Adapting natural resource management to climate change in the Thompson-Okanagan 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 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 Thompson-Okanagan region, in the southern interior of the province, includes the Thompson-Okanagan plateau as well as portions of the Coast and Cascade mountains to the southwest and the Columbia Ranges to the northeast. The topography is incised by several large lakes, including Okanagan and Shuswap, and rivers, including the Thompson, Shuswap and Fraser. Lying in the rain shadow of the Coast and Cascade Mountains, this region has some of the warmest and driest ecosystems in BC.

At the broadest scale, the region can be divided into three sub-regions: eastern portions of the Coast and Cascade Mountains, the central Thompson plateau, and a western portion of the Columbia Ranges (see Figure 1, next page). These divisions, defined by ecoregion boundaries, represent enduring features that will shape ecosystems in any climate. The leeward western sub-region is mostly dry, although some moist Pacific air travels through low passes. The rolling plateau includes north-south valleys associated with large river systems that carry warm dry air from the Columbia Basin. Pacific air brings high precipitation to the mountainous eastern sub-region.[7]

Vegetation communities form an intricate mosaic in the Thompson-Okanagan, varying with latitude and elevation from open bunchgrass steppes in the hot, dry valleys of the south, through transitional parkland with widely-spaced ponderosa pines and Douglas-firs, to inland temperate rainforests of western redcedar and western hemlock at low elevations in the Columbia Ranges and dense coniferous in the cold, wet higher elevations. For information on biogeoclimatic (BEC) zones in this region, visit BEC WEB.

Because of landscape complexity, climate adaptation will require dividing the mountain ranges and plateaus into finer-scaled units. Climate vulnerability analyses of the Kamloops TSA, in the northern portion of the region, can provide guidance.[8] In the Kamloops TSA, analyses were based on five "ecozones" (groups of BEC subzones representing broad landscapes with similar climates, vegetation and ecological processes)[9]: **dry Douglas-fir and ponderosa pine ecozone** (e.g., IDFxh, PPxh subzones in southern valleys); **dry lodgepole pine ecozone** (e.g., MSxk, IDFdk subzones in the south of the district); **transitional ecozone** (e.g., ICHmw, ICHdw, IDFmw subzones along valleys running from the Columbia Highlands to the Thompson-Okanagan Plateau); **plateau ecozone** (e.g., MSdm, SBSmm and ESSFdc subzones); and, **cool and wet ecozone** (e.g., ESSFwc and ICHwk subzones in the Columbia Highlands and Mountains) (Figure 1).

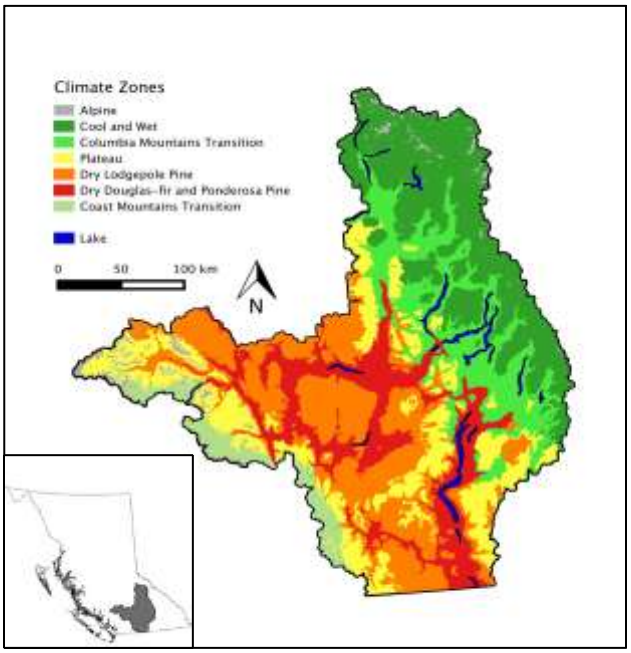

Figure 1. Climatically-relevant sub-regions within the Thompson-Okanagan Region. Delineation of eco-zones is based on analyses in the Kamloops TSA, with data extrapolated to the south and west.[10] Spatial data from DataBC.

