Successional Responses to Natural Disturbance, Forest Management, and Climate Change in British Columbia's Forests

Extension Note

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Abstract

Natural and human-induced disturbance such as wildfire, insect and disease outbreak, windthrow, and forest harvesting are important drivers for forest renewal, post-disturbance stand structure, and ecosystem function. Each disturbance or combination of disturbances sets up a forest to proceed down a certain successional pathway in terms of structure and function. Using the context of Ecoprovinces and Ecosystem Types, successional pathways of a variety of ecosystems found in British Columbia are briefly described, and the ways in which forest management practices have affected those pathways are discussed. This Extension Note also describes how projected changes in temperature and precipitation may also affect these natural disturbance drivers. The information contained in this article is based on a larger synthesis report that is available in FORREX Series 28 and is designed to facilitate further conversation around building resistant and resilient forests for the future.

KEYWORDS: successional pathways; climate change; natural disturbance; fire; insects; diseases

Introduction

Natural and human-induced disturbances such as wildfire, insect and disease outbreak, windthrow, and forest harvesting are important drivers in British Columbia for forest renewal, stand structure, and ecosystem function. Each disturbance or combination of disturbances sets up a forest to proceed down a certain successional pathway in terms of structure and function. Changes in temperature and precipitation that are projected to take place as a result of increases in CO_2 emissions will also play a role in influencing the various disturbance agents and in how those agents will direct a forest's future pathway. Because of the complexity of forest dynamics and the uncertainly that climate change brings, it is important for those tasked with managing BC's forests to gain strategic and broad-scale knowledge on how various stand structure attributes within a forest community respond to changes brought about by various natural and man-made disturbances. This knowledge can help to guide the implementation of practices that can reduce the vulnerabilities of these forests and potentially increase their resistance and resilience in the context of changing natural disturbance patterns.

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This Extension Note is one in a series of short working synopsis pieces in this issue of JEM, which is part of larger project funded by Future Forest Ecosystem Scientific Council. These pieces are designed to provide natural resource managers with a brief snapshot of how forest dynamics in various parts of the province have worked in the past and how they have been influenced by human disturbance in the present. They also contemplate what the future may hold as a result of changes to natural disturbance regimes based on projected increases in temperature and precipitation. This Extension Note is based on a larger synthesis entitled "Successional Responses to Natural Disturbance, Forest Management and Climate Change in British Columbia's Forests" (Swift & Ran 2012) that is part of FORREX Series 28. It is hoped that this brief synopsis will enhance the dialogue that is currently taking place around managing for change. This note is also part of the information package that can contribute information to the FORREX Decision Support Framework. These conversations are essential if we are to manage for change and take advantage of opportunities that may arise so that our forests can continue to provide the expected ecological services the public of BC has come to expect.

The following series of notes is presented using the Canadian Committee on Ecological Land Classification (CCELC) framework of "Ecoprovince." This framework was selected so that information presented here could link to the wildfire projection work being conducted by Dr. Phil Burton of the Canadian Forest Service that is also part of this FFESC project. More information on this framework can be found at the BC Ministry of Environment "Ecoregion Classification System" website (n.d.). This Extension Note lists various Ecoprovinces. Within each Ecoprovince one or two specific Ecosystem Types are discussed, including their natural successional pathways, how forest management has influenced those pathways, and generally how climate change is projected to further direct the future of each Ecosystem Type. Much of the information related to projections of ecological shifts as a result of climate change is based on the work conducted by Hamann and Wang (2006). It is important to note that more refined ecosystem-specific climate change projections are available in some local jurisdiction such as the Kamloops, Strathcona, Nadina, and Quesnel Timber Supply Areas (TSAs). This work has primarily been supported by the Provincial Future Forest Ecosystem Initiatives.

The following Ecoprovinces and Ecosystem Types are briefly covered in this document:

Table 1. Ecoprovinces and Ecosystems

Ecoprovince	Ecosystem Type(s)	Ecoprovince	Ecosystem Type(s)
1. Coast and Mountains	Coastal Western Hemlock Coastal Douglas-fir	5. Sub-Boreal Interior	Sub-Boreal Spruce Engelmann Spruce-Subalpine Fir
2. Southern Interior	Interior Douglas-fir Montane Spruce	6. Boreal Plains	Boreal White and Black Spruce
3. Southern Interior Mountains	Interior Cedar-Hemlock Engelmann Spruce-Subalpine Fir	7. Northern Boreal Mountains	Spruce-Willow-Birch
4. Central Interior	Sub-Boreal Pine Spruce	8. Taiga Plains	Boreal White and Black Spruce

Ecoprovince: Coast and Mountains

Ecosystem Types: Coastal Western Hemlock and Coastal Douglas-fir

Natural successional pathway – Coastal Western Hemlock

- Topography and aspect play a role in the type of disturbance; nutrient and moisture regimes play a major role in the successional pathway for stands in this ecosystem,
- Dry to moist ecosystems at lower elevations follow a successional pathway that is dominated by fire disturbance events that have historically occurred approximately every 200 years (Natural Disturbance Type 2). Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) are the primary species that can come in after a large-scale disturbance such as fire.
- Wet and very wet subzones/variants and higher Mountain Hemlock forests follow a successional pathway dominated by gap disturbance dynamics from winds, landslides, debris flows, and avalanches. Gaps are usually filled by understory tree species through advanced regeneration and (or) seed germination of western red cedar (*Thuja plicata*), western hemlock, and amabilis fir (*Abies amabilis*). Often these openings follow a shrub-dominated successional pathway for an extended period especially where established advance regeneration is not found on the site. Grand fir (*Abies grandis*) can be found on drier lower elevation sites.

Natural successional pathway – Coastal Douglas-fir (CDF)

- Historically, wildfire seems to be the principle disturbance in this ecosystem, which has helped to establish and maintain Douglas-fir in the area. Human activity over the past 10,000 years however, has resulted in uncertainty about what the natural successional pathways for this forest type might be. There is also a lack of knowledge related to the natural range of variability for these forests.
- Besides human activities, deer and their browsing have also played a role in how these forests have evolved over time.

