Adapting natural resource management to climate change in the Kootenay Boundary 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 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 Kootenay Boundary Region of southeast BC has extremely varied terrain characterized by a series of north-south trending mountain ranges (Rockies, Purcells, Selkirks and Monashees). It is home to forests with some of the greatest diversity of tree species in BC, as well as grasslands, alpine meadows, glaciers, wetlands, and inland temperate rainforests. Owing to its complex topography, the region's climate and ecosystems vary considerably over short distances. For information on biogeoclimatic (BEC) zones in this region, visit BEC WEB.

Climatic sub-regions within the Kootenay-Boundary may be categorized into three primary ecological zones: dry, wet and moist (see Figure 1, next page). The **Boundary** trends from dry in the south to moist in the north and east; it includes grasslands, mixed dry to moist forests, and subdued high elevation terrain which differentiates it from much of the remainder of the region.

The **Columbia** is primarily wet. Inland rainforests of cedar and hemlock (at low and mid elevations) and spruce, subalpine fir, and, in the west, mountain hemlock (at upper elevations) are characteristic, with the wettest areas found along the Revelstoke Reservoir. Mixed forests with Douglas-fir, cedar, hemlock, and lodgepole pine are common along low to mid elevations along the Kinbasket Reservoir, and montane spruce forests occur south of Golden.

The **West Kootenay**, which includes the Arrow, Kootenay, Duncan, and Slocan valleys, contains a mix of dry, wet and moist ecosystems. It has a strong north-south climate gradient, with dry to moist mixed species forests in the south, moist to wet forests in the centre, and wet inland rainforest in the north.

Ecosystems and climates in the **East Kootenay** are also highly diverse. Grasslands and dry forests in lower elevations of the Rocky Mountain Trench separate the Rocky Mountains from the Purcell Mountains. Montane spruce forests with mixed lodgepole pine, spruce, Douglas-fir, and larch typify mid elevations, although scattered interior cedar-hemlock forests occur in moister areas. Subalpine forests are predominantly mixed spruce, subalpine fir, and lodgepole pine in drier climates, with moist ESSF in the Elk, Bull, upper Kootenay, St Mary's, and Spillimacheen valleys, and Yoho National Park.

Extensive wetland complexes occur around Creston and in the Rocky Mountain Trench, from Columbia Lake north to Golden. Large riparian habitats are rare throughout the Columbia and West Kootenay due to flooding for hydroelectric dams.

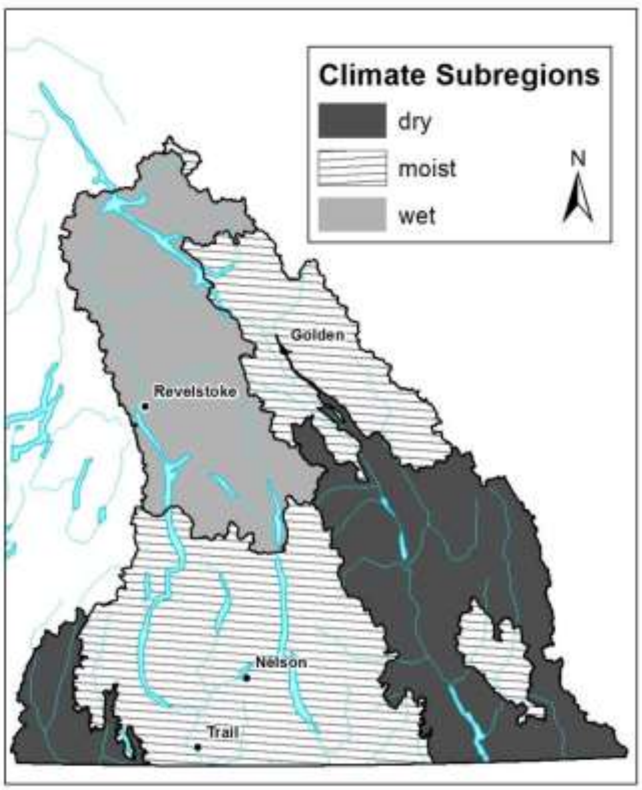

Figure 1. Climatically-relevant sub-regions within the Kootenay Boundary Region

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 Kootenay Boundary Region, its Plan2Adapt tool for projecting future climate conditions, ClimateBC,[7] and a regional vulnerability assessment.[8]

The climate in the Kootenay Boundary Region has already changed noticeably 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; by the 2050s, temperature is expected to warm an additional 1.1 to 3.2°C[9]. Projections suggest the region may warm, on average, by 2 to 5°C (in winter, spring and fall) and 3 to 7°C (summer) by the end of this century, similar to moving from Revelstoke to Vancouver, or Nelson to Osoyoos (3.1°C and 2.6°C warmer respectively).

Significance of Increasing Temperatures

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

Precipitation in the Kootenay Boundary Region has increased over the past century, despite significant variability year to year, with a trend of increasing precipitation in spring. Future projections suggest precipitation will increase by 10 to 25% in winter, spring and fall, and decrease by up to 30% in summer. The impacts of these changes will be greatest in ecosystems where precipitation is already a limiting factor for tree growth, particularly in the dry and moist climate sub-regions.

Warming will decrease snowpack throughout much of the region at low elevations, while increased precipitation in the northern portions of the region and at high elevations may increase snowpack. At mid to upper elevations, temperatures may become too warm to maintain snow. Snowpack reductions may lead to more rapid melting and earlier drying of soil. Significant moisture stress, particularly in summer, is expected. More frequent and intense precipitation extremes are also predicted over this century, as well as more rain on snow events in some areas.