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 Thompson-Okanagan Region, its Plan2Adapt tool for projecting future climate conditions, and ClimateBC.[11]

The climate in the Thompson-Okanagan Region has changed over the past century and is expected to continue to change. On average over the region, over 1°C of warming has occurred during the 20th century, with warming occurring in all seasons. Projections suggest the region may warm, on average, an additional 1.6 to 4.4°C by the end of this century, similar to moving from Williams Lake to Merritt or Princeton to Kamloops (3.3°C warmer). Summer is projected to warm more than other seasons.

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.[12]

Precipitation is fairly uniform over most of the region relative to other regions in BC, but varies considerably among years. Over the entire Thompson-Okanagan, annual precipitation has increased over the past century, although winter precipitation has decreased from 1951 – 2009. Projected changes are modest, with about a 10% decrease in summer by the 2080s and a 10% increase in other seasons. In a region with such high topographical variation, high variability in future precipitation is likely at smaller scales.

Summary of climate projections for the Thompson-Okanagan for the 2050s*

Climate variable	Change in Thompson-Okanagan[13]	Variation within region
Temperature		
Mean (°C)	+1.8 (1.1 to 2.7)	Slightly higher in south
Summer (°C)	+1.9 (1.3 to 2.7)	Slightly higher in south
Winter (°C)	+1.6 (0.8 to 3)	Slightly lower in south
Precipitation (%)		
Annual	+6 (-1 to 11)	Consistent over region
Summer	-9 (-19 to 1)	Biggest decrease in north
Winter	+7 (-4 to 15)	Consistent over region
Snowfall (%)		
Winter	-11 (-20 to 0)	Biggest decrease in south
Spring	-55 (-75 to -12)	Consistent over region
Snowpack	Decrease	Become intermittent or disappear at lower elevations
Frost-free days	+24 (14 to 35)	Greater increase at lower elevations and in south
Growing Degree Days	+319 (183 to 482)	Greater increase at lower elevations and in south
Extreme weather	More heat waves[14]	Particularly at lower elevations

*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.[15]

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, heatwave) can become a 1 in 10 year event.[16]

5. Impacts to Ecosystems

Ecosystem Climate Envelopes

Climate envelopes describe the climatic conditions associated with currently mapped biogeoclimatic (BEC) subzone/variants.[17] 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 generally projected to shift upslope and northward across BC,[18] resulting in expansion of some existing lower valley and plateau ecosystems as well as creation of novel ecosystem assemblages. By the 2050s, climate envelopes for current Thompson-Okanagan BEC zones are predicted to shift about 85 – 250 m upward in elevation and up to 175 km northward (Figure 2). Dry subzones are vulnerable, as the hotter, drier climate becomes less suitable for lodgepole pine and Douglas-fir. In these sites, forests may shift to grassland on south aspects and at lower elevations due to reduced moisture and increased fire frequency. The transitional subzones face moderate to high vulnerability due to drought stress and increased disturbance.[19] Although the ICH climate envelope is projected to expand, some subzones may come to resemble a combination of IDF and ICH, and dry sites may shift to shrubby or grassland ecosystems.[20] The plateau subzones are less likely to shift to grassland, but the current MS zone could shift to a new state comprised of a variety of communities. The wet cool subzones will be least impacted by drought and, in the absence of fire, could develop into a novel community including cedar and grand fir.