Forest management and succession in the Ecoprovince

- The Coastal Douglas-fir forests are under pressure from a variety of sources including forest management. This pressure has also had significant impact on the succession of these forests.
- Forest management itself has had a profound impact on structure, dynamics, and function of ecosystems especially in those wet coastal systems that are driven by small gap dynamic disturbance. This is due to the fact that forest management practices have in the past been inconsistent with this natural disturbance regime.
- Variable Retention was introduced to focus attention on maintaining key ecological features and structures. It provides flexibility to manage the forest with a focus on maintaining and (or) enhancing biodiversity through a range of options including varying amounts and types of retained forest and the creation of small openings and in some cases extended rotations. Concerns have been raised about the maintenance of species diversity in second growth stands to ensure future resiliency. Some research suggests that a greater diversity of species can be found in the younger successional stages, while other research suggests an increase in diversity as the stand ages. The intensity of man-made disturbances will affect recovery of species richness with treatments such as severe burns (where species diversity may remain depressed for a long period of time or become locally extirpated).
- Based on tree species diversity data published by the B.C. Ministry of Forests

(MOFR) in 2008, 31% of forests in this Ecoprovince were considered monocultures before harvest – decreasing to 27% post-harvest (based on free-growing status).

- 7% of CWH and 20% of CDF forests were considered monocultures before harvesting, and 9% to 26% post-harvest. This increase in the proportion of monocultures might be partially attributed to vegetation management practices prior to free-growing status. For example, in moist and wet ecosystems, vegetation competition flourishes after logging, and vegetation control efforts would unintentionally suppress the regeneration of secondary tree species.

Climate change and forest succession in the Ecoprovince

- Climate change impacts on successional responses are expected to be greater in the southern dry ecosystems as compared to the wet to very wet ecosystems.
- The expected changes to southern dry ecosystems (progressively warmer and drier) are an increase in natural disturbance frequency, with drought and insect outbreaks likely to be more significant.
- Mortality of susceptible species such as western red cedar is expected to continue in this forest type but may expand into another niche where its performance may improve (such as in the Mountain Hemlock zone). Western hemlock, with its shallow rooting pattern and presence on coarse soils, may also be impacted if moisture becomes limiting.
- Decreased moisture and increased temperature are projected to result in higher fire frequency and perhaps more severe fires (although this is also subject to changes in weather patterns as well as climate effects). This decrease in moisture may also result in species such as red alder (*Alnus rubra*) spreading upwards, as this species is very sensitive to drought.
- Climate change is also projected to increase the number and intensity of storms thereby increasing windthrow on high-risk sites and landslide disturbance on wet to very wet ecosystems.
- Coastal Douglas-fir ecosystem has the potential to expand its range northwards along the coast and upslope by over 300% between the years of 2071 and 2100, based on bioclimatic envelops (Hamann and Wang 2006).
- Over the longer-term (post 2050), lowland coastal temperate forests could undergo significant losses because some dominant species, such as Douglas-fir and western hemlock, might not receive sufficient chilling to induce cold-hardiness and would then suffer serious damage from recurring frost based. This is based on projections from the Tree and Climate Assessment Tool for modelling ecosystem responses to climate change (Burton and Cumming 1995; Nitschke and Innes 2008). If this mortality happens, Garry Oak ecosystems and other deciduous forests are projected to expand.
- Higher elevation coastal forests would generally benefit from longer growing seasons stimulating higher productivity. More productive species such as western hemlock would seed in from below. This projection leaves the Mountain Hemlock (MH) zone with limited space to move so this ecosystem may be replaced over time. This will put species associated with these high elevation forests at risk due to the discontinuous nature of the current MH zone and its potential disappearance within the next 30 to 50 years.
- There is also an expectation of sea rise with climate change, which could impact roads and road infrastructure at lower elevations.

Key Resources

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Ecoprovince: Southern Interior

Ecosystem Types: Interior Douglas-fir and Montane Spruce

Natural successional pathway – Interior Douglas-fir (IDF)

- Forests in this ecosystem are dominated by Interior Douglas-fir trees of all ages and sizes with Ponderosa Pine (*Pinus ponderosa*) playing a more dominant role on drier sites, hybrid spruce *(Picea engelmannii* X *Picea glauca*) on wetter and cooler sites, and lodgepole pine (*Pinus contorta*) at higher elevations where there has been recent fire.
- All forests in this ecosystem are classified as Natural Disturbance Type 4, with frequent stand maintaining fires (low intensity surface fires) and rare stand-replacing events with a mean return interval of 150 to 250 years. This varied intensity and frequency of wildland fire (the primary mechanism influencing stand structure and succession) across the landscape has resulted in a mosaic of mostly uneven-aged forests.
- Dominant agents for natural disturbance include: wildfire, bark beetles, root rots, and defoliators such as western spruce budworm (*Choristoneura occidentalis*) and Douglas-fir tussock moth (*Orgyia pseudotsugata*). Each agent has a significant effect on stand and landscape dynamics.
- In the drier areas of this ecosystem, frequent fires (every 10 to 20 years at a size of less than 50 ha) have kept the forests at bay by killing most of the young trees. Due to thick bark, old Douglas-fir trees tend to survive, but many young trees growing in the understory do not. Without these regular low intensity surface fires, trees establish in these drier open grassy areas and over time grasslands become overgrown with trees.
- High intensity fires occur, on average, every 150 to 200 years and can burn more than 50 ha. These are stand-destroying fires that kill trees of all ages. Following these types of fires, pine (ponderosa or lodgepole, depending on the elevation) is often the first tree to colonize but replaced with Douglas-fir over time. At higher elevations, lodgepole pine is the typical successional species after these fires.
- Fire intensity and frequency also vary with topography, which influences soil moisture redistribution. This influences the intensity and spread of fire, leading to structurally complex forest landscape composed of multi-aged patches with poorly defined stand boundaries.
- On wetter sites, particularly in the cooler part of the IDF – fires are less frequent and perhaps less intense which enables hybrid spruce to establish and grow along with Douglas-fir.

Natural successional pathway – Montane Spruce (MS)

- Subalpine fir (*Abies lasiocarpa*) and hybrid spruce are the main climax trees species but rarely dominate the landscape because of frequent stand-replacing fires and low ability of these species to regenerate successfully in large openings. They are, however, a major component of the overstory on wet and cooler sites such as riparian areas and on northern aspect slopes.

