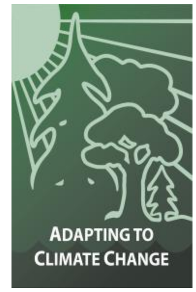
Natural Disturbance



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Introduction

Disturbance and succession shape the composition and structure of vegetation within stands and across a landscape, influencing ecosystem structure, function, resilience and ecosystem services (Daniels and Gray 2006, Chapin 2009). Vegetation, in turn, influences the probability of disturbance, creating a feedback loop. Ongoing disturbance creates a “shifting mosaic” of vegetation patches. Thus, where disturbance and succession processes remain relatively constant, landscapes can be characterized by the typical range of types and sizes of vegetation patches they contain (White and Pickett 1985). Viewed over an appropriately long time scale, disturbance is part of ecosystem dynamics.

“Disturbances” are temporally discrete events that alter ecological communities and populations and change resource availability or the physical environment (White and Pickett 1985, Daniels and Gray 2006). “Disturbance regimes” characterize the temporal and spatial pattern of disturbance on a given landscape over time (White and Pickett 1985). The frequency, size and severity of disturbance varies with disturbance agent and with ecosystem (Figure 1). Gap-forming and stand-initiating processes bound the continuum of disturbance size and severity.

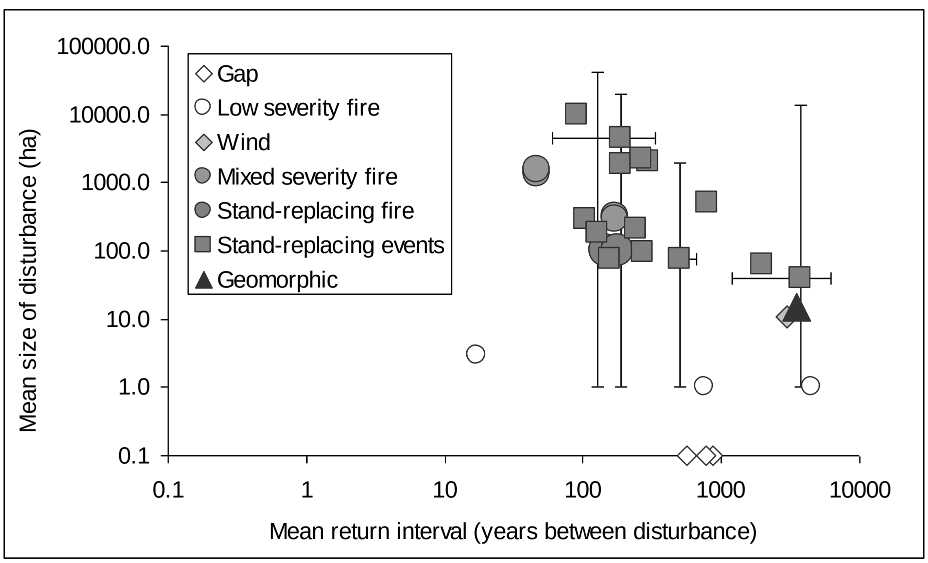

Figure 1. Disturbance size versus return interval for different types of disturbance in BC. Darker shading shows relatively more severe disturbance. Error bars show range of variation for selected examples. Data from Table 2 of Wong et al. 2004.

The frequency of stand-initiating disturbance and the rate of forest renewal determine the age-class structure of vegetation across the landscape and the time available for gap-replacement processes to create complex structure within stands. Based on the negative exponential model of a constant disturbance rate with randomly located disturbance events, an average of thirty-seven percent of a natural landscape will be older than the disturbance return interval (i.e., years between successive disturbances; Daniels and Gray 2006).

Disturbance frequency in BC varies by biogeoclimatic subzone (Figure 2). Differences in climate among subzones influence both the prevalence of disturbance agents (Table 1) and the distribution of susceptible vegetation. Dry ecosystems have the highest rates of stand-initiating disturbance; coastal areas have very low rates (Price and Daust 2004, Daniels and Gray 2006); moist ecosystems are intermediate. In wet coastal areas, gap replacement dominates disturbance with a mean return interval of about 800 years (Table 2 of Wong et al. 2004). In the IDF and PP, low-severity, stand-maintaining fires (i.e., many Douglas-fir and ponderosa pine trees survive) dominate disturbance, with a mean return interval of about 18 years (Table 2 of Wong et al. 2004). The Appendix provides additional information on disturbance agents.