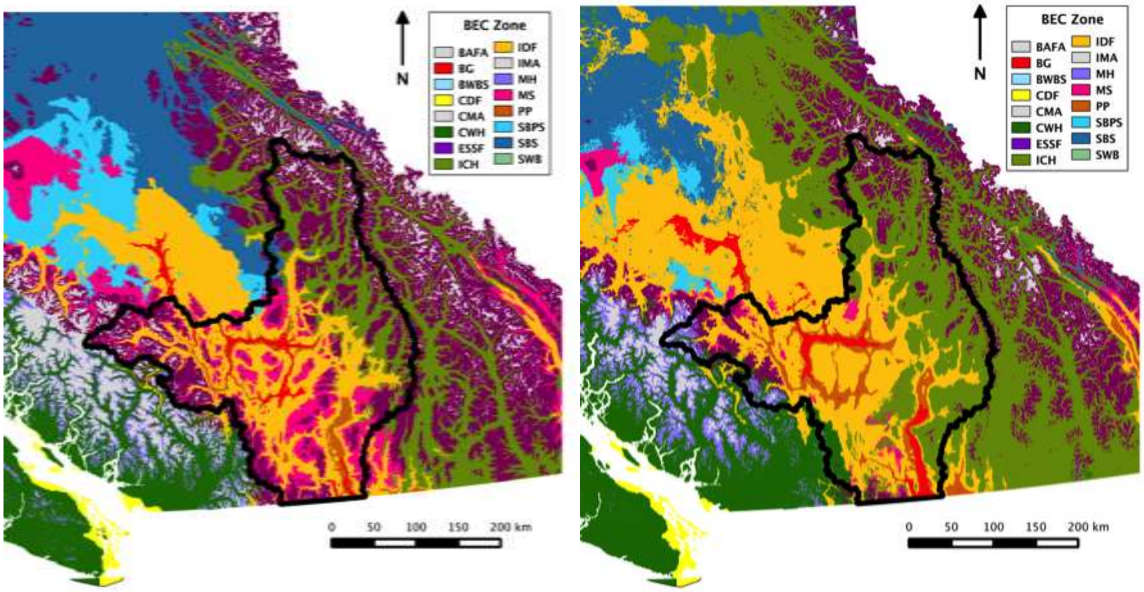

Figure 2. Current BEC zone locations (based on BEC8) and projected future (2041-2070) BEC zone locations. Future map shows consensus of multiple projections. Maps from ClimateBC.

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.[21] In the Kamloops TSA, the area influenced by natural disturbances could double over the next century, with drought, fire and insects expected to be primary disturbance agents.[22] 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. In the Thompson-Okanagan, hotter, drier summers, coupled with increased mortality due to drought stress and insects, will increase fire hazard. Fires are projected to be larger, more intense and more frequent. Forested ecosystems in the region are already undergoing massive shifts in structure due to loss of mature lodgepole and ponderosa pines to mountain and western pine beetles. Mortality due to Armillaria root rot will likely decrease in dry ecozones and increase in the transition ecozones. Douglas-fir will likely experience increased mortality from the tussock moth and the bark beetle. Drought will also impact grasslands.

The increased prevalence of disturbance will vary by climatic sub-regions, elevation and forest type, with the biggest changes projected for dry forested ecosystems at low elevations.

Disturbance	Projected changes[23]*
Fire and drought	• **Drought** will **increase** in all but the coolest, wettest ecozones; drought is expected to increase **mortality** in many tree species, including lodgepole pine, Douglas-fir, spruce, subalpine fir and trembling aspen. • **Fire size** will **increase**; the risk of large wildfires is particularly high in dry ecozones with lodgepole pine. • **Fire intensity** will **increase** with more intermittent to full crown fires. • **Fire frequency** will **increase**; for example, in the Okanagan, the area experiencing fires every 50 years or less may expand from 34% to over 90% by 2085.

	• **Fire refugia** will **decrease**; for example, in the Okanagan, refugia may decrease from 41 to 2% of the landscape by 2085.
Insects and disease	• **Insects** are projected to **increase substantially** in dry and transitional subzones. • **Mountain and western pine beetles** have already caused substantial mortality in logdepole and ponderosa pine in dry and plateau ecozones; this risk will continue if lodgepole pine trees survive. • **Spruce beetles** may **increase** throughout the region in the short term. • **Armillaria** root rot will likely **decline in dry** subzones and **increase in transitional** ecozones as ecosystems dry.

* Studies cover different portions of the region.

Hydrology and Fish

The Thompson-Okanagan Region is expected to follow projected provincial trends in hydrology, although the effects will vary with location, elevation and aspect.[24] 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 northern subzones, 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.

Particularly in the Okanagan basin, domestic and agricultural water use is substantial and expected to grow. With a semi-arid climate, water levels are already below low-flow thresholds in some streams. Competition for limited water resources will increase as seasonal water flow decreases; water allocation challenges will increase with climate change.

Loss of vegetation from 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[25]
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. • **Increased flashiness** 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.
Summer flows	• **Smaller spring snowpack** and **earlier** spring **freshet** will **lower** summer **low flows**, **lengthen** the low-flow **period**, and **decrease groundwater storage**. • Some **perennial** streams may **become intermittent** or ephemeral. • **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 (some are already affected) without adaptation.
Variability	• **Variability** in **peak flow** will likely increase, leading to **unstable stream morphology** in some systems. • **Mid-winter melt** events will likely **increase** at lower elevations.

