Adapting natural resource management to climate change in the West and South Coast Regions:

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[7] 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 West and South Coast Regions contain large islands, including Graham and Moresby (Haida Gwaii) and Vancouver Island, many small islands, coastal lowlands and the Insular and Coast Mountain ranges. As well as the Lower Fraser drainage basin, there are many small to large coastal watersheds. At the broadest scale, northwest-southeast mountains on the west coast of the mainland and on some larger islands are enduring features that divide the area into generally western windward and generally eastward leeward portions with different climatic regimes. Mountains represent enduring features that will shape ecosystems in any climate regime. The region has a range of climates, including the wettest part of the province, with relatively mild seasonal variations in temperature, moderated by the ocean.[8]

Current ecoprovince boundaries represent a reasonable division of the Coast Region into two broad climatically-relevant portions (see Figure 1). At this broad scale, current forested biogeoclimatic (BEC) zones[9] match the division well: the **Coast and Mountains** ecoprovince is dominated by CWH and MH and the **Georgia Depression** ecoprovince by CWH and CDF. Hypermaritime, maritime and submaritime subzones provide an enduring division at a medium scale. Work is underway to define finer-scaled sub-regions, which will further refine enduring boundaries along latitudinal gradients. For more information on BEC zones in this region, visit BEC WEB.

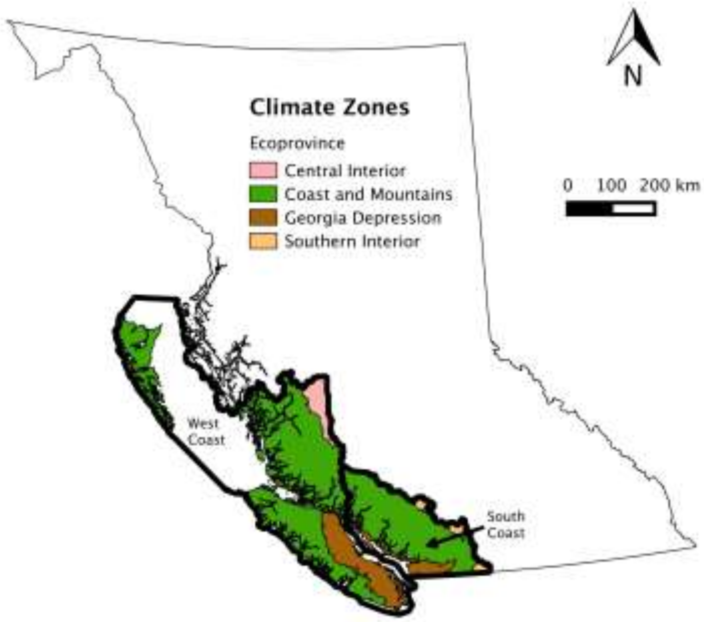

Figure 1. Climatically-relevant sub-regions within the West and South Coast Regions. Spatial data from DataBC.

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 summaries for the South Coast and West Coast, its Plan2Adapt tool for projecting future climate conditions, and ClimateBC. [10]

The coastal climate has changed over the past century and is expected to continue to change. Averaged across the coast, over 1°C of warming has occurred during the 20th century. Projections suggest the West Coast may warm, on average, an additional 1.2 to 3.5°C by the end of this century and the South Coast an additional 1.9 to 5°C, similar to moving from Prince Rupert to Victoria (2.5° warmer).

Significance of Increasing Temperatures

While it is normal for temperatures to vary considerably between seasons or from day to night, even a fraction of a degree rise in temperatures, when averaged over decades, is significant for ecosystems. For example, the mountain pine beetle epidemic was triggered by a series of warm winters that accompanied an increase in average temperature of less than one degree over a century. Climate is changing an order of magnitude faster than Canada's tree species can migrate or adapt.[11]

Precipitation trends are more complex, varying across the region and from year to year. Current winter precipitation ranges from over 1,000 mm on the outer coast to less than half that in rain-shadow areas. Over the entire region, annual precipitation has increased over the past century, although winter precipitation decreased from 1951 – 2009. Projected changes in precipitation are relatively modest compared to historical variability, with about 10% decrease in summer and a 10% increase in other seasons by the end of this century. Snowfall is projected to decrease considerably in both winter and spring.