Summary of climate projections for the Kootenay Boundary for the 2050s

Climate variable	Change in Kootenay Boundary[11]	Variation within region[12]
Temperature Mean (°C) Summer (°C) Winter (°C)	 +1.9 (1.1 to 2.8) +2.4 +__	In alpine/subalpine areas, temperature is projected to increase from ~ -1.2°C to 0.5°C. At low elevations in dry sub-regions, temperature is projected to increase from 6.1°C to 9.4°C (7.8 - 11.7%).
Precipitation (%) Annual Summer Winter	 +5 (3 to 10) -6 (-18 to 0) +8 (-2 to 17)	Decline in growing season precipitation will have the greatest impacts where vegetation is already near thresholds: in the driest climate sub-region and on the driest sites within all climate sub-regions.
Snowfall (%) Winter Spring	 -5 (-12 to 7) -48 (-68 to -9)	The amount of precipitation as snow (PAS) in the dry sub-region is projected to drop -21 to -30% (0 to -68%) at high to low elevations, respectively. In the wet sub-region, declines of -12 to -18% (+5% to -60%) are projected.
Snowpack	Decrease	Especially in low elevations; increase (due to more precipitation) is projected in the north and at high elevations; rain-on-snow events are also likely to increase.
Frost-free days	+24 (15 to 35)	Greater increase at lower elevations and in south
Growing degree days	+295 (168 to 434)	Greater increase at lower elevations and in south
Extreme weather	More heat waves, summer drought, extreme precipitation[13]	The MWMT[14] is projected to increase by ~4°C across all sub-regions; however, heat waves would be most extreme at low elevations where temperatures already exceed 35 °C in summer heat waves.

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 over the years. Even with constant variability, the frequency and magnitude 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.[15]

5. Impacts to Ecosystems

Ecosystem Climate Envelopes

Climate envelopes describe the climatic conditions associated with mapped biogeoclimatic (BEC) subzone/variants.[16] These envelopes can be used to predict future bioclimates (BEC subzone/variants), which can help scientists and resource professionals integrate climate variables and visualise the potential extent and implications of climate change. However, they **do not** predict what future ecosystems will look like for several reasons. First, ecosystems do not move as a unit and not all species will migrate to new climates together; second, current climate projections are based on average climate values, ignoring the extreme events that can shape ecosystem structure and composition; third, bioclimate envelopes do not capture variability in site-level conditions. **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.**

Bioclimate envelopes are projected to shift upslope and northward across BC;[17] however, projections for the Kootenay Boundary Region show complex patterns, with bioclimate envelopes that fit most closely to this region in the 2080s being found today as far south and east as Colorado and Kansas, and as far north as coastal Alaska.[18]

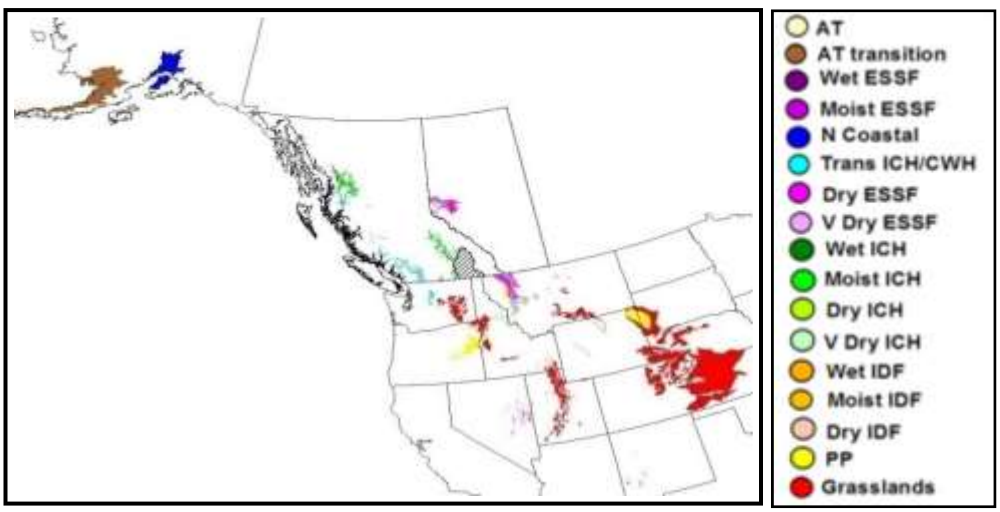

Figure 2. Current locations of bioclimate envelopes that may occur in the West Kootenay in the 2080s[19]

At low and mid elevations in the West Kootenay,[20] bioclimate shifts reflect a decrease in moisture availability, with climate scenarios showing the same directional trends, and differing only in the magnitude or rate of change. At the lowest elevations in the southern portion of the Kootenays, all scenarios project shifts from drier Interior Cedar-Hemlock or Interior Douglas-fir bioclimate envelopes to grassland-steppe envelopes. The extent of this shift is significant and more recent research[21] shows this trend extending across the Boundary to the ridge tops, and throughout low and mid elevations of the Rocky Mountain Trench.