Biodiversity

Climate shapes species distributions and ecological communities.[26] 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 climates currently live tens or even hundreds of 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. The Thompson-Okanagan region is more vulnerable to such regime shifts than most of BC due to: marginal summer moisture available for tree establishment on some sites; the frequency and severity of droughts (both current and anticipated); and, lower summer moisture needs for grassland, savannah, scrubland, and desert-dwelling species.

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 degraded and **fragmented habitat**, making **dispersa**l 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, which reduces large dead standing and downed wood) can **exacerbate impacts** of climate change. • **Old forest** will **decline** due to increased disturbance and harvesting, threatening associated species; e.g., in the **Kamloops TSA**, old growth patches are projected to **decline by 30 – 50%** with an 80% reduction of large (>1,000 ha) patches. • 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**). • **Deciduous trees**, including trembling aspen and paper birch, that provide critical habitat for many birds and other species, may be **lost from dry ecosystems**. • In the Okanagan, over two-thirds of **faunal species** are classified as **medium to high risk**, particularly species requiring **late-successional forest.**[27]
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 bird migration depends on day length, but their insect 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. • The Thompson-Okanagan already has many invasive plant species, including knapweed and cheatgrass. **Grasslands** and **dry forest ecosystems** are particularly impacted and will be increasingly vulnerable to **invasive species** following disturbance, facilitating regime shifts.
Wildlife[28]	• 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 affect **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.[29] Fires and harvesting will shift the age-class distribution towards younger stands. Most tree species will be unable to migrate quickly enough to follow the climate envelopes to which they are adapted. Uncertainty about climate projection leads to uncertainty about which trees may be best-suited to changing conditions. 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	• Many tree species will face unprecedented **drought stress** and **regeneration challenges** at **lower elevations** beyond 2050. • In **dry ecozones**, **risk to lodgepole pine** establishment and survival will be **very high**. • Parts of the landscape may become climatically **suitable** for **grand fir** and **western white pine**.
Productivity	• **Tree growth** will likely **increase** in **moister, cooler ecosystems** due to elevated CO_2 coupled with 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. • Some dry ecosystems may **shift** from productive **forest to grassland**.
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. • **Drought-stressed trees** are **more susceptible** to certain insects and pathogens; e.g., **lodgepole pine** is susceptible to a range of disturbance agents when stressed. • Tree mortality in **transitional subzones** will be heightened by warmer, seasonally drier conditions. • Several **deciduous and coniferous species** will likely suffer **diebacks**. The current trend of **birch die-back** is expected to **worsen**.
Competition	• Competition will occur after natural disturbance; **shrub**s may be **favoured**.

Range

Grassland ecosystems will shift in response to climate change due to increased drought, and a decline in forests 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.[30]

Feature	Projected changes
Productivity	• **Productivity** will **decrease** at **lower elevations** due to increased **drought** and resultant increase in **invasive plants**, particularly if grazing levels remain unchanged. Deeply rooted **perennial grasses** will **perform best**. • **Productivity** will **increase** at **higher** elevations. • Frequent **drought** may lead to **fluctuating herd sizes**.
Competition	• Many **desirable plant 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. • **Invasive plants** may be particularly **favoured** following **fire** in forests with little existing understory vegetation.
Water	• **Dispersed surface water** sources available for livestock will **decrease**.
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.[31] 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[32]

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[33] provide an excellent resource.

Practice Considerations

Hydrology

To protect aquatic ecosystems, water availability and infrastructure near watercourses, adaptation consists of managing water removal to ensure sufficient flow, 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 or tools
Projected ecosystem change: Decreased flow in summer and longer low-flow period	
• Manage water allocations/use to maintain water supply during low flows • 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 • Manage livestock grazing levels	• Drought guidance[34] • 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[35]
• Maintain ditches and deactivate roads ○ 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 table 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 seasonally 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 • Stream quality crossing index • Water quality and livestock grazing BMPs
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 Equivalent Clearcut Area (ECA) to 30 to 50% of THLB
• Anticipate increased natural disturbance and manage harvest to stay within ECA limits
  ○ Evaluate the hydrological implications of salvaging disturbed stands
  ○ Account for increased runoff from burned sites in ECA calculations
• Manage roads to minimize impacts to flows
• Protect stream sources from timber harvesting and compaction by livestock and machinery
• Leave live standing vegetation and downed wood barriers next to all riparian areas on rangeland
	• Interior watershed assessment
	• Post disturbance watershed effects[36]
	• Landscape fire management planning
	• Water quality and livestock grazing BMPs

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.