Summary of climate projections for the West and South Coast for the 2050s*

Climate variable	Change in West Coast	Change in South Coast	Sub-region variation
Temperature (°C) Annual Summer Winter	 +1.4 (0.8 to 2.2) +1.4 (0.9 to 2.1) +1.3 (0.5 to 2.2)	 +1.7 (1.1 to 2.5) +1.8 (1.3 to 2.5) +1.5 (0.7 to 2.5)	 Fairly consistent Biggest increase in Georgia Basin Fairly consistent
Precipitation (%) Annual Summer Winter	 +6 (0 to 11) -10 (-18 to 2) +6 (-2 to 12)	 +6 (-2 to 11) -14 (-23 to 3) +6 (-4 to 14)	 Fairly consistent Smallest decrease in mountains and north Fairly consistent
Snowfall (%) Winter Spring	 -28 (-46 to -10) -51 (-72 to -14)	 -24 (-40 to -10) -52 (-73 to -14)	 Biggest decrease in Georgia Basin and western Vancouver Island (-34 to -40) Fairly consistent
Snowpack	Decrease	Decrease	Biggest decrease at high elevations on the mainland coast[12]
Frost-free days	+22 (13 to 32)	+24 (14 to 36)	Greater increase in Coast and Mountains
Growing Degree Days	+327 (204 to 506)	+336 (205 to 506)	Greater increase Georgia Basin
Extreme weather[13]	More heavy precipitation, windstorms and heat waves	More heavy precipitation, windstorms and heat waves	Storms more likely on outer coast

*Based on 1961-1990 baseline. Projected changes in temperature continue to increase past 2050. Source: PCIC's 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.[14]

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 the 10% increase in precipitation predicted for the Georgia Basin in the 2080s could increase the frequency of slope instability by 165%.[15]

5. Impacts to Ecosystems

Ecosystem Climate Envelopes

Climate envelopes describe the climatic conditions associated with currently mapped biogeoclimatic (BEC) subzone/variants.[16] These envelopes help scientists and resource professionals integrate climate variables and visualise the potential extent and implications of climate change, but they **do not** predict what future ecosystems will look like for several reasons. First, ecosystems do not move as a unit; second, current climate projections are based on average climate values, ignoring the extreme events that can shape ecosystem structure and composition; third, climate envelopes do not capture site-scale shifts well. **Nonetheless, projections can help estimate the relative stress that climate change poses to an ecosystem and its potential to recover to a new functional state.**

Climate envelopes are projected to shift upslope and northward across BC.[17] By the 2050s, climate envelopes for current CWH and MH zones are predicted to shift about 200 – 300 m upward in elevation and 35 - 55 km northward; the CDF climate envelope is predicted to vary little (Figure 2). High elevation ecosystems across the region will likely experience the highest stress,[18] with MH and CMA envelopes projected to lose significant area (70% and 44% respectively) by the 2050s. Conversely, the CWH climate envelope is projected to lose little current area and to expand inland and upslope. Projections for some areas of the coast are uncertain as no existing ecosystems along western North America match the projected envelopes.[19] Current work is projecting BEC climate envelopes into the US and north coast (southeast Alaska) to increase understanding of potential future ecosystem distribution in BC's south.