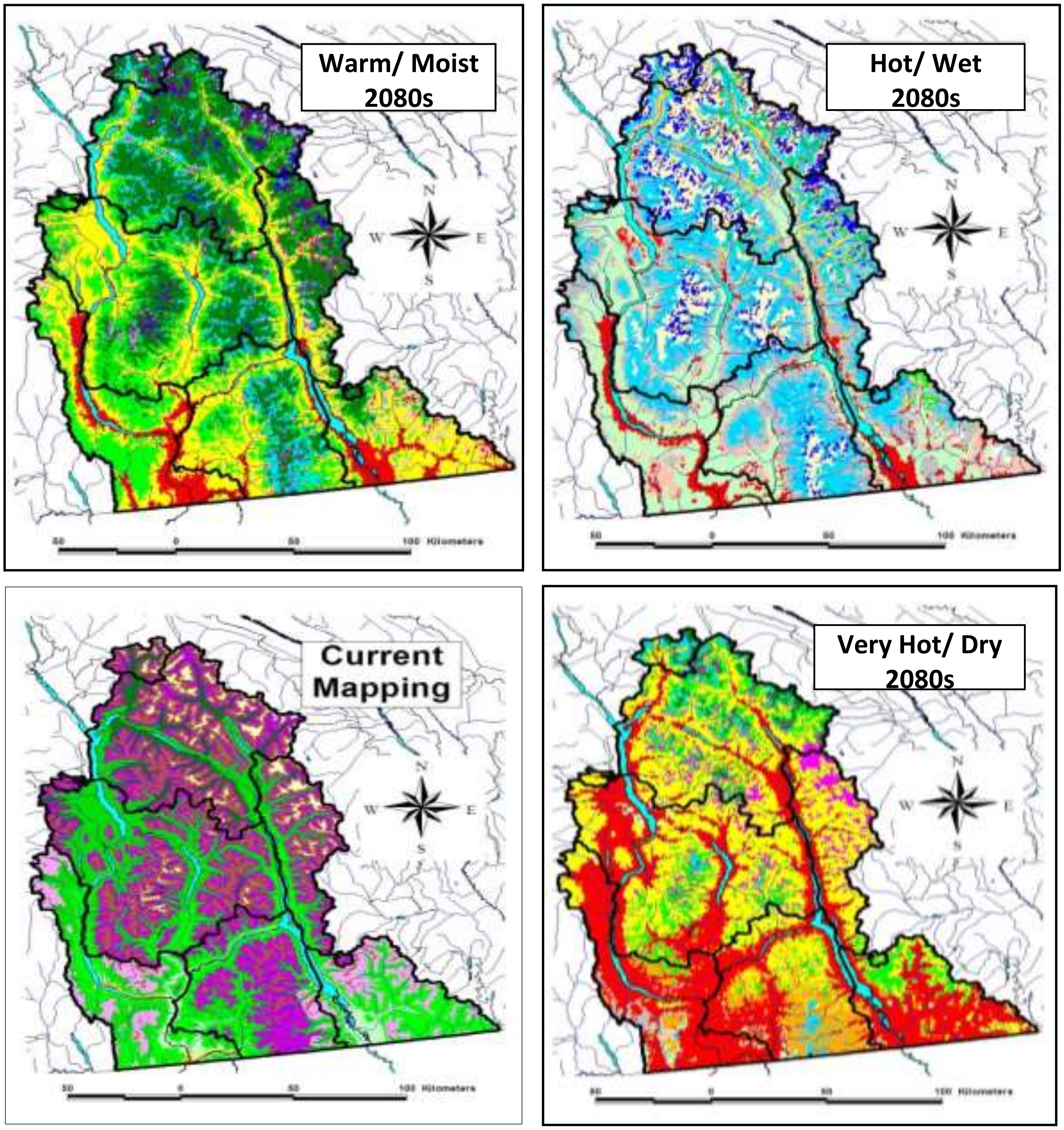

Figure 3. Bioclimate envelope shifts projected by 3 climate scenarios for the 2080s, compared to current mapping of generalized ecosystems (Utzig 2012). Greens and purples reflect ICH and ESSF forests, while reds, yellows, and oranges reflect grassland and open dry forests. Blue reflects coastal/transition forests.

At higher elevations, the results from climate scenario modelling are more variable, with one scenario projecting an upward shift of existing ICH bioclimate envelopes, another trending to more coastal transition systems (CWH/ ICH), and a third showing a shift to drier Ponderosa pine dominated types. All scenarios project a significant decrease in ESSF, parkland and alpine envelopes.

These projections reflect only a few of the many possible futures for this region. However, where trends from different models agree, this increases confidence in the projections.

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.[22] In the Kootenay Boundary Region, the shift to warmer, drier conditions across low elevations is predicted to result in a significant increase in fire frequency, especially in the West Kootenay. As well, increased temperatures during all seasons are expected to result in more frequent, intense, and longer insect and pathogen outbreaks.

In addition to increases in wild fires and forest insects and diseases, the Kootenay Boundary Region is expected to experience an increase in floods and mass wasting, primarily due to extreme storm events, shifts in hydrologic regimes, and the interacting effects of these and other natural disturbances.