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, communities at risk
  ○ Include strategically placed landscape-level fuel breaks
  ○ Manage OGMAs flexibly to address changing conditions and to maintain adjacent old forest retention
	• 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 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) in dry ecozones and on dry sites in other ecozones[38] • Adjust stocking standards for dry, vulnerable sites where reforestation may be a challenge (e.g., do not attempt to reforest sites that are predicted to shift from PP to BG)	• Drought risk assessment tool • Enhancing biodiversity through partial cutting
• Retain downed wood in a relatively undisturbed state ○ Particularly important on dry sites and in riparian ecosystems	• 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) ○ 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)	• See Trees section

• Retain naturally-occurring and regenerating species (including deciduous trees and shrubs) and plant a diverse species mix
• Encourage deciduous trees
  ○ Avoid removing aspen in dry and transition ecozones
  ○ Maintain deciduous species in moist transition ecozones
	• Climate change stocking standards[39]

Potential adaptation strategies	Supporting policy guidance, information or tools
○ Encourage deciduous species in cool and wet ecozone	
• 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 • Minimize road use (e.g., use gates, deactivate) • Establish competitive vegetation in ditches, on side slopes and other disturbed soil as soon as possible • Undertake 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 to maintain late seral vegetation communities ○ Adjust stocking rates and distribution ○ Particularly important near susceptible ecosystems (e.g. grass and wetlands, saline areas, dry, open forested ecosystems and riparian areas)	• Managing rangeland invasive plants
• Minimize site disturbance, especially multiple disturbances ○ Important on susceptible sites (e.g., steep warm forested slopes, grasslands, saline ponds, wetlands, rock outcrops) ○ Minimize off-road vehicle access in grasslands, wetlands, riparian areas and harvested areas • Minimize summer logging on susceptible sites (e.g. dry, grassy sites) • Account for invasive plants in site plans	

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 decreases in projected beetle-related tree mortality over the long term, modest decreases in disease, and modest increases in tree growth in areas with sufficient moisture. Decreases in projected beetle-related mortality are, however, partly attributable to a changing forest age-class structure (i.e. there are fewer old trees).

In the Kamloops TSA, analyses suggest that reducing reliance on lodgepole pine for reforestation would increase forest resilience significantly.[40] Other potentially useful adaptation strategies include targeting harvesting towards stands that are vulnerable to natural disturbance, partial cutting to assist regeneration, and incremental silviculture to increase fire resistance.

Adaptation may have limited success in reducing fire disturbance because losses due to wildfire are expected to double in the next 40 years, and effective fire control in average-weather years can be negated by large disturbances 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	
• Plant climatically-suited species and genetic stock ○ For example, increase ponderosa pine in dry sites dominated by Douglas-fir, increase Douglas-fir in dry lodgepole pine sites • Establish operational trials to test survival and growth • Monitor select plantations to test survival and growth annually	• Kamloops Future Forest Strategy • Tree species selection tool • FFT assisted species migration guidance • Chief Forester standards for seed use[41] • Climate-based seed transfer interim policy measures • Seed zone maps
Projected ecosystem change: Increased drought stress	

• Reduce reliance on lodgepole pine
  ○ Avoid stand conversions to lodgepole pine across lower elevation and plateau landscapes (e.g. do not consider lodgepole pine a "preferred" species in the dry lodgepole pine ecozone, dry sites in the transition ecozone, or the plateau ecozone)
  ○ Promote Douglas-fir and ponderosa pine in these lower elevation and plateau ecozones
  ○ Fertilize existing young lodgepole pine stands to shorten rotation and replace with more resilient species mixture, if cost effective
• Reduce reliance on spruce in moist transitional ecozone
  ○ Encourage species mixture including Douglas-fir, ponderosa pine, western larch and western white pine
• Target harvest of stands that are vulnerable to natural disturbance
	• Kamloops Future Forest Strategy

• Partially cut stands on dry subzones and sites to retain shelter and moisture to protect fragile regeneration ○ Especially on vulnerable sites such as south-facing slope or areas prone to frost • 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
• 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-	• Landscape fire management planning • Fire management stocking standards[42] • Fire and fuel management guidelines[43] • Kamloops Future Forest Strategy