- This forest type is classified as Natural Disturbance Type 3 – with frequent stand-initiating events at approximately 150-year intervals.
- Lodgepole pine can aggressively colonize burnt areas, often with high density, and maintain dominance in the landscape, displaying even-aged and even-sized canopy structure.
- Subalpine fir and hybrid spruce commonly occur as advance regeneration beneath the canopy of lodgepole pine forests in areas where the ground remains moist enough to support their regeneration.
- In wetter climatic areas and on moisture-receiving sites, mature stands usually contain a mix of lodgepole pine, hybrid spruce, and subalpine fir. Douglas-fir is an important component of many stands in the dry MS, particularly on sites with well drained soils and dry moisture regimes. It can also dominate steep southern slopes.
- Stand-replacing fire and severe Mountain Pine Beetle (MPB) (*Dendroctonus ponderosae*) outbreaks are the two main agents that maintain the forests of lodgepole pine at various successional stages across the landscape.
- Less severe disturbances created by low intensity fires, bark beetles, fungal pathogens, and dwarf mistletoe (*Arceuthobium americanum*) opens the canopy and allows the establishment of shade tolerant spruce and subalpine fir.
- Historically, lodgepole pine, MPB, and fire have formed a relationship to drive forest renewal and succession that favours lodgepole pine. For example, lodgepole pine when old enough and present in adequate numbers provides a primary food source for the beetle. Following an extensive outbreak of the beetles, many dead lodgepole pine then become the source of fuel for wildfire. Because of the serotinous nature of lodgepole pine cones, this species is often the primary species that will regenerate after fire.
- Work by Axelson et al. (2009) found that stand-replacing fires can initiate even-aged seral lodgepole pine stands and that multiple MPB disturbances can also create stands that have variable canopy and cohort structure. These latter structures can contribute to the succession of non-pine species that are shade tolerant (interior spruce, subalpine fir).
- Mixed severity fires can also occur, creating complex structures of uneven-aged lodgepole pine stands with multiple MPB disturbances maintaining this structure and can contribute to the succession of pine and non-pine tree species (e.g., trembling aspen (*Populus tremuloides*).

Forest management and succession in the Ecoprovince

- The historic fire regime of mixed frequency and severity over much of the region is believed to be the prime mechanism for creating and maintaining landscape heterogeneity and stand structural diversity. However, with recent fire suppression management, changes are taking place.
- Without frequent stand-maintaining fires, IDF forests may develop an understory composed of shrubs and a higher density of small diameter trees. Fire suppression can also result in increased levels of insect infestation as higher densities have also been shown to result in low tree vigour that in turn increases the susceptibility of trees to insect outbreaks, particularly bark beetles and defoliators.
- As fire frequency decreases through fire suppression, fire return intervals increase, resulting in the increase in size and structure of the fuel loads. This increase in fuel loads makes these stands more susceptible to catastrophic stand-replacing fires.

- When larger and more intense fires do occur, it favours some species such as lodgepole pine, leading to stands of simplified species composition and structure. It also has the potential to create an unnatural increase in the proportion of over-mature forests on the landscape.
- Clearcut harvesting has also been a significant disturbance in this Ecoprovince. With the increased use of tree planting (in come cases single species planting) and decreased reliance on natural regeneration after logging, there have been some questions raised as to post-harvest stand structure and species composition at multiple scales.
- Selective logging (primarily in the form of diameter-limit cutting) was widely practiced in the IDF resulting in residual stands that are multi-storied, with trees smaller in diameter with less vigour. This makes them prone to disturbance by other biotic agents such as bark beetles, defoliators, and diseases.
- According to BC MOFR (2008) approximately 56% of the IDF and 43% of the MS forests are considered a monoculture before harvesting. The percentage decreases to 29% and 14% respectively in post-harvest forests at free-growing. This decrease may be due to significant amounts of natural regeneration and in-growth after planting.
- The amount of deciduous forest has also increased significantly from 500 ha before harvesting to 12,537 ha at free-growing.

Climate change and forest succession in the Ecoprovince

- A complex series of effects from climate change are projected in this Ecoprovince including increase in the area burned and the frequency of fire; biological thresholds of some local species will be exceeded; reduction in disturbance refugia (areas buffered against climate change); loss of regeneration ability of some current species; influx of new species; the contraction and expansion of ranges (including invasives); changes in ecosystem composition; and decrease in habitat for some fauna.
- There are projections that the Ponderosa Pine (PP) ecosystem will eventually become similar to Bunch Grass (BG) ecosystems of today, and much of the current IDF may become more like the PP zones.
- Other projections suggest an increase in the BG zone and the MS having similar conditions to those of the IDF (and potentially even disappearing).
- Some species like lodgepole pine are projected to lose significant area of suitable habitat where as the ranges of most common hardwoods are largely unaffected.
- Upper elevation species such as subalpine fir and spruce are projected to be gradually replaced by Douglas-fir and western larch (*Larix occidentalis*); however, Douglas-fir forests are projected to remain substantially unchanged, with possible increases of drought-tolerant ponderosa pine.
- Not all species and functions will move into the available spaces created by the changing environment because individual species move and adapt at different rates and scales. Thus, the new assemblage of species and their interaction with their new environment, and the potentially new disturbance agents, may lead to very different paths of succession than those of today.

Key Resources

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Ecoprovince: Southern Interior Mountains

Ecosystem Types: Interior Cedar-Hemlock and Engelmann Spruce-Subalpine Fir

Natural successional pathway – Interior Cedar-Hemlock (ICH)

- This ecosystem is characterized by high tree species diversity and has the most structurally complex stand in BC. However, western red cedar and western hemlock are characteristic climax tree species.
- Other tree species include ponderosa pine, Douglas-fir, western larch, lodgepole pine, hybrid spruce, subalpine fir, western white pine (*Pinus monticola*), trembling aspen, and white birch (*Betula papyrifera*).
- Occurrence and frequency of tree species on any one site is dependent on site and soil conditions, disturbance history, and local climate.
- In wetter parts of the ICH, where wildland fires are rare events, trees grow to great sizes and ages – containing many snags and large accumulations of fallen logs and other woody debris.
- Natural disturbance regimes are as complex as the ecosystem. All dry and marginally moist ICH units are considered Natural Disturbance Type 3 – with infrequent stand-initiating events at approximately 150-year intervals – this leads to landscape mosaic filled with young and old forest patches.
- The moist ICH units are Natural Disturbance Type 2 – with infrequent stand-replacing events occurring at a mean return interval of approximately 200 years; and the wet to very wet ICH units classified as Natural Disturbance Type 1 – with rare and small stand-replacing events occurring with a mean return interval of approximately 250 years. This leads to large tracts of very old trees. However, fire will occur more frequently on south-facing slopes, creating different seral stage distribution on the valley floors, lower toe-slopes, and mid-slopes of valleys.
- In the absence of fires, and in the period between fires, gap dynamics caused by the interaction between root rot and windthrow are key components of forest succession at the stand level. Other important disturbance agents include: bark beetles, defoliators such as western hemlock looper (*Lambdina fiscellaria lugubrosa*), and pathogens such as armilaria root rot (*Armillaria ostoyae*).