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

Disturbance	Projected changes
Fire, drought and wind	• Longer fire season and more frequent, **severe and extensive wildfires** in areas that become very dry, leading to greater area burned throughout much of the region. • Potential for **catastrophic fires** will increase significantly in **currently moist ecosystems** with **dense forest** types and **high fuel loads** (e.g., around Nelson, Castlegar, Kaslo, Nakusp, Revelstoke). • For the **West Kootenay**, there could be up to **15 (South) to 300 (North) times greater area burned** by the 2050's, with minimum increases of at least 3 to 4 times by then[23]. • At higher elevations and in the Rocky Mountains, where precipitation is projected to increase in some seasons, the implications for fire regimes are less clear; but, increased fire and drought stress are expected from the IDF to the ESSF in much of the Trench. • Earlier melt, combined with intense hot and dry summer conditions and a longer dry season, will result in potentially significant **moisture stress** for tree species. As a result, **tree regeneration** will be increasingly **difficult** in many low elevation areas, primarily in the **south**ern portion of the region. • **Reduced water supply** during a longer dry season throughout the region (especially in the south) will increase drought and fire probability. • Increasingly frequent and severe storms will **increase blowdown** throughout the region.
Insects and disease	• **Drought stress** (from increased summer temperatures and decreased moisture availability) will make trees in the region more susceptible to a wider range of insects and disease.[24] • **Bark beetles** (Douglas-fir beetle, western balsam beetle, spruce beetle, mountain pine beetle) and **defoliators** (western hemlock looper, western spruce budworm, Douglas-fir tussock moth) are expected to increase, causing tree **mortality and growth declines**. • The potential for some bark beetle outbreaks (e.g., spruce and Douglas-fir beetles) will be **exacerbated by** more frequent severe **wind events** that create **blowdown** (which facilitates build-up of beetle populations). • **Spruce leader weevil, white pine blister rust, Armillaria root disease**, and other rusts and **foliar diseases** common in **lodgepole pine and larch** will likely increase in frequency and severity, reducing growth and increasing mortality of **regenerating young stands**.

Disturbance	Projected changes
	• **Invasive and endemic secondary insects and diseases** may change from innocuous to severely disruptive; an invasive, **balsam wooly adelgid** has already spread from Idaho and Montana into the Kootenay Boundary Region, causing mortality in subalpine fir. • Diseases such as **larch needle cast and dothistroma** that previously only caused growth loss will increasingly contribute to tree mortality. • The incidence of **decline syndromes**[25] may increase as a result of suboptimal growing conditions throughout the region. • Overall, given the complex variables influencing forest insects and diseases, the potential for **unanticipated outcomes** is high.
Hydrogeomorphic (flooding and mass wasting)	• Greater risk of **flooding** and **high water table** during extreme weather events and rapid melt periods, which could trigger **mass movements**. • **Shifts** from snow to rain dominated **hydrologic regimes** at lower to mid elevations and from snow to mixed rain and snow regimes at upper elevations may alter timing and magnitude of **flood risks**. • An increase in drought events and wildfires may reduce the erosion-protecting and water-transpiring cover of hillslopes, leading to **mass movements**. • **Thawing of permafrost** in high alpine areas (especially in northern and eastern parts of the region) could lead to more rockfall and landslides.

Existing natural disturbance regimes will influence the relative vulnerability or resilience of an ecosystem to climate change. Low elevations in currently wet regions (e.g., around Nakusp, Trout Lake, Kinbasket and Revelstoke) are highly vulnerable because the natural disturbance regime is projected to change from a gap-dynamic dominated system to one dominated by more frequent stand replacing fires. Vulnerability is further increased because seed sources for species adapted to the new climate and fire regime are unlikely to be found in the immediate vicinity. Succession in these ecosystems may therefore stall following disturbance with unknown long-term consequences for ecosystem recovery.

Significant changes are also predicted for the currently dry ecosystems in valley bottoms in the southern part of the region (around Grand Forks, Castlegar, Slocan, Creston), as these ecosystems shift to open forest and grassland systems. These are dramatic shifts that will include severe fires and/or insect and disease outbreaks, but the ecological resilience (e.g., species recovery potential) of these drier forested ecosystems is potentially higher than for wetter forests because the anticipated fire regime is more similar to current conditions, and species adapted to future conditions are more likely to be found locally.

However, if these low elevation ecosystems are overtaken by invasive species (e.g. knapweed, hawkweeds, cheatgrasses), vulnerability will become high and ecosystem succession may stall. These predictions have significant forest management implications, including a much higher risk of severe wildfires and potentially significant reductions in timber supply, wildlife habitat supply, and ecosystem services.

Hydrology

The Kootenay Boundary Region is expected to follow projected provincial trends in hydrology.[26] In most areas, increasing winter temperatures and increasing precipitation in winter, spring and fall will likely shift the hydrologic regime from snowmelt-driven to hybrid rain/snow-driven, leading to more frequent rain-on-snow events and smaller spring snowpacks. These changes will affect peak flows, sediment loads, channel stability and low flows. Predictions for significant decreases in summer precipitation will also result in longer summer low-flow periods and lower flows overall, which will significantly increase risks to water supply and fish and riparian habitat.

Many interactions can be expected. For example, 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.

Cumulative Effects

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

Feature	Projected changes
Hydrologic regime	• A **shift** from snowmelt driven to **hybrid rain/snow** driven regimes with more **rain-on-snow** events. • Mid to low elevations will shift from snow to rain dominated, which could **increase winter peak flows.**
Peak flows	• With increased warming, **earlier** spring and summer **peak flows** are projected. • As glaciers melt, glacier-fed watersheds will first experience an increase in flow, followed by decreased and earlier peak flows, similar to snow-dominated regimes. • A shift to a hybrid rain/snow regime could lead to **more frequent and spiky peak flows** during fall and winter, which could disturb the streambed and disrupt spawning habitat.
Spring recession	• **Loss of snow-driven regimes** 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	• **Smaller spring snowpack** and **earlier** spring **freshet** will **lower** summer **low flows**, lengthen the low-flow period, and decrease groundwater storage. • Over time, loss of **glacial meltwater** will lengthen summer low-flow periods. • In some cases, longer periods of late summer and early autumn **low flows** will transform small streams from perennial to intermittent flow. • **Temperature** will **increase** in many streams and lakes, altering aquatic ecology and putting temperature-sensitive **fish and aquatic invertebrates** at **risk**.
Variability	• **Variability** in **peak flow** will likely increase, leading to unstable stream morphology.