Potential adaptation strategies	Supporting policy guidance, information or tools
reduction ○ Balance fuel reduction with biodiversity objectives • Do not reforest areas where climate change creates conditions where there is a low probability of producing commercial timber	
• Reduce human-caused fires	• Wildfire Management Branch prevention strategy
• Manage fire hazard around communities • Reduce risk in interface areas ○ Prioritize wildfire risk reduction within 2 km of communities & in areas with critical infrastructure and high environmental and cultural values	• Strategic wildfire prevention initiative[44] • Fuel hazard assessment and abatement • FireSmart program • FireSmart communities
Projected ecosystem change: Increased disease-related mortality	
• Plant climatically-suited species and genetic stock	• Forest health and species selection • 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[45] • Stocking standards reference guide • Climate change stocking standards
Projected ecosystem change: Increased beetle-related mortality	
• Plant climatically-suited species and stock ○ Reduce reliance on lodgepole pine and spruce	• 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 2-4 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.[46] 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. 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 to reflect changing productivity, 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 to 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 forage species (e.g. bluebunch wheatgrass or rough 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[47] • Range ecosystem descriptions • Range management principles
Projected ecosystem change: Changes to water supply	

• Control access to water with strategic fencing, barriers 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

Potential adaptation strategies	Supporting policy guidance, information or tools
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 Thompson-Okanagan, it is suggested that trend monitoring include:

- Climate: temperature, precipitation, snowpack, glacial melt and extreme weather.
- Disturbance: fire weather index,[48] mass earth movements, insect and disease prevalence by seral stage, and soil moisture.
- Hydrology: stream flow by watershed, water temperature, channel stability, forest cover, erosion, and suspended sediment.
- Biodiversity: regime shifts, seral stage, habitat supply, species health, connectivity, invasive species and distribution shifts.
- Tree growth and health.
- Range: plant communities and condition, and 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 Thompson-Okanagan 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] Adapting forest management in the Kamloops TSA to address climate change: Kamloops Future Forest Strategy (also known as K1) (2009); Validating impacts, exploring vulnerabilities and developing robust adaptive strategies under the Kamloops Future Forest Strategy (also known as K2) (2011)

[9] BEC subzone acronyms: IDFxh = Very Dry and Hot Interior Douglas-fir; PPxh = Very Dry and Hot Ponderosa Pine; MSxk = Very Dry and Cool Montane Spruce; IDFdk = Dry Cool Interior Douglas-fir; SBPS = Sub-boreal Pine and Spruce; ICHmw = Moist Warm Interior Cedar Hemlock; IDFmw = Moist Warm Interior Douglas-fir; MSdm = Dry Mild Montane Spruce; SBSmm = Moist Mild Sub-boreal Spruce; ESSFdc =Dry Cold Engelmann Spruce Sub-alpine Fir; ESSFwc = Wet Cold Engelmann Spruce Sub-alpine Fir; and ICHwk = Wet Cool Interior Cedar Hemlock

[10] Advice on extrapolation of climate zones for the south and west was provided by regional ecologist, Michael Ryan

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

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

[13] Median and range (10^{th} – 90^{th} percentile) from a standard set of Global Climate Model projections (Plan2Adapt)

[14] Based on trends for all of BC

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

[16] 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

[17] BECWeb includes information on BEC and climate change

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

[19] See Endnote 8

[20] 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)

[21] For more information, see Chapter 2c (Natural Disturbance) of *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests,* Haughian et al, Expected effects of climate change on forest disturbance regimes in British Columbia (2012), and Endnote 18

[22] See Endnote 8

[23] See Endnotes 8, 20 and 21

[24] 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

[25] See Endnote 24

[26] For more information, see Chapter 2e (Forested Ecosystems) of A Climate Change Vulnerability Assessment for British Columbia's Managed Forests, and Endnote 8

[27] See Endnote 20

[28] For more information, see Chapter 2f (Wildlife) of *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests* and Endnote 20

[29] For more information, see Hamann and Wang, Potential effects of climate change on ecosystem and tree species distribution in British Columbia (2006) and sources in Endnote 26

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

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

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

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

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

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

[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] Nelson et al, Guidance to adapt forest management for climate change in the Kamloops TSA (2012)

[41] Refer to Section 8, Page 15

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

[46] 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)

[47] For more information on managing the effects of climate change on BC rangelands, refer to: (i) L. Fraser et al, Climate Change and BC Range (2013); (ii) 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, (iii) Range Branch's *Range Management Responses to Climate Change* (to be published in summer 2015)

[48] Provincial fire research and monitoring needs