Natural successional pathway – Engelmann Spruce-Subalpine Fir (ESSF)

- This Ecosystem Type is one of the most geographically extensive and ecologically diverse in BC.
- All of the dry ESSF ecosystems in this Ecoprovince are classified as Natural Disturbance Type 3 – with infrequent stand-initiating events at approximately 150 year intervals; while the moist subzones are classified as Natural Disturbance Type 2 – with infrequent stand-replacing events occurring as a mean return interval of approximately 200 years. The wet and very wet subzones are classified as Natural Disturbance Type 1 – rare stand-replacing events and a mean disturbance return interval of approximately 250 years.
- Climax species are Engelmann spruce (*Picea engelmannii*) and subalpine fir which tend to grow as closed canopy forests at lower and middle elevations
- The ESSF in this Ecoprovince has higher diversity of tree species, especially at lower elevations with a wetter and milder climate as compared to its northern counterpart (Sub-Boreal Interior Ecoprovince), but lower diversity of tree species as compared to zones below it in elevation. Subalpine parkland, consisting of tree islands interspersed with herb-dominated meadows, can commonly be found growing at elevations above this ecosystem.
- Seral lodgepole pine is common in subzones/variants with a frequent fire history.

- Other tree species such as western hemlock are commonly found in the wet part of this zone with western red cedar and western white pine frequently occurring in warmers parts. Deciduous trees are generally uncommon in the ESSF.
- In the drier ESSF the common occurrence of lodgepole pine reflects the greater frequency of wildland fire compared to wetter parts of the ecosystem.
- After fire, lodgepole pine is often the first tree species to colonize the burnt area. With stand development, Engelmann spruce and subalpine fir dominates the tree regeneration underneath this pine canopy.
- If fire is absent for a sufficiently long period of time, the dominant canopy species will shift to Engelmann spruce and subalpine fir.
- Although fire is a major disturbance agent and occurs relatively frequently in the dry ESSF, the fire-initiated stands are not necessarily even-aged because post disturbance regeneration can take decades to establish due to the relatively harsh climate for tree regeneration.
- Although fire return intervals in wets parts of the ESSF are long, there is evidence that most Engelmann spruce and subalpine fir forests originated from fires. These large fire-origin stands were subsequently transformed to take on a fine-scale pattern of all-aged cohorts, reflecting patchy mortality and regeneration caused by senescence or less severe disturbance such as budworm, bark beetles, or windthrow. These agents create small canopy openings that enable the understory species such as subalpine fir and Engelmann spruce to establish and grow.
- Despite similarities in stand structure and specie composition, age class distributions show large differences, suggesting that a variety of site-specific developmental pathways may exist in this Ecosystem Type.

Forest management and succession in this Ecoprovince

- A typical ICH forest often contains several tree species at the stand level. Sustained wildland suppression may facilitate the shift in tree species composition to late seral species.
- In the event of major insect outbreaks (e.g., MPB), the mortality of one component of the canopy will free up growing space for the residual component.
- Forest harvesting remains the dominant form of human-induced disturbance in both the ICH and the ESSF ecosystems in this Ecoprovince.
- While a variety of silvicultural systems have been employed in attempts to create landscape patterns that mimic the natural disturbance regimes of these ecosystems, clearcut logging followed by tree planting has remained the dominant silviculture system on the managed landscape.
- Based on BC MOFR (2008) data the trends in tree species changes based in the managed landscape include approximately 15% of ICH forests considered a monoculture before harvesting, decreasing to 11% post-harvest at free-growing; approximately 16% of ESSF forests are considered a monoculture before harvesting, increasing to 22% post-harvest at free-growing (a result perhaps of the delay in natural regeneration in this harsh environment); and deciduous species in the ICH increased from 12,205 ha in managed forests compared to 266 ha of pre-harvested forests. The statistics of individual tree species type (i.e., pure and leading) changes in pre- and post-harvested ICH and ESSF forest of this Ecoprovince are shown in Table 2. This information suggests that there are no species diversity shifts at stand and site levels, however further analysis may be required to confirm this.

Table 2. Changes of Tree Species Composition in Pre- and Post-Harvested ICH and ESSF Forests of the Southern Interior Mountain Ecoprovince

BGC/Spp Type	Cw (%)	Fd (%)	Pl (%)	Sx (%)	Lw (%)	Hw (%)	Bl (%)
ICH (pre-harvesting)	18.4	22.6	17.7	20.5	4.6	13.4	1.9
ICH (post-harvesting)	12.1	21.4	18.3	27.3	2.7	5.0	5.9
ESSF (pre-harvesting)	<0.1	1	14.9	66.2	<1	<1	14.0
ESSF (post-harvesting)	<0.1	<1	17.2	37.5	<0.1	<0.1	37.5

Cw= western red cedar; Fd=Douglas-fir; Pl=lodgepole pine, Sx=hybrid spruce; Lw=western larch, Hw=hardwoods, Bl=subalpine fir

Climate change and forest Succession in this Ecoprovince

- Based on projections from ecosystem-based climate envelope studies, the ICH is one of the zones that could potentially expand the most through shifts upward and northward by the median year of 2085. Spatially, much of the landbase that is currently occupied by the wetter ecosystems of the ESSF, Sub Boreal Spruce, and MS could become suitable for ICH. In the meantime, the current ICH ecosystem climate space will remain substantially unchanged.

While the ecosystem-climate space may remain relatively stable, the following dynamics of tree species within ICH forests has projected to change.

- Ponderosa pine, already a component in some dry and warm climate ecosystems of the ICH, may expand significantly to other dry to moist but warm ICH ecosystems. Where local climates are expected to become wetter and cooler, ponderosa pine may only be suited for well-drained and warm slope sites.
- Douglas-fir, one of dominant species currently in dry and moist ICH ecosystems, may expand to wet and very wet ICH ecosystems, at least on well to moderately well drained sites. The performance of Interior Douglas-fir plantations established decades ago in ICHvk (very cold) and ESSFwk (warm-cold) variants shows potential for the assisted migration of Douglas-fir (Ran, S. and Coupé, R., personal field observations, [2011]). Douglas-fir also has the potential to migrate onto a significant portion of the landbase currently occupied by SBS and MS ecosystems.
- Western larch, a species in some ICH ecosystems but with limited geographic distribution, is expected to undergo a large geographic expansion. Initial experience and performance of the species in out-planting trials in the SBS landscape during past decades show the potential for expanding this species although further research is needed in this area.
- Lodgepole pine, a common species of ICH ecosystems and dry to moist ESSF sites is expected to gain new habitat at upper elevations but lose habitat to ponderosa pine at lower elevations and in warm ICH areas. Numerous examples of decades-old lodgepole pine plantations in wet and cool or cold ESSF ecosystems demonstrate the adaptability of this species outside the range of its current climate (Ran, S. and Coupé, R., personal field observations, 2011, although some of the plantations are suffering from diseases such as foliar and stem rust. The overall area change (frequency) of lodgepole pine is projected to remain relatively stable in the ICH.