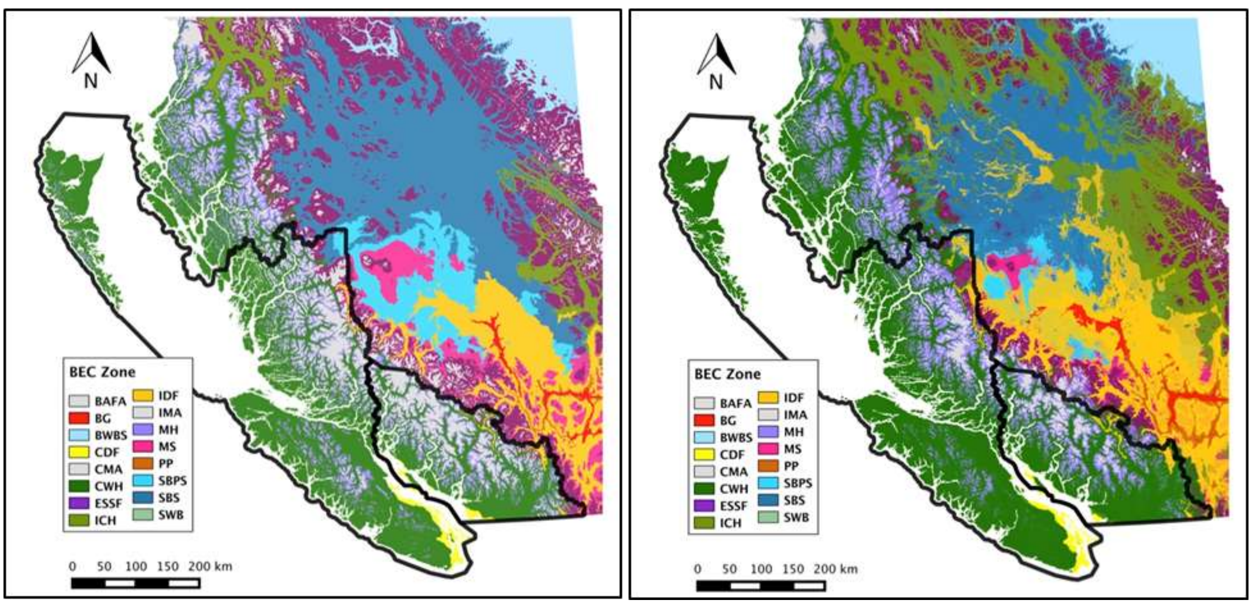

Figure 2. Current BEC zone locations (based on BEC8) and projected future (2041-2070) BEC zone locations. Future map shows consensus of multiple projections. Maps retrieved from ClimateBC.

At a smaller scale, the wettest and driest ecosystems may experience regime shifts. For example, arbutus and western redcedar may decline on southeast Vancouver Island. Changes in climate increase the importance of understanding site conditions and how ecosystem process and function are related to these conditions.

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.[20] Changes in **mean climatic conditions** support range expansion of forest pests that are currently limited by climate. So far, coastal ecosystems have not seen the massive shifts experienced in interior and northern regions where pines and aspens have experienced die-back.

Changes in **extreme weather events** lead to increased abiotic and biotic disturbances. Particularly important on the coast, more severe winter storms will influence flooding, landslides and windthrow. Although the coast is less likely to experience severe heat waves than other portions of the province, periods of relative drought in summer projected for the South Coast, parts of Vancouver Island, and the inland portion of the Bella Coola Valley will influence fire hazard and drought stress.

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

Disturbance	Projected changes
Wind and mechanical damage	• Intense **storm events** may **increase**. • **Windstorms** may **damage** ecosystems along susceptible portions of coast (up to 14% increase in speed of high-wind events projected in spring). Frequency of **catastrophic blowdown** in Northern Vancouver Island, Haida Gwaii, and the central coast may **increase** to approximate the current wind disturbance regime in southeast Alaska. • **Damage** to trees from **ice and snow** may increase with increased storms and increased freeze-thaw events in colder areas.
Fire and drought	• **Fires and drought** may **increase** by the 2080s due to decreased summer precipitation (monthly severity ratings increase by 30 – 60%); the Georgia Basin is predicted to experience the biggest increase in severity.
Hydrogeomorphic (flooding and mass wasting)	• **Increased** winter precipitation may increase the frequency of **slope instability** and mass wasting. Storm-mediated precipitation may increase 40 – 60% in the South Coast. • Maritime watersheds that **shift** from a **hybrid** rain/snow-driven to a **rain-driven** hydrological regime will likely experience the greatest change in flow patterns. • **Increased peak flows** and related sediment delivery may affect aquatic ecosystems and fish habitat as well as damage infrastructure. • **Loss of forest cover** (due to fire or other disturbances) may increase chance of **mass wasting**. • Increased **storm surge** events may affect coastal ecosystems. • **Loss of snow and ice** at high elevation may increase mass wasting from increasing freeze-thaw of exposed rock.
Insects and disease	• **Spruce beetles** may increase as a result of increased adaptive seasonality. • **Swiss needle cast** may increase if seasonal moisture trends continue to change. • Outbreaks of **western hemlock loopers** may increase as a result of the combined effects of more frequent droughts, changes in forest cover, and expanded range of western hemlock.