Flood Return Intervals
Small changes in mean climate can cause large changes in flooding frequency and magnitude. For example, current 50-year floods may become 5-year events and future 50-year floods might be what we now consider a 1,000-year flood.[27]

Biodiversity

Climate shapes the distribution of species and how they group into ecosystems.[28] When the climate changes, species can die out, move, be displaced by encroaching species, or adapt to new conditions. Species most suited to a rapidly changing climate will be those that are 'r-selected' or 'weedy species' – i.e., those tolerant of a wide range of conditions combined with rapid reproductive rates. Small or fragmented populations, or species with low reproductive rates, will adapt less quickly and are more likely to die out.

Many species and ecosystems in the Kootenay Boundary Region, and across BC, are already in decline.[29] Key stressors include loss of habitat from human settlement and hydroelectric dams, and loss of riparian systems, cottonwood forests, and wetlands due to draining and hydrologic changes. As well, landscape changes, including fragmentation of forested landscapes as a result of harvesting, agriculture and roads, reduces available habitat and limits the ability of species to move. Climate change will exacerbate the impacts of human development on species and ecosystems.

Feature	Projected changes
Cumulative effects	• Past human activities have degraded and **fragmented habitat**, making **dispersal** in response to climate-related disturbance more **difficult** for **specialist species**. • Forest fragmentation is particularly notable in the Rocky Mountain Trench, the West Arm of Kootenay Lake, the Elk Valley, and the Highway 3 corridor. • **Extinction threat** is likely to increase for species already in decline due to **habitat loss** as ecosystems change in response to climate change. • **Salvage harvesting** following wildfires and insect infestations can **exacerbate impacts** of fragmentation and climate change. • Without management intervention, climate change will exacerbate the effects of **over-grazing**, excessive **soil disturbance**, and other soil-damaging processes on the **spread** of **invasive** species.
Species communities[30]	• Species **communities** will **reassemble** into new combinations as some established species decline or disappear, new species colonize, and interactions change. • Some ecosystems may undergo **regime shifts** (e.g. from **forest to shrubs or grassland**), benefiting some species, although increases in invasive noxious species may reduce forage potential in these new habitats. • **Habitat** for some species will **alter in distribution and abundance** (e.g., caribou habitat will be negatively impacted by increasing fire regimes; wetlands may further decline). • Few species and ecosystems will be unaffected by climate change.
Interactions	• **Ecological processes** and **relationships** among species (e.g., predation, pollination and mutualism) may **uncouple** as the timing of events changes and becomes more variable (e.g., if migration depends on day length, but prey abundance depends on temperature).

Feature	Projected changes
Invasive species	• **Invasive species** (plants and other organisms) are expected to **increase** as temperatures and disturbance increase, as they are adapted to change and colonizing new habitats. • Current **indigenous species** may be **less competitive** in new climate and disturbance conditions, facilitating invasive plant population expansion. • **Dry ecosystems** in Boundary and East and West Kootenay are already **highly vulnerable** to invasive plant species, and this vulnerability is expected to increase and **expand into moist and wet ecosystems**. **New invasive species** are expected to arrive, negatively impacting forage and biodiversity values. • **Species** for which **migration is 'assisted'** by management activities (e.g., trees) could **act** as **invasive** species. Shorter species movements (such as those planned for trees) are less likely to negatively affect ecosystem function, but overall **effects** are **unknown** and should be **monitored**.

Trees

Tree species distributions are expected to shift gradually in response to climate change due to physiological tolerances and the ability of established trees to persist under variable climatic conditions.[31] In the Kootenay Boundary Region, significant tree mortality is expected, especially at low and mid elevations, due to natural disturbance and decline syndrome type mortality.[32]

Feature	Projected changes
Distribution	• Changes to **tree** species **distributions** in the Kootenay Boundary Region are expected to follow the provincial trend of **moving north and upwards** in elevation,[33] although the magnitude of change in this region is highly variable and uncertain. • At low to mid elevations, **drought-resistant** and **fire tolerant species** will likely be **favored** (Douglas-fir, Ponderosa pine, western larch) although many areas are predicted to surpass thresholds for even these species and become grassland, brushland, or open forest. Climatic suitability for these species is projected to extend to ridge tops in the Boundary, and surprisingly far north into the current 'ICH wetbelt', although significant seed sources for Ponderosa pine and other species may be limited further north. • **Douglas-fir, western hemlock and western redcedar** may **expand** their **range**,[34] although long generation times, genetic specialization to local areas, and extreme climatic and disturbance events could prevent successful tree migration. • **Western redcedar** is predicted to **decline** on currently **dry sites** as a result of increased moisture stress and insect/disease damage (e.g., from western hemlock looper); cedar mortality has already been observed on drier slopes around Kootenay Lake and the southern Bonnington Range. • At **high elevations**, **tree mortality** is likely to **increase** due to fire, insects and disease, but it is hard to predict how individual tree species will respond given the wide range of projected bioclimate envelopes for high elevation areas. • Suitable **genetic provenances** are likely to **shift** for most species, although for many (e.g., western larch, lodgepole pine), **Kootenay seed sources** have the **broadest applicability** across varying climates.[35] • Aside from climate change, tree species **distribution shifts** will also be **limited** by **soil availability** or suitability, **insect and disease** prevalence, and localized **site conditions**.