- Hybrid spruce is projected to continue as a major species in ICH ecosystems, occurring on the wet sites of drier and warm climates and will move upward to gain some habitat lost by Engelmann spruce.
- Deciduous species such as white birch and trembling aspen are expected to be a component in many ICH forests, particularly in lower elevation dry, moist and warm ecosystems. Maintenance of a deciduous component is generally considered significant for managing biodiversity and resilient ecosystems of future forests.

Key Resources

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Ecoprovince: Central Interior

Ecosystem Type: Sub-Boreal Pine Spruce

Natural successional pathway – Sub-Boreal Pine Spruce (SBPS)

- This zone consists of two principle ecosystems – lodgepole pine forests and wetlands.
- Lodgepole pine is the most common tree species and sometimes the only tree species found growing in extensive forest stands of very dry climate on the Chilcotin Plateau – this includes the understory as well.
- Stands of hybrid spruce occur on moist and wet sites but they are usually small and located primarily around the edges of non-forested wetlands and adjacent to streams.
- In wetter part to the north and east, hybrid spruce is occasionally found in the canopy of mature pine stands, as well as in the understory.
- Trembling aspen is a common seral species but localized.
- Douglas-fir, subalpine fir, black spruce (*Picea mariana*), and black cottonwood (*Populus trichocarpa*) occur sporadically on some sites and in some geographically limited areas.
- Because of the poorly developed drainage systems, the landscape contains abundant wetlands, most of which are devoid of trees, and the boundary between wetlands and dry upland forests is often abrupt.
- The dominant disturbance agent in the SBPS is fire of mixed to high severity, even though other agents such as MPB and Spruce Beetle (*Dendroctonus rufipennis*) are also capable of causing mortality at a large scale. In the dry to very dry parts of this ecosystem, such as the Chilcotin Plateau, stand-replacing events are dominated by a mixed severity fire regime, i.e., many frequent, small- to medium-sized fires punctuated by extremely large fires every 40 to 100 years. Fire is less frequent in the wetter areas where fire intervals range from 91 to 170 years.

- Lodgepole pine is highly susceptible to wildland fire, but after fire, new pine seedlings establish quickly. As a result, few stands in these forests are more than 120 years old, and most consist of dense pine trees, all of a similar age. The natural thinning process in densely regenerated stands can take a long period of time, and some of the extremely dense stands remain stagnant for extensive periods of time.
- MPB has long been an integral part of this forest type with endemic populations existing and small outbreaks occurring. Cold winters that killed most of the over-wintering larvae, and pine trees that are sufficiently vigorous to resist the beetle attack, have for the most part kept outbreaks in check. When winters are warmer and pine trees older and less vigorous, the number of beetles can reach epidemic proportions such as what has recently occurred.

Forest management and succession in this Ecoprovince

- The dominant silviculture system in this Ecosystem Type is even-aged management using clearcut logging with a variety of cutblock sizes. More recently, this has changed to MPB salvage logging using clearcutting.
- After harvesting, natural regeneration with or without site preparation has been the principal regeneration strategy.
- These naturally regenerated stands are often unevenly stocked, with dense patches and small stocking voids – pre-commercial thinning and fill planting are often required in order for the stands to reach full stocking and free-growing status.
- For purposes of greater stocking distribution control and shorter regeneration delay, tree planting has increasingly been the principle method of regeneration.
- Partial harvesting systems such as single-tree selection have only been used in stands where Douglas-fir is a prominent component with reforestation resulting from the release of advanced regeneration and ingress by natural Douglas-fir.
- In lodgepole pine stands, canopy openings created by harvesting, insects, pathogens, and wind, are generally restocked by sufficient natural regeneration without site preparation, particularly in larger openings that are over 0.01 ha.
- The decrease in natural regeneration rate for higher elevation pine stands indicates that some form of site preparation may be required on wetter sites due to undesirable conditions of the seedbed.
- Even-aged, single species monoculture is the dominant forest type, with more species found under wetter climates (MOFR 2008). Before harvest, 76% of stands are considered a monoculture with the percentage decreasing to 56% after harvesting at free-growing. This decrease in the managed landscape may indicate the significant amount of natural regeneration of secondary tree species that is occurring, particularly in wetter parts of the SBPS. There has also been an increase in planting of Douglas-fir and hybrid spruce in wetter parts of the managed landscape in recent years, however, lodgepole pine is still the principle tree species type in both pre-harvested (90.5%) and post-harvested (84.4%) stands at free-growing.
- There is also a significant increase in deciduous species (notably trembling aspen) after harvesting, with less than 1% in pre-harvested stands and over 5% in managed stands post-harvest. Other tree species such as Douglas-fir and hybrid spruce remained virtually unchanged in proportions, i.e., 5% for Douglas-fir and 3% for hybrid spruce (MOFR 2008).

Climate change and forest succession in this Ecoprovince

- SBPS ecosystems under a changing climate projection show the potential for a large decrease in lodgepole pine and increased frequency of Douglas-fir.

- By the end of the century, projections suggest that the SBPS ecosystem as presently defined could disappear almost entirely and be replaced largely by a more IDF-like ecosystem.
- Some wetter climate SBPS ecosystems near the east and northern boundary of the present range may be replaced by an ICH-like ecosystem.
- Projected changes in annual and summer precipitation are greatest in the central Chilcotin Plateau and in a north-south band east of the Fraser River.
- Winter precipitation is projected to increase over most of the region, especially in the north-west and north-central areas.
- The MPB outbreak has significantly affected this ecosystem, however with or without management intervention (which includes large scale salvage), lodgepole pine will be able to grow back over much of its previous area through natural or artificial means of regeneration. Managing the post-MPB landscape is a serious challenge and the species or species mix selected for planting post-salvage will determine the succession pathways of future forests. In all cases, lodgepole pine will remain an important component of future ecosystems either through tree planting or natural regeneration.