Hydrology

The Coast regions are expected to follow projected provincial trends in hydrology.[21] Increased winter temperatures and precipitation, and reduced snowfall in spring (i.e., more rain), will likely shift hybrid rain/snow-driven hydrological regimes to rain-driven regimes, changing flow timing, variability and magnitude. Earlier thaws and changed peaks pose hazards to infrastructure.

Glaciers will continue to shrink. Particularly important on the coast, an increase in the frequency and magnitude of storms will likely increase windthrow, flooding and landslides.

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

Cumulative Effects

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

Feature	Projected changes
Hydrological regime	• **Glaciers** will continue to **thaw**. • Less water stored in glaciers and as snow will **shift regimes** from hybrid rain/snow-driven towards **rain-driven** in the central coast and high-elevation sites on the south coast. • **Rain-driven regimes** on the **outer coast** will follow changes in storm frequency and intensity. • **Rain-on-snow events** may increase in some areas and decrease in others. • **Altered timing** of peak and low flows.
Peak flows	• **Spring peak discharge** will **change**; in some areas and years, particularly with shifts to rain-driven regimes, peaks may be earlier and lower; at other times and places, they may be earlier and higher due to increased winter storms. The outcome is difficult to predict. • More frequent and higher magnitude flows could **disturb streambeds and spawning** habitats.
Spring recession	• Changes in hydrological regimes could **reduce** the **spring recession** (a relatively stable period of moderate flow and temperature following the spring peak), affecting the sorting and deposition of sediment and profoundly impacting aquatic habitat.
Low flows[22]	• A **smaller spring snowpack** and earlier spring freshet will reduce summer low flows, increase the low-flow period, and decrease groundwater storage. • **Loss** of **glacial meltwater** over the long term will reduce summer low flows. • **Temperature** may **increase** in some streams and lakes, posing risk to temperature sensitive fish.
Variability	• **Variability** in peak flow frequency and magnitude will likely **increase**, leading to **unstable stream morphology**.

Flood Return Intervals

Small changes in mean climate can cause large changes in flooding frequency and magnitude. For example, current 50-year floods may become 5-year events and future 50-year floods might be what we now consider a 1,000-year flood.[23]

Fish

Climate variability drives fluctuations in salmonid abundance by influencing physical environment, food availability, competition and predation. Response varies by species, population and life stage. Optimal conditions for native salmonids include high precipitation, deep snowpack, cool air and water temperatures, cool coast ocean temperatures, and abundant north-to-south upwelling winds in spring and summer – features that are projected to change. Anticipated impacts will also likely affect other native, non-salmonid species such as sticklebacks, but information is insufficient to predict responses.

Feature	Projected changes
Increased stream water temperature	• Increased incidence and severity of **disease** in some **salmonid** species. • **Changed behaviour** (e.g., movement to higher elevations to remain within suitable thermal envelopes). • In cool areas, **productivity** might **increase**. • **Decreased incubation** and **freshwater residence** time could impact prey availability or result in a thermal mismatch between freshwater and marine environments leading to **decreased survival** of juveniles. • Decreased dissolved oxygen could **decrease carrying capacity** for fish.
Increased lake water temperature	• Warming could **decrease** critical **littoral habitat** and feeding opportunities. • **Salmonid thermal niche** will **change** as cold-water habitat shrinks or shifts into deeper water. • Introduced **warm-water species** (e.g. smallmouth and largemouth bass, yellow perch, common carp) may **increase**.
Low summer flows	• **Cumulative effects** of development and increased summer drought will **exacerbate** naturally **low flows** in many small coho and trout-rearing streams.
Peak flows	• Changed timing of peak flows could lead to a **mismatch** between **hydrological regime** and **migration and spawning**. • Changed timing or magnitude of peak flows could lead to **fewer migrating smolts**, decreased speed of migration or increased predation.
Winter flooding	• Low elevation habitat could experience increased **sediment deposition** thereby **decreasing spawning habitat** and reducing **egg survival**.
Isolated populations	• Changed climate poses **risks** to **isolated peripheral fish** populations (e.g. headwater stocks of cutthroat trout and Dolly Varden) that may have disproportionate conservation value. • **Increased fire** intensity and extent could **impact habitat** and **kill fish**, with potentially high impacts in isolated populations.
Marine changes	• Changes in **sea level**, estuarine hydrological regimes, and **storm surges** might **impact salmonids**.