Feature	Projected changes
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** due to three factors: **limited moisture** or nutrients; populations are not adapted to changed seasonality and increased **extreme events;** and, **maladaptation** increases susceptibility to insects and disease. An increase in **decline syndromes** is anticipated throughout the region. • Some dry ecosystems may **shift** from productive **forest to grassland**.
Natural disturbance	• Drier soil moisture conditions in areas already close to moisture thresholds (e.g., southern areas including around Castlegar, Pend d'Oreille, Grand Forks, Cranbrook) may cause **drought induced mortality** for a **variety of species** (western larch, lodgepole pine, western redcedar, western hemlock, spruce, and even Ponderosa pine). • **Increased fire extent, frequency and severity** are projected to cause widespread tree mortality at all elevations. **Moist and wet cedar-hemlock forests** in the West Kootenay and Columbia will be at particularly **high risk** given disturbance regime shifts (from rare to frequent fires) combined with drier summers and high current fuel loads. • Increasing temperatures and drought-stress will make trees in this region more **susceptible** to **insects and disease**.
Dispersal ability	• Most tree species and populations will not be able to migrate quickly enough to follow the climate envelopes to which they are currently adapted. • **Shifts** in timing and duration of **seasons** can lead to **maladaptation**. For example, species such as Douglas-fir and western hemlock are dependant on winter chilling which may not be met with warmer winters. These types of maladaptation could lead some species to die out in their natural historic ranges. • **Lack of seed sources** may further slow population response times (e.g., for ponderosa pine, moving north into existing wet ICH forests). • **Poor (coarse or shallow) soils** will **limit upward movement** of trees at higher elevations. • **Mountainous terrain** and **fragmentation** will **limit** lateral **connectivity** and tree movement. • **Natural disturbances** will become the **agent of change**, with species likely to remain on site until a disturbance event. **Post-disturbance regime shifts** may occur (e.g. **shrubs** or **weedy species** may be **favoured** over forests).

Ecological Surprises

Current vulnerability modeling does not factor in ecological surprises or complex climate-ecological relationships. Forests of the Kootenay Boundary Region typically have high tree species diversity, which likely provides some resilience or buffering to the impacts of change. Despite this, significant ecological change has already been observed. For example, white pine was historically a key species in lower elevation ecosystems, yet mature white pine is extremely rare today as a result of white pine blister rust and focused harvest. More recently, paper birch has seen significant mortality due to complex factors related to climate change.[36] Western redcedar is also showing significant declines on drier sites due to moisture stress. Significant declines of these tree species have unknown implications for ecosystem function. Simplistic predictions for complex ecosystems cannot replace long-term interdisciplinary research and monitoring.

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 and wildlife. 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.[37]

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 and wildlife (e.g., elk) populations**.
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 **favoured** following **fire** in forests with little 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**.
Interspecies competition	• **Competition for forage** between **livestock** and **wildlife** may increase, particularly at lower elevations where productivity and disturbance are expected to reduce forage availability.

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 Central BC indicate the economic benefits of diversifying managed forests to reduce forest health risks and increase resilience.[38] 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[39]

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 and research) to reduce uncertainty where possible;
- Recognition that uncertainty increases with time span considered; and,
- Acceptance that uncertainty will remain and that decisions will involve either using precaution to maintain a desired value or putting 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). In addition to the practices described below, best management practices for ecosystem management[40] provide an excellent resource on how to manage for ecological resilience.

Practice Considerations

Hydrology

To protect aquatic ecosystems, water availability and infrastructure near watercourses, adaptation strategies consist 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.

Potential adaptation strategies	Supporting policy guidance, information and tools
Projected ecosystem change: Decreased flow in summer and fall, 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 • Balance harvesting by elevation and aspect to desynchronize flow and prolong freshet • Promptly reforest harvested areas • Retain sufficient riparian vegetation along small streams to mitigate evaporation losses and maintain stream flow • Manage livestock grazing levels	• Drought guidance[41] • Water quality and livestock grazing BMPs
Projected ecosystem change: Increased stream temperature	
• Retain adequate riparian vegetation next to streams and wetlands o Particularly important in temperature sensitive watersheds (e.g., for Bull trout)	• Watershed monitoring[42]
• Maintain ditches and culverts, deactivate roads, and restore natural drainage patterns as soon as possible o Important on segments that discharge directly into streams or wetlands, especially in temperature sensitive watersheds	
• Avoid harvesting sites with high water tables o Important for sites that feed streams or wetlands, particularly in temperature sensitive watersheds • Balance harvesting by elevation and aspect to desynchronize flow and prolong freshet	

Potential adaptation strategies	Supporting policy guidance, information and tools
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 livestock 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 hydrological implications of salvaging wildfire and insect-disturbed stands
  ○ Account for increased runoff from burned sites in ECA calculations
• Avoid harvesting in active floodplains and areas with high water table; reassess floodplain and riparian mapping to accommodate projected changes in the occurrence of extreme precipitation and snowmelt events
• 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 rangelands
	• Interior watershed assessment
	• Post disturbance watershed effects[43]
	• 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 and tools
Projected ecosystem change: Loss of old forest habitat and connectivity due to increased tree mortality and disturbance	

• 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
	• Biodiversity Guidebook