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Ecoprovince: Sub-Boreal Interior

Ecosystem Types: Sub-Boreal Spruce and Engelmann Spruce-Subalpine Fir

Natural successional pathway – Sub-Boreal Spruce (SBS)

- The climax species in this ecosystem are hybrid spruce and subalpine fir, which often dominate the coniferous forests on the landscape, particularly in wet sites and (or) the wetter subzones.
- Black spruce occasionally occupies cold air sites with moist to wet soil moisture regimes.
- In drier parts of the zone, lodgepole pine is a dominant species with hybrid spruce and subalpine fir in the under story. Douglas-fir also occurs on well drained, dry, and warm sites and is mixed with other species on most circamesic sites in the southern portion of the Ecoprovince.
- All the dry and moist subzones are classified as Natural Disturbance Type 3 with frequent stand-replacement events with a mean return interval of approximately 150 years. All the wet and very wet subzones are classified as Natural Disturbance Type 2 with infrequent stand-replacing events with a mean interval of approximately 200 years.
- Many natural forests in this zone are of complex structure and mixed ages. In fire-originated stands, an even-aged overstory of lodgepole pine often has a multi-aged understory due to delayed regeneration of hybrid spruce and subalpine fir.

- In wetter landscapes where fire is less common, insect and disease attacks are often species- and age-specific, leading to open multi-aged stands. Deciduous tree species such as trembling aspen and white birch are common components of pioneer stands on dry to moist upland sites after wildland fire and dominate in areas of land clearing and prescribed fire.
- As forest stands succeed from early to late successional stages, vascular plant diversity is found to decrease whereas canopy structure becomes more complex as gap dynamics develop. Although the SBS forests contain few tree species, successional changes are pronounced, with structure changing more than composition in the course of succession.
- The progress of forest succession is often triggered by lightening caused fires. In most situations lodgepole pine re-seeds and dominates an area directly after fire. If the fire is too severe, deciduous trees can re-establish through root or stump sprouting or from seeds that disperse to the site within a year or two after the fire. These deciduous trees may dominate the ecosystem for a long time, but are eventually replaced by conifers.
- In some cases mature forest remnants are left by wildland fire in sub-boreal landscapes and some of these remnants have an uneven-aged, episodic pattern of lodgepole pine regeneration.
- Patch mortality can also be caused by insect and pathogens and the associated gap dynamics can generate a fundamentally different successional pathway than that of the stand-replacing fires. The gap dynamics generally favour a succession dominated by late seral species, usually shade-tolerant species growing in the understory (such as subalpine fir), whereas fire removes this component and favours the re-establishment of early seral, shade-intolerant species.
- The widespread and high-severity of MPB can also cause lodgepole pine mortality over a large area, such as during the recent MPB epidemic. This can put natural succession on a variety of different pathways including regenerating back to lodgepole pine (if dead stands burn), or a succession dominated by advanced regeneration by late seral species (usually more shade-tolerant species such as hybrid spruce and subalpine fir).
- As a result of the various disturbance processes, the SBS landscape typically is heterogeneous (a mosaic of forests) with variable patch sizes, species composition, and age class distributions.

Natural successional pathway – Engelmann Spruce-Subalpine fir (ESSF)

- Engelmann spruce and subalpine fir are the climax species in this ecosystem, with lodgepole pine frequently occurring or dominating in drier parts.
- Compared to the more southern Ecoprovince, the ESSF of the Sub-Boreal Interior Ecoprovince typically has fewer tree species, even though other structural attributes are as complex as those found in the southern ESSF.
- The common occurrence of lodgepole pine in the dry ESSF reflects the greater frequency of wildland fires compared to wetter areas. All moist ESSF ecosystems are classified as Natural Disturbance Type 2 with infrequent stand-replacing events with a mean return interval of approximately 200 years, while all wet ecosystems are classified as Natural Disturbance Type 1 with rare stand-replacing events and a mean disturbance return interval of approximately 250 years.
- Underneath the lodgepole pine canopy, Engelmann spruce and subalpine fir dominate the tree regeneration. In the absence of fire for a sufficiently long period of time, canopy dominance shifts to Engelmann spruce and subalpine fir.
- In wet ESSF forests where large, stand-replacing disturbances are infrequent or rare, small-scale disturbances associated with the mortality and replace-

ment of individual trees are a primary source of heterogeneity in forest composition and structure.

- Due to the rare stand-replacing events and long life cycles, particularly for Engelmann spruce, the majority of the ESSF landscape is dominated by old forests.

Forest management and succession in this Ecoprovince

- Forest harvesting and salvage logging of MPB-attacked forests and fire suppression are important management regimes that potentially affect the successional pathways of future forest ecosystems of the SBS landscape.
- MPB is currently the dominant agent driving disturbance on the moist to dry portions of this Ecoprovince resulting in high overstory mortality.
- In response to this overstory mortality, widespread salvage logging and large fires now account for most of the disturbance.
- In wetter hybrid spruce and subalpine fir stands, the dominant disturbance remains clearcut harvesting. Artificial regeneration using tree planting is the common method of restocking these sites.
- At the landscape level, the BC MOFR (2008) reported tree species composition and diversity in pre- and post-harvested forests in the SBS and ESSF for this Ecoprovince. For example, in the SBS, monoculture forests have increased from 27% pre-harvesting to 32% post-harvest at free-growing; in the ESSF, monoculture forests have increased from 14% pre-harvesting to 27% post-harvest at free-growing; and deciduous types (pure and leading) have increased from 0.3% per-harvesting in the SBS to 7.3% post-harvest at free-growing. A similar rate was also reported in ESSF ecosystems.
- The details of the specific trends by species are displayed in Table 3.

Table 3. Changes in Species in Pre- and Post-Harvested Forests of SBS and ESSF

BGC/Spp type	SBS			ESSF		
	Pl (%)	Sx (%)	Bl (%)	Pl (%)	Se (%)	Bl (%)
Pre-harvesting	46.9	48.1	2.0	21.9	55.3	16.2
Post-harvesting	47.1	39.3	3.9	26.6	47.9	20.3

Pl=lodgepole pine; Sx=hybrid spruce; Bl=subalpine fir; Se=Engelmann spruce

- The massive MPB outbreak in the pine forest of the SBS landscape poses a serious challenge for forest management. This pine forest type constitutes approximately 47% of all species in the SBS and the majority of these pine forests has been killed by this insect.