Biodiversity

Climate shapes species' distributions and ecological communities.[24] Populations faced with a changed environment can die out, move, be displaced by encroaching species, or adapt to the new conditions. Many species that are adapted to projected future climates currently live several hundred kilometres distant from that area; only the fastest dispersers will be able to keep up with the pace of change. Most invasive plants and generalist weedy species are well-adapted for broad movement. For some ecosystems, potentially irreversible regime shifts may follow intense disturbances, particularly if invasive plants colonise and block historical successional paths.

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

Feature	Projected changes
Cumulative effects	• Past human activities have altered, degraded and **fragmented habitat**, making **dispersal** in response to climate-related disturbance more **difficult** for **specialist species**. • Human response to increased disturbance (e.g. extensive **salvage harvest**) can **exacerbate impacts** of climate change. • **Old forest** will **decline** due to disturbance and harvesting, threatening associated species.
Ecological communities	• **Communities** will **reassemble**, often into new combinations, as some established species decline or disappear, new species colonise and interactions change. • Some ecosystems may undergo **regime shifts** (e.g., increased grasslands and decreased forests in Georgia Depression). • Capacity for **Garry oak and other meadow** ecosystems might **increase**.
Ecological interactions	• Ecological **processes** and **relationships** among species (e.g. predation, pollination, mutualism) may **uncouple** as the timing of events changes and becomes more variable (e.g., if migration depends on day length, but prey abundance depends on temperature).
Invasive species	• **Invasive species** (plants and other organisms) are expected to **increase** as temperatures and disturbance increase. • Some current **indigenous** species may be **less competitive** in new climate and disturbance conditions, facilitating invasive plant population expansion. • Increasing **Garry oak** meadow ecosystems will be vulnerable to **invasive plants**.
Wildlife[25]	• Wildlife and trophic **interactions (e.g., predation**) will be particularly **affected** by changes in **snowpack** and **freeze-thaw** regimes. Impacts vary by species.

Trees

Tree species distributions will shift gradually in response to climate change due to physiological tolerances, natural disturbance, and competition.[26] Many tree species will be unable to migrate quickly enough to follow the climate envelopes to which they are adapted. Uncertainty about climate projections leads to uncertainty about which trees may be best-suited to changing conditions. 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 species in the Coast regions seem physiologically resilient. • In some coastal ecosystems, small changes in mean temperature around the rain-snow threshold have already led to a precipitous **decline in yellow-cedar** following the loss of a protective snow blanket. • **Western redcedar** and **arbutus** may be **lost from drier sites** in southern BC due to water stress.
Productivity	• **Tree growth** will likely **increase** in some areas, particularly in the wet, cool mid coast, due to elevated CO_2 coupled with warmer temperatures. • **Growth potential**, however, **may not be realised** because of **limited nutrients**, because populations are not adapted to changed seasonality and increased **extreme events**, or because **maladaptation** increases susceptibility to insects and disease. Provenances are adapted to even narrower climatic conditions than species. • Projections for the **Sayward Forest** showed **decreased productivity** for most **conifers** on **drought-limited sites** with summer temperatures above 20C, the same or **higher productivity** on **cooler and moist** sites for most conifers, and **improved productivity** for **western white pine**.
Natural disturbance	• **Insects and pathogen** outbreaks could **increase** tree **mortality**, even in healthy rapidly-growing trees. • **Stressed trees** are more **susceptible** to insects and pathogens.
Competition	• **Migrating** tree species may **not** be able to **out-compete established species**. • **Competitive interactions** among trees and other plants may change in unexpected ways leading to **shifts in species dominance**.

