	

• Reduce reliance on lodgepole pine especially in dry subzones
  ○ Promote Douglas-fir and ponderosa pine in these subzones
  ○ Target harvest of susceptible pine stands
• Ensure that species mix will provide a harvestable stand (e.g. in some sites, higher densities of lodgepole pine may be appropriate providing that landscape diversity is maintained)
	• Kamloops Future Forest Strategy

• Partially cut or thin stands on dry subzones and sites to retain shelter and moisture • Manage stand densities consistent with moisture availability to maintain and promote vigour • Adjust stocking standards to reflect lower site capabilities	• Drought risk assessment tool • Kamloops Future Forest Strategy
Projected ecosystem change: Increased fire hazard	
• Increase fire resilience at the landscape level by creating strategic fuel breaks, 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

• Assess fire hazard
• 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
• Do not reforest areas where climate change creates conditions where there is a low probability of producing commercial timber
	• Landscape fire management planning
	• Fire management stocking standards[37]
	• Fire and fuel management guidelines[38]
	• Kamloops Future Forest Strategy

• Reduce human-caused fires ○ Control access during fire season (e.g. by gates)	• Wildfire Management Branch prevention strategy
• Manage fire hazard around communities • Use grazing to manage fine fuels • Reduce risk to structures in interface areas	• Strategic wildfire prevention initiative[39] • Fuel hazard assessment and abatement • FireSmart program • FireSmart communities
Projected ecosystem change: Increased disease-related mortality (mainly younger stands)	
• Plant climatically-suited species and genetic stock	• Forest health and species selection • TSA forest health strategies

Potential adaptation strategies	Supporting policy guidance, information or tools
• 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[40] • 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	• See above • 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 ○ Reduce reliance on lodgepole pine	• 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

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.[41] 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 aim to capitalize on opportunities (e.g., longer grazing season) and to reduce negative impacts (e.g., increased invasive plants and drought stress) of climate change and cumulative effects. Steps towards adaptation include: revising expectations for rangelands to include climate dynamics; expecting higher variability in productivity; maintaining late seral native perennial grass species; adjusting stocking rates and timing of use to reflect lower productivity in dry sites and to facilitate desired plant communities; and, considering the need for new water developments to sustain livestock drinking water.

Potential adaptation strategies	**Supporting policy guidance, information or tools**
Projected ecosystem change: Changes in forage supply	
• Reduce allocation where forage supply is projected to decrease (e.g., some low elevation grasslands); manage for conservative stocking rates that allow recovery • Increase allocation where forage supply is projected to increase (e.g., higher elevation forested pastures) • Investigate assisted migration of selected species forage species (e.g., bluebunch wheatgrass, rough fescue or Idaho fescue) as understory species as forest canopies open • Relocate infrastructure such as fences and water developments to align with the shifting forage resource • Plan for changing conditions; for example, prepare for increased drought events with contingency forage	• Range climate change guidance[42]
Projected ecosystem change: Changes to water supply	
• Provide controlled access to surface drinking water sources by strategic fencing, barrier placement and the use of pumps and troughs • Use off-stream watering to limit livestock access and impacts to streams • Protect springs and seepage areas from livestock trampling • Redesign or create new water developments where needed to sustain livestock drinking water	• Water quality and livestock grazing BMPs
Projected ecosystem change: Increased invasive plant species	
• Maintain aggressive control program for high priority weeds ○ Especially in areas projected to lose perennial herbaceous species	• See invasive plants under Biodiversity section

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 Cariboo, it is suggested that trend monitoring include:

- Climate: temperature, precipitation, snowpack, glacial melt and extreme weather.
- Hydrology: stream flow by watershed, water temperature, channel stability, forest cover, erosion, suspended sediment, trampling.
- Disturbance: fire weather index,[43] wildlife, mass earth movements, insect and disease prevalence by seral stage, and soil moisture.
- Ecosystem state: regime shifts, connectivity, mature and old forest cover, habitat supply, invasive species and distribution shifts.
- Tree growth and health.
- Range: plant communities and condition, drought conditions.

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 Cariboo 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

1. Regional specialist – Mark Hamm, Resource Manager, Cariboo Region, Mark.Hamm@gov.bc.ca (250-398-4399).
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: IDF = Interior Douglas-fir; BG = Bunchgrass; SBPS = Sub-Boreal Pine – Spruce; MS = Montane Spruce; SBS = Sub-Boreal Spruce; ESSF = Engelmann Spruce Subalpine Fir; 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] Nitschke and Innes, Integrating climate change into forest management in South-Central British Columbia: an assessment of landscape vulnerability and development of a climate-smart framework (2008)

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

[19] 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

[20] An analysis of streamflow trends in the Cariboo is underway (contact Scott Jackson at scott.jackson@lorax.ca for more information)

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

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

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

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

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

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

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

[28] BC Drought Response Plan 2010 (being updated) and Dealing with Drought (a Handbook for Water Suppliers in BC) (2009)

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

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

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

[32] Redding, Lapp and Leach, Natural disturbance and post-disturbance management effects on selected watershed values (2012)

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

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

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

[36] Refer to Section 8, Page 15

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

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

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

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

[41] 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)

[42] 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)

[43] Provincial fire research and monitoring needs