Management responses to the infected forests and follow-up actions have major implications on the successional pathways of future forests such as:

- Forest stands can develop into a mixed-species forest if there is abundant advanced regeneration of spruce, fir, and other tree species, or if post-logging silviculture establishes seedlings of diverse species and origin (late-seral succession);
- Forest stands can re-establish to new pine forests through forest fire or logging, followed by the establishment of lodgepole pine from scattered cones or planted trees as well as trembling aspen (early seral succession);

- Forest regeneration can be indefinitely deferred or inhibited by shrub growth in situations where there is little or no advance regeneration, and where no fire, harvesting or silviculture has occurred (Burton 2010).

Climate change and forest succession in this Ecoprovince

- Future warming is predicted to be greater in northern BC than in the south and more pronounced in the winter than in the summer, particularly when looking at daily minimum temperatures.
- Ecosystem-based climate envelope studies have projected the potential for a 69% loss of the SBS ecosystem climate space by the 2050s and 85% by the 2080s.
- Much of the moist and wet SBS areas may evolve into ecosystems that are ICH-like, while the drier SBS ecosystems may become suitable for IDF-like ecosystems.
- At the species level, hybrid spruce and subalpine fir are expected to continue as important species on the landscape, with Douglas-fir projected to eventually dominate the landscape. This projection is in part due to the lower frequency of early frosts, the reduced severity of growing season frosts, and a significant increase in the length of its growing season.
- Although there are uncertainties associated with species distribution modelling, the trend of a warming climate is consistent and many species such as Douglas-fir, and to a lesser extent western red cedar and western hemlock, are already a component of the SBS ecosystems in certain limited geographic areas. The risk of the assisted adaptation of these species onto the managed SBS landscape seems low and the opportunities in the post-MPB landscape is high.
- For the ESSF, projections suggest a significant retreat under the changing climate – while Engelmann spruce and subalpine fir are expected to continue to dominate the landscape. Other lower-elevation species such as lodgepole pine, western red cedar, western hemlock, and deciduous species will increase in importance in their upward migration, particularly on disturbed sites.

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Ecoprovince: Boreal Plains

Ecosystem Types: Boreal White and Black Spruce

Natural successional pathway – Boreal White and Black Spruce (BWBS)

- Due to the combination of fire history and extensive cultural disturbance in the form of land clearing and prescribed fire, trembling aspen dominates about half of the forests, and balsam poplar (*Populus balsamifera*) is common on lower slopes along stream and river courses.
- White spruce (*Picea glauca*) dominates moister sites where there has been limited disturbance history with lodgepole pine present as a seral species on drier and poorer sites.
- Black spruce forests, often with a minor component of tamarack (*Larix laricina*), are common on organic soils. Black spruce also occurs mixed with lodgepole pine on upland sites with cold soils or limited rooting depth.

- Tamarack occurs to a limited extent as pure stands on very wet, rich sites and occurs rarely on some upland sites.
- Muskeg is a common ecosystem throughout the landscape, with the most common trees in this Ecosystem Type being stunted black spruce and tamarack. This ecosystem usually occurs over poorly drained, deep layers of peat.
- Other minor but important ecosystems include boreal grassland and scrub communities occupying steep, south-facing slopes, and small but productive marsh and shallow lake ecosystems.
- Fire is the key stand-replacing disturbance along with flooding which occurs on broad fluvial terraces adjacent to large rivers.
- The disturbance rate from fire is generally estimated to be about 1% of the total forested area per year (i.e., a fire cycle of 100 years), but will vary from area to area depending on climatic and topographic factors.
- Historically, large wildland fires (>1000 ha) dominated the landscape and upland sites were regenerated quickly by dense trembling aspen, mixed trembling aspen and spruce, or lodgepole pine, resulting in large patches of relatively even-aged forests.
- On wetlands, black spruce, tamarack, Alaska paper birch (*Betula neoalaskana*), and occasionally white spruce regenerate after fire.
- In small areas where past fires were intense, stand may regenerate to willow or alder.
- Almost all regeneration occurs within a few years of disturbance. However, as white spruce and black spruce increase in size they become more obvious in many stands originally dominated by trembling aspen or lodgepole pine. This shift occurs more rapidly and these species become more dominant in the canopy on wetter sites.
- Post-fire stands on upland sites are often initially very dense and self-thin over time.

Forest management and succession in this Ecoprovince

- In the absence of fire, the natural stand dynamics of boreal mixedwood forests are characterized by a gradual shift from broadleaf-dominated to conifer-dominated.
- As a result, unmanaged stands 0- to 80-years old vary in composition from "pure" broadleaf to "pure" conifer, and the presence of conifer-dominated stands on the landscape increases with age.
- Conventional forest practices promote either a deciduous or coniferous component after harvesting even where the original stand was considered mixed.
- Current management practices fail to recognize the dynamic nature of boreal mixedwoods succession and species composition and the concept that forest type proportions change over time. This is in part due to the rapid early growth rates of aspen compared to slower initial growth of white spruce, which make it difficult to balance growing space requirements when both species are regenerated at the same time.
- The amount of white spruce natural regeneration after harvest has, in general, been irregular in its distribution and highly variable in its densities. The proportion of white spruce natural regeneration after harvest has been shown to be similar to its presence in mature aspen-dominated stands, but its distribution is more irregular after harvest.
- Stands that have previously been mixedwood have often become dominated by deciduous post-harvest due to root suckering being promoted by full sunlight exposure and soil warming.

- Mixedwood forest promotions appear to have increased in managed stands at the free-growing stage compared to pre-harvest forests – mixedwood forests account for 54% in pre-harvested stands, which increases to 85% post-harvest free-growing. This may be in part due to the definition of "mixedwoods" that is used and the assumptions that are made for the collection of this information for reporting purposes. According to local experts, the area of "mixedwood" stands being harvested (depending on the definition) has been far less than the "pure" end of the spectrum over the past 25 years (R. Kabzems, personal communication, December 2011).
- To successfully regenerate the white spruce component of the mixedwood stand, temporal separation of the two species has been the most common approach, using practices such as retaining white spruce advance regeneration or under-planting aspen stands with white spruce. Having the presence of aspen in the overstory serves to ameliorate frost and winter injury problems and suppresses understory vegetation that may compete with white spruce and can further reduce the attack by white pine weevil (*Pissodes strobi*).

Climate change and forest succession in this Ecoprovince

- Ecosystem-based climate change envelope studies suggests that much of the warmer BWBS that occurs within this Ecoprovince could become climate space for IDF-like ecosystems by 2050 and ponderosa pine ecosystems by the median year of 2085, although growing season frost may be a major factor preventing the establishment and survival of Douglas-fir.
- Fire frequency and severity are expected to increase (possibly double) in annual area burned as a result of warming combined with decreased summer precipitation. This is expected to result in a greater proportion of grassland and younger forests on the landscape.
- Climate change is projected to dramatically alter the structure and composition dynamics of the boreal forest, however, the mixedwood tree species such as trembling aspen and white spruce are expected to continue as prominent components of future forests.