Ecological Surprises

Current vulnerability modelling does not include ecological surprises or complex climate-ecological relationships. The decline of yellow-cedar in some regions is a good example of the unpredictability of impacts: yellow-cedars are essentially freezing due to warmer winters as snowpack declines and allows frost to damage roots.[27] 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 Central BC indicate the economic benefits of diversifying managed forests to reduce forest health risks and increase resilience.[28] And, designing and maintaining roads and bridges to a higher standard will likely minimize repair and compensation costs after flood events. Some adaptation strategies are also potential climate change mitigation or carbon storage strategies (e.g., establishing forest 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 with climate change.

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

Uncertainty[29]

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

Managing in the face of uncertainty requires:

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

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

Practice Considerations

Hydrology

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

Potential adaptation strategies	**Supporting policy guidance, information or tools**
Projected ecosystem change: Increased risks of landslides and surface erosion (that affect streams or infrastructure)	
• Avoid locating roads and cutblocks on or above unstable terrain • Design and maintain roads and drainage structures to accommodate increased peak flow and sediment transport in areas likely to become wetter: e.g., improve surface on high hazard roads; seed erodible cut slopes; build adequate ditches; replace selected culverts with bridges; limit road density in erosion-prone areas	• Coastal watershed assessment • Water quality evaluation[31] • Forest road engineering guidebook • Guidelines for managing terrain stability
Projected ecosystem change: Increased peak flows	
• Consider changes in precipitation patterns (especially storm events) when designing Equivalent Clearcut Area (ECA) limits • Anticipate increased natural disturbance and manage harvest to stay within ECA limits ○ Account for increased runoff from burned sites in ECA calculations • Evaluate hydrological implications of salvaging disturbed stands • Assess flood risk and increase design criteria for infrastructure • Limit development on known floodplains	• Coastal watershed assessment • Post disturbance watershed effects[32] • Practice guidelines for flood assessment
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[33]
• Maintain ditches and culverts and deactivate roads to restore natural drainage as soon as possible ○ Important to prevent water warming on sites that feed streams, particularly in temperature sensitive watersheds	• See above

Potential adaptation strategies	Supporting policy guidance, information or tools
• Avoid harvesting sites with high or seasonally fluctuating water tables ○ Important for sites with high water tables that feed streams, particularly in temperature sensitive watersheds	• See above

Fish

Adaptation strategies for hydrology will benefit fish. Other strategies focus on maintaining and increasing the availability of high quality habitat to improve the resilience of fish to climate change.

Potential adaptation strategies	Supporting policy guidance, information or tools
Projected ecosystem change: Isolated populations	

• Minimize cumulative effects and increase conservation priority of isolated populations
• Consider habitat restoration to allow for reintroductions and population expansion to areas of newly suitable habitat
• Maintain fish passage
  ○ Remove anthropogenic barriers to migration
  ○ Assess existing culverts; remediate as necessary
	• Riparian management
	• Stream crossing, fish passage and fish habitat guidance[34]
	• Critical habitat for species at risk[35]

Projected ecosystem change: Changed peak flows, low flows and stream temperature	

• Maintain and/or increase high-quality habitat to improve resilience
• Minimize cumulative effects (e.g. urban and agricultural development, water withdrawals)
  ○ Follow best-management practices to conserve flows for fish
  ○ Retain riparian buffers
• See Hydrology above
	• Riparian areas regulation[36]

Projected ecosystem change: Loss of littoral habitat, shift of coldwater habitat, proliferation of introduced warm water species in lakes	
• Maintain lakeshore riparian zones and functional littoral habitat	• Riparian management

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.[37]

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[38]
  ○ Include riparian areas, wildlife tree patches, and old growth management areas in retention areas
  ○ Include corridors crossing elevation gradients
  ○ Include habitat for specialized species and communities at risk
	• Biodiversity Guidebook