Potential adaptation strategies	Supporting policy guidance, information and tools
○ Include habitat for specialized species and communities at risk ○ Include strategically placed landscape-level fuel breaks ○ Manage OGMAs flexibly to address changing conditions and to maintain adjacent old forest retention	
• Limit salvage in retention networks (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[44]
Projected ecosystem change: Loss of suitable microclimate and soil conditions to re-establish historic ecosystem following harvest (e.g., potential for regime shift from forest to grassland)	
• Avoid harvesting sensitive sites ○ Maintain sufficient old or mature forest on sites likely to be resistant to climate change (e.g., sites expected to remain moist despite climate change) ○ Retain forest cover adjacent to wetlands and seepage sites to protect riparian areas • Partially-cut stands where specific species' seed sources will be favoured in future (Py, Lw, Fd), and to minimize effect of increased isolation	• Drought risk assessment tool • Enhancing biodiversity through partial cutting
• Retain natural levels of dead wood, both as snags and downed wood ○ Particularly large sized, where present ○ Plan for recruitment throughout the rotations	• Wildlife trees and coarse woody debris policies • FREP CWD backgrounder • CWD management
• Promote rapid site recovery to appropriate species, especially on dry sites (e.g., reforest dry sites; retain deciduous trees)	• 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); use adaptive management to monitor success	• See Trees section
• Retain naturally-occurring and regenerating species (including deciduous trees and shrubs) and plant a diverse mix of species at both stand and landscape scales	• Climate change stocking standards[45]
• Use stand tending to influence successional pathways ○ Particularly where climate change projections indicate large shifts in bioclimates or where specific values or habitats are of concern (e.g., caribou, other wildlife)	• See Trees section
Projected ecosystem change: Increased spread of invasive plants following disturbance	
• Minimize roads, especially in currently unroaded areas and susceptible ecosystems • Minimize road use (e.g., use gates and limit seasonal access) • Wash equipment to remove seeds/plants prior to moving into new areas,	• Invasive plant management practices • Invasive species council of BC • Invasive species working group; IAPP Map, E-Flora BC

Potential adaptation strategies	Supporting policy guidance, information and tools
and ensure gravel sources are free of invasive plants and their seeds • Establish competitive vegetation in ditches, on side slopes and other disturbed soil as soon as possible • Monitor and treat affected areas, particularly for new and noxious invasive plants species	

• Manage grazing to maintain late seral vegetation communities
    ○ Adjust stocking rates and distribution
    ○ Particularly important near susceptible ecosystems (e.g. grasslands in PP/IDF, riparian and wetland areas)
	• Managing rangeland invasive plants

• Minimize site disturbance, especially multiple disturbances
    ○ Particularly important on susceptible (e.g., dry, grassy) sites
    ○ Evaluate the risk of spreading noxious weeds prior to soil disturbance or prescribed burning, and modify practices where risks are high
    ○ 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. However, many uncertainties exist and should be considered when determining sustainable harvest levels.

For example, 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. With more frequent extreme temperatures and drought projected, the Kootenay Boundary Region will likely experience a substantial increase in dry and very dry years, corresponding to more frequent, severe and extensive wildfires in dry areas, and greater area burned throughout much of the region. Landscape fire management planning is aimed at reducing these losses as much as possible.

Climate Change and Timber Supply Review

Declines in tree survival and growth as a result of climate change are expected to have profound impacts on mid and long term timber supply. Government is considering the effects of climate change on trees as part of timber supply review processes across the Kootenay Boundary Region. Analyses are looking at potential impacts from (i) changes in disturbance rates and severity, and (ii) changes in growth and yield. Outcomes will help ensure sustainable harvest levels into the future.

Potential adaptation strategies	Supporting policy guidance, information and tools
Projected ecosystem change: Increased tree growth potential on sites with sufficient moisture	
• Plant climatically-suited species and genetic stock ○ Especially on sites with a growing season moisture deficit • Establish operational trials to test survival and growth	• Tree species selection tool • FFT assisted species migration guidance • Chief Forester standards for seed use[46] • Climate-based seed transfer interim policy measures • Seed zone maps
Projected ecosystem change: Increased drought stress	
• Partially cut stands on dry sites to retain shelter and moisture, while improving fire resiliency ○ Especially on sites with growing season moisture deficit • Manage stand densities consistent with moisture availability to maintain and promote vigour • Adjust stocking standards to reflect lower site capabilities	• Drought risk assessment tool
Projected ecosystem change: Increased fire hazard (all stand ages)	
• 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-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
• Identify high priority areas (e.g., areas with high value timber, wildlife, and old-growth) for fire suppression
	• Landscape fire management planning
	• Fire management stocking standards[47]
	• Fire and fuel management guidelines[48]

• Reduce human-caused fires
  ○ Control forest access during extreme fire seasons (e.g., use gates)
  ○ Educate forest workers and recreationalists on fire prevention
	• Wildfire Management Branch prevention strategy

• Manage fire hazard around communities • Reduce risk in interface areas ○ Prioritize wildfire risk reduction within 2 km of communities and in areas with critical infrastructure and high environmental and cultural values	• Strategic wildfire prevention initiative[49] • Fuel hazard assessment and abatement • FireSmart program