Key Resources

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Ecoprovince: Northern Boreal Mountains

Ecosystem Type: Spruce-Willow-Birch Zone

Natural successional pathway – Spruce-Willow-Birch (SWB)

- Lower elevations of the SWB (except cold air-prevailing valley bottoms) are generally forested with white spruce and trembling aspen.
- At higher elevations, shrub and parkland dominate the landscape with deciduous shrubs such as scrub birch and willow.
- Seral stands of lodgepole pine are relatively uncommon, indicating that fire disturbance intervals are less frequent compared to adjacent low elevation ecosystems.
- The disturbance regime in this forest type is Natural Disturbance Type 2 with a mean return interval of approximately 200 years for stand-replacing events.
- Due to extensive cold air drainage and cold temperatures, stands are often sparsely treed.
- Older forests have short, large-diameter white spruce with variable amounts of subalpine fir.
- Black spruce is common on upland sites, often with lodgepole pine on cooler aspect slopes and in wetlands.
- Balsam poplar occurs along streams and rivers and is often associated with white spruce.

Forest management and succession in this Ecoprovince

- Very few forestry and agriculture activities occur in the SWB landscape.
- Habitat management uses extensive prescribed burning in many valleys, which have created large seral trembling aspen forests and many grassy slopes.
- In the absence of repeated stand-replacing events, these aspen forests will gradually shift to mixedwood and eventually be replaced by spruce-leading forest types.

Climate change and forest succession in this Ecoprovince

- Climate impact models suggest that the SWB ecosystem climate space will decrease by 69% by 2025 and by 93% by 2055, shifting to a climate similar to the current ESSF (Hamann and Wang 2006).
- Although many of the existing tree species such as white spruce, subalpine fir, lodgepole pine, and trembling aspen will remain on the landscape under the changed climate, the structure and density of the forests will undergo significant change – becoming denser and multi-storied with significantly better productivity under increased temperatures and longer growing season.
- Projected increased frequency and severity of natural fires will play an important role in realizing this ecosystem climate space change.

Key Resources

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Ecoprovince: Taiga Plains

Ecosystem Type: Boreal White and Black Spruce

Natural successional pathway – Boreal White and Black Spruce (BWBS)

- Aspen and white Spruce mixedwood forests dominate the better-drained sites, with black spruce forests dominating the extensive poorly drained sites along with a mix of tamarack on the slightly richer sites.
- Black spruce also occurs mixed with lodgepole pine on poorer upland sites and on steeper cool aspects where permafrost is present.
- Lodgepole pine is relatively common especially on drier sites in combination with black spruce or on very well-drained sites with coarse soils.
- Fire is one of the key stand-replacing disturbance agents along with flooding which occurs along broad fluvial terraces adjacent to large rivers.
- The disturbance rate from fire is generally estimated to be about 1% of the total forested area per year (i.e., a fire cycle of 100 years), but will vary from area to area depending on climatic and topographic factors.
- Historically, large wildland fires (>1000 ha) dominated the landscape and upland sites were regenerated quickly by dense trembling aspen, mixed trembling aspen and spruce, or lodgepole pine, resulting in large patches of relatively even-aged forests.
- On wetlands, black spruce, tamarack, Alaska paper birch, and occasionally white spruce regenerate after fire.
- In small areas where past fires were intense, stand may regenerate to willow or alder.
- Almost all regeneration occurs within a few years of disturbance. However as white spruce and black spruce increase in size they become more obvious in many stands originally dominated by trembling aspen or lodgepole pine. This shift occurs more rapidly and these species become more dominant in the canopy on wetter sites.
- Post-fire stands on upland sites are often initially very dense and self-thin over time.
- Tomentosus root disease (*Inonotus tomentosus*) is thought to be a key disturbance agent affecting white spruce and in some localized areas, and may cause conversion from spruce-dominated stands to aspen-dominated over the course of 20 to 40 years.
- Eastern spruce budworm (*Choristoneura fumiferana*) may also cause significant mortality of mature to immature spruce, especially on floodplain forests, and may lead to conversion of mixed stands to almost pure aspen stands.

Forest management and succession in this Ecoprovince

- The dynamics of trembling aspen-white spruce stands in this Ecoprovince are distinguished by the large size of individual trees, longevity, and the low occurrence of internal decay in trembling aspen.
- After disturbance, there appear to be two patterns of species establishment.
- In co-dominant stands, recruitment periods for trembling aspen and white spruce overlap, with white spruce being recruited over a 29- to 58- year lag behind the aspen, thus indicating a dominant recruitment episode rather than continuous recruitment.
- The white spruce in co-dominant stands do not appear to go through a period of suppression and then release associated with stand-level trembling aspen mortality, which is commonly described in other boreal mixedwoods.

- See Kabzems and Garcia (2004) for description of longer time period mixed-wood succession in this Ecoprovince.

Climate change and forest Succession in this Ecoprovince

- Predicted changes to ecosystems of the BWBS is simi1lar to Boreal Plains Ecoprovince, but will take longer to occur due to the colder climate of this Ecoprovince which is influenced by cold and dense arctic air.
- By the median year of 2055 (2040 to 2070), the BWBS ecosystem is projected to remain similar to its present state, although disturbances such as wildfire are expected to be more frequent and intense due to increased temperature and decreased precipitation.
- By the median year of 2085, projections suggest that the ecosystem climate space may be similar to the current IDF and Ponderosa Pine climates (Hamann & Wang 2006).

Key Resources

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How well can you recall the main messages in the preceding article?
Test your knowledge by answering the following questions.

Successional Responses to Natural Disturbance, Forest Management and Climate Change in British Columbia's Forests

1. What are two (2) important natural disturbance drivers in British Columbia's forests?
   a) Windthrow and fire
   b) Insects and diseases
   c) Hurricanes and tornadoes

2. What ecosystem in the BC interior is projected to remain relatively stable under Hamann and Wang's climate change scenarios?
   a) Interior Douglas-fir
   b) Interior Cedar Hemlock
   c) Sub-Boreal Spruce
   d) Sub-Boreal Pine Spruce

3. What coastal ecosystem has been placed under the most pressure by human-inducted disturbance?
   a) Mountain Hemlock
   b) Coastal Western Hemlock
   c) Coastal Douglas-fir
   d) None of the above

ANSWERS: 1=a & b; 2=b; 3=c.