• Limit salvage in retention network (e.g., partial cut or avoid harvest) ○ Particularly important where stands buffer microclimate or provide large structure	• Chief Forester's retention guidance • Post-disturbance biodiversity management[39]
Projected ecosystem change: Loss of suitable microclimate and soil conditions to re-establish historic ecosystems following harvest (e.g., potential regime shift from forest to grassland)	
• Avoid harvesting sensitive sites ○ Particularly important on dry sites • Partially-cut stands (e.g., retain partial overstory shelter), especially on hot dry sites[40]	• Drought risk assessment tool • Enhancing biodiversity through partial cutting
• Retain large downed wood ○ Particularly important on drier sites	• Wildlife trees and coarse woody debris policies • FREP CWD backgrounder • CWD management
• Promote rapid site recovery to appropriate species (e.g., reforest dry sites; retain deciduous trees on moist 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 (e.g., avoid planting non-climatically-suited species and/or facilitate migration)	• See Trees section
• Retain appropriate naturally-occurring and regenerating species (including deciduous trees and shrubs) and plant a diverse species mix	• See Trees section • Climate change stocking standards[41]
• Use stand tending to influence successional pathways	• See Trees section
Projected ecosystem change: Increased spread of invasive plants following disturbance	
• Minimize roads ○ Especially important in currently unroaded areas and susceptible ecosystems • Minimize road use (e.g., use gates, deactivate) • Establish competitive vegetation in ditches, on side slopes and other disturbed soil as soon as possible • Wash equipment to remove seeds and plants prior to moving into new areas • Follow best management practices for invasive plants	• Invasive plant management practices • Invasive species council of BC • Invasive species working group; IAPP Map, E-Flora BC

Potential adaptation strategies	Supporting policy guidance, information or tools
• Minimize site disturbance, especially multiple disturbances ○ Particularly important on susceptible (e.g., riparian or dry) sites • Minimize summer logging on susceptible 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.[42] Growth rate may increase or decrease by species, provenance, site, climate, disturbance and other factors. Adaptation strategies have the potential to shift overall climate-induced impacts on timber supply from negative to positive or neutral.

Potential adaptation strategies	Supporting policy guidance, information or tools
Projected ecosystem change: Changed tree growth potential	
• Plant climatically-suited species and genetic stock • Establish operational trials and monitor plantations to test survival and growth	• Tree species selection tool • FFT assisted species migration guidance • Chief Forester standards for seed use[43] • Climate-based seed transfer interim policy measures • Seed zone maps
• Consider fertilizing sites that have limited nutrients but sufficient moisture	
• Partially cut or thin stands on dry sites to retain shelter and moisture and increase fire resiliency	• Drought risk assessment tool
• Increase stand-scale species diversity	• See below
Projected ecosystem change: Increased disease-related (mostly younger stands) and insect-related (mostly older stands) mortality	
• Plant climatically suited species and genetic stock ○ Especially on sites facing drought and areas shifting to wetter climate	• Forest health and species selection • Regional & TSA forest health strategies • Coastal TSA Forest Health Overview[44]
• 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
• Minimize mechanical damage from wind, snow and ice	• BCTS windthrow manual

Potential adaptation strategies	Supporting policy guidance, information or tools
• Consider shorter rotations ○ Especially for relatively productive sites most susceptible to insect-related disturbance	
• Monitor and control insect population sources (e.g., sanitation harvesting) ○ Focus on stands where benefit of control outweighs cost to non-timber values	• Forest health strategies • Provincial bark beetle management strategy • Chief Forester's retention guidance
• Consider targeting harvesting towards most susceptible stands • Use a greater variety of harvesting systems to create more diversity in regeneration sites and options	• Regional & TSA forest health strategies • Resilient harvesting systems[46]
Projected ecosystem change: Increased fire hazard (all stand ages; dry sites)	
• 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	• Landscape fire management planning
• Assess fire hazard • Increase fire resilience at the stand level by managing surface fine fuels, species composition, density, crown base height, crown bulk density and age-class of forest stands • Reduce post-harvest fine fuels as necessary (e.g., biomass recovery, broadcast burning, pile and burn, mulching, chipping) ○ Choose appropriate season and weather for fuel-reduction	• Landscape fire management planning • Fire management stocking standards[47] • Fire and fuel management guidelines[48]
• Reduce human-caused fires	• Wildfire Management Branch prevention strategy
• Manage fire hazard around communities • Reduce risk to structures in interface areas	• Strategic wildfire prevention initiative[49] • Fuel hazard assessment and abatement • FireSmart program • FireSmart communities

Assisted Migration

When trees are harvested 50-120 years after they are planted, the climate could be 3-5 degrees warmer, exposing the trees to maladaptation and health risks. Moving populations of trees today (assisting migration) from their current location is one potential solution; growth and health are better when seeds are transferred to match the climate in which they evolved. However, trees have complex symbiotic relationships with many ectomychorrizal fungal species in the soil and in some cases these bonds are tightly linked to local nutrient and climate conditions.[50] 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.