Potential adaptation strategies	Supporting policy guidance, information and tools
• Promote deciduous trees for fire breaks where ecologically appropriate	• FireSmart communities
Projected ecosystem change: Increased disease and insect related mortality (mainly younger stands)	
• Plant climatically suited species and genetic stock ○ Especially sites facing drought and areas with the potential for wetter seasonal climates (e.g., to reduce needle diseases) ○ Avoid mono-cultures that puts stands at high risk of complete mortality	• 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 and genetic diversity (e.g., plan retention and reforestation at the landscape level to promote diversity at multiple scales) ○ 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[50] • Stocking standards reference guide • Climate change stocking standards
Projected ecosystem change: Increased beetle-related mortality (mainly mature stands)	
• Plant climatically-suited species and genetic stock	• See above
• Increase stand and landscape 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.[51] 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 and tools
Projected ecosystem change: Changes to forage supply	

• Reduce allocation where forage supply is projected to change
    ○ Decrease allocation in some low elevation grasslands
    ○ Manage for conservative stocking rates that allow recovery
    ○ Reallocate forage to areas where forage supply is increasing
• 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 and appropriate herd sizes
	• Range climate change guidance[52]
	• 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

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 local adaptation strategies that are more likely to achieve management objectives under a changing climate, practitioners and decision-makers need to understand changes in climatic variables and key ecological responses at relevant spatial scales. In the Kootenay Boundary Region, it is suggested that trend monitoring and modeling include:

- Climate: temperature, precipitation, snowpack, glacial melt and extreme weather.
- Disturbance: fire weather index,[53] mass earth movements, insects and disease prevalence by seral stage, soil moisture, and windthrow.

- Hydrology: rainfall patterns, stream flow by watershed, channel stability, condition of forests, temperature, erosion, and suspended sediment.
- Biodiversity: changes in availability and connectivity of key wildlife habitat and old growth; wetland and cottonwood forest conditions in areas with moisture deficit; and, invasive plant species and distribution shifts.
- Trees: tree growth; changes to post free-growing conditions as a result of disturbance; BEC variants at high to extreme risk of drought-induced mortality; and, forest ingrowth at high elevations.
- Grasslands: effects of drought and invasive species on grassland plant communities and forage supply.

Moving Forward

Successful regional adaptation will require innovation and collaboration. Shared leaning among practitioners, decision-makers and communities has the best potential for developing suitable adaptation strategies for the Kootenay Boundary 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 contact– Deb MacKillop, Ecologist, Kootenay Boundary Region, Deb.MacKillop@gov.bc.ca (250 354-6389).
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] The sites provide definitions and calculation details for indices

[8] See Holt et al, Vulnerability, resilience and climate change: Adaptation potential for ecosystems and their management in the West Kootenay (2012)

[9] The lower range of the projections are from the most optimistic scenarios (B1 greenhouse gas emissions in IPCC-4), while the upper estimate is from the newer, more "realistic" scenarios (rpc8.5, IPCC-5)

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

[12] Data were analysed by climate subregion and elevation band (low, mid, high, and treeline) using ClimateBC and the rpc8.5 scenario for six GCM climate models (D. Spittlehouse, September 2014)

[13] Based on trends for all of BC

[14]Mean warmest month temperature

[15] 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

[16] BECWeb includes information on BEC and climate change

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

[18] Some studies have looked for the next nearest climate envelope but limited the search to those existing in BC today (e.g., Wang et al, 2012); in these cases, patterns of change appear simpler and don't reflect the full extent of possible change

[19] See Footnote 8 (Report#5)

[20] Three climate scenarios that illustrate the range of climate projections for BC were investigated for the West Kootenay - 'Hot/Wet', 'Warm/Moist', and 'Very Hot/Dry'. All scenarios project an increase in temperature for all seasons by the 2080s, as well as an increase in precipitation in winter, spring and autumn and a decrease in precipitation in summer (except the Hot/Wet scenario, which had a very slight increase in summer precipitation). The Very Hot/Dry scenario is distinct in its projection of much hotter and drier summers and warmer springs and autumns – but trends remain similar to the other models.

[21] Utzig, *Conservation planning in the face of climate change: A case study in Southeastern British Columbia* (2015); a link to this report will be added as soon as it is published (anticipated in 2015)

[22] 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 Footnote 8

[23] See Footnote 8

[24] Tilman et al, Climate Change Effects and Adaptation Approaches for Ecosystems, Habitats, and Species: A Compilation of the Scientific Literature for the North Pacific Landscape Conservation Cooperative Region: Executive Summary (2013)

[25] Decline syndromes are diseases characterized by slow, progressive deterioration in health, vigour, and growth that cause widespread tree mortality; they mostly affect mature trees and are typically caused by a complex assortment of interacting factors, including both abiotic and biotic factors

[26] For more information, see Chapter 2b (Hydrology and Aquatic Ecosystems) of *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests*

[27] See Footnote 15

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

[29] Austin, Taking Nature's Pulse: The Status of Biodiversity in British Columbia (2008)

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

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

[32] Based on projections for the West Kootenay (See Footnote 8)

[33] Gray and Hamman, Tracking suitable habitat for tree populations under climate change in western North America (2012)

[34] Douglas fir suitability is projected to move upslope but decline at low elevations; see Flower et al, Using an ensemble of downscaled climate model projections to assess impacts of climate change on the potential distribution of spruce and Douglas-fir forests in British Columbia (2012)

[35] Jaquish and Rehfeldt, *Ecological impacts and management strategies for western larch in the face of climate change* (2010)

[36] Research is underway to examine causes of birch decline in the Southern Interior; preliminary findings suggest drought and spring freeze-thaw events may be causal factors (M. Murray, pers com, 2014)

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

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

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

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

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

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

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

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

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

[46] Refer to Section 8, Page 15

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

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

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

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

[51] 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)

[52] 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)

[53] Provincial fire research and monitoring needs