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. On the coast, it is suggested that trend monitoring include:

- Climate: temperature, precipitation, snowpack, glacial melt, wind and extreme weather.
- Hydrology: stream flow by watershed, channel stability, forest cover, water temperature, erosion, suspended sediment.
- Disturbance: mass earth movements, insect and disease prevalence by seral stage, soil moisture, fire weather index and wildfire.[51]
- Tree growth: understory vigour, productivity by species (e.g. Douglas-fir on dry sites in southwest forests), nutrient content and turnover in understory leaves, and tree health.
- Biodiversity: regime shifts, seral stage, habitat supply, species health, invasive plant species and distribution shifts.

Some of these data are already collected, but are not analysed regularly. A climate network that covers sub-regional variability with sufficient weather monitoring stations (e.g., the high elevation microclimate station network across the central coast) will be important. In some cases, further modelling and experimental evaluation (e.g. of changes in vegetation in different sites with climate change) will improve predictions and refine strategies.

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 West and South Coast Regions that foster resilient ecosystems and sustain natural resources into the future. This document could be a helpful catalyst in collaborative efforts.

Contact for More Information

1. Regional specialist – Heather Klassen, Research Ecologist, West Coast Region, Heather.A.Klassen@gov.bc.ca (250-751-7114).
2. Provincial specialist – Kathy Hopkins, Technical Advisor, Climate Change, Competitiveness and Innovation Branch, kathy.hopkins@gov.bc.ca (250-387-2112).

February 22, 2016

[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] Christensen et al, The report of the Ecological Society of America committee on the scientific basis for ecosystem management (1996)

[8] 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

[9] BEC zone acronyms: CWH = Coastal Western Hemlock; MH = Mountain Hemlock; CDF = Coastal Douglas-fir

[10] The websites provide definitions and calculation details for indices

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

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

[13] Based on trends for all of BC

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

[15] Miles, Effects of climate change on the frequency of slope instabilities in the Georgia Basin, BC (2001)

[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] Where stress is measured by the dissimilarity between current and projected-future plant communities

[19] Holt and Kehm, Conservation and adaptation in British Columbia: strategic opportunities in a climate changing world (2014)

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

[21] 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

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

[23] 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

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

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

[26] 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 Footnote 24

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

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

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

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

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

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

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

[34] Fish-stream Crossing Guidebook; Fish Passage - Culvert Inspection Procedures; Fish Habitat Rehabilitation Procedures

[35] Critical habitat is defined under the *Species at Risk Act* (SARA) as habitat that is (i) necessary for the survival or recovery of a listed wildlife species, and (ii) identified as the species' critical habitat in a recovery strategy or action plan for the species; see Rosenfeld and Hatfield, Information needs for assessing critical habitat of freshwater fish (2005)

[36] The Riparian Areas Regulation under the *Fish Protection Act* applies to urban areas (not Crown forests), but provides useful guidance for minimizing overall cumulative effects of resource development on water flows

[37] Bunnell and Kremsater, Actions to promote climate resilience in forests of British Columbia (2012)

[38] This adaptation strategy would also assists trees at various scales by, for example, providing migration corridors and conserving ectomycorrhizal fungi

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

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

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

[42] See Footnote 37

[43] Refer to Section 8, Page 15

[44] A revised Coastal TSA Forest Health Overview is anticipated for release in 2015

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

[46] Studies in the Alex Fraser Research Forest indicate the economic viability of using harvest systems to reduce risks and increase resilience; see Dymond et al, Diversifying managed forests to increase resilience (2014)

[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] 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)

[51] Provincial fire research and monitoring needs