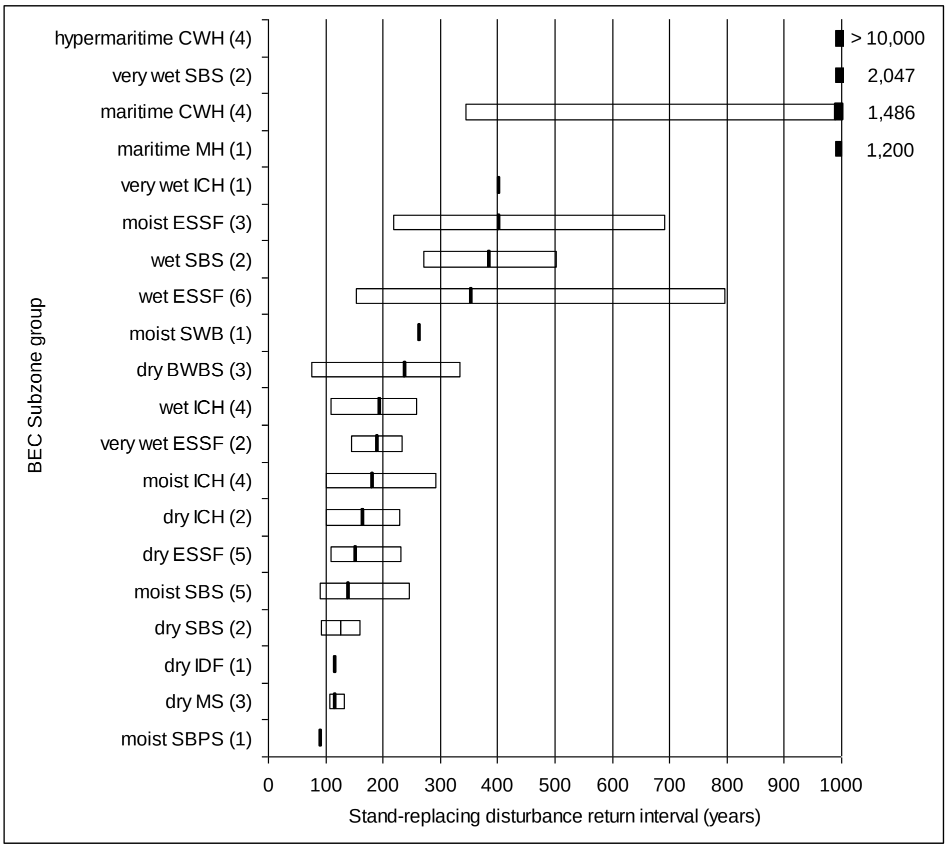

Figure 2. Average and range of mean or median return interval (i.e., years between stand-initiating disturbance) for different subzone groups (number of studies per group shown in brackets); averages greater than 1,000 shown on right. Data includes "stand-replacing events", "large episodic events", "fire", "stand-replacing fire", "wind" and "geomorphic" disturbances reported in Table 2 of Wong et al. 2004. Where disturbance changed over time, the most recent time period was chosen.

Disturbance "severity" refers to the level of impact to vegetation or the environment (Daniels and Gray 2006). Severe disturbances (e.g., intense fires) affect overstory trees, understory vegetation, soil and the forest floor and favour fire-adapted pioneer species like pine (Keeley and Zedler 1998). Less severe disturbances (e.g., mountain pine beetle) leave the understory and often a substantial overstory intact (Burton 2008), favouring shade-tolerant species such as interior spruce (*Picea engelmannii x glauca*) and subalpine fir (*Abies lasiocarpa*). Gap-replacement processes are often disease-mediated (Wong et al. 2004) and may or may not expose soil (e.g., by windthrow). Regeneration in gaps reflects nearby seed sources and the suitability of the substrate (Lepage et al. 2000).

Table 1. Summary of disturbance agents by BEC zone, based on agents described in text of Wong et al. 2004. Shaded boxes indicate dominant disturbance agents, when documented. Two Xs indicate disturbance is often stand replacing in zone. This table identifies examples of well-studied disturbance agents; it is not a thorough review.

Agent	CDF	CWH	MH	ICH	BG	PP	IDF	SBPS	MS	SBS[A]	ESSF	BWBS	SWB	AT
Abiotic														
Wind		XX	X	X				X		X	XX	X		X
Snow/ice											X	X		X
Frost														X
Avalanche											XX			X
Geomorphic		XX												
Flooding		XX								X				
Low severity fire					X	X								X
Mixed or high severity fire[B]	XX	XX	XX	XX			XX	XX	XX	XX	XX	XX	XX	
Drought					X	X								
Biotic														
Vertebrates											X			X
Bark beetles[C]				X		X	XX	XX	XX	XX	X	X		
Insect defoliators[D]				X		X	XX	X		X	X	X		X
Stem and needle disease						X		X			X	X		X
Root rot			X	X		X	X	X			X	X		
Stem rot		X	X								X			
Mistletoe		X				X		X						

[A]In the SBS, flooding, two-year cycle budworm, western hemlock looper and forest tent caterpillars can cause low to moderate severity disturbance.
[B]Also includes fires of unspecified intensity that were unlikely to be low severity.
[C]Includes mountain pine beetle, spruce beetle, western balsam bark beetle and Douglas-fir beetle.
[D]Includes western spruce budworm, eastern spruce budworm, two-year cycle budworm, western black-headed budworm, western hemlock looper, western false hemlock looper, forest tent caterpillars and Douglas-fir tussock moth.

Stand-initiating disturbances, even severe ones, leave legacies of standing live and dead trees and downed wood (Figure 3) that serve a variety of ecological roles (Lindenmayer et al. 2008, Rosenvald and Lohmus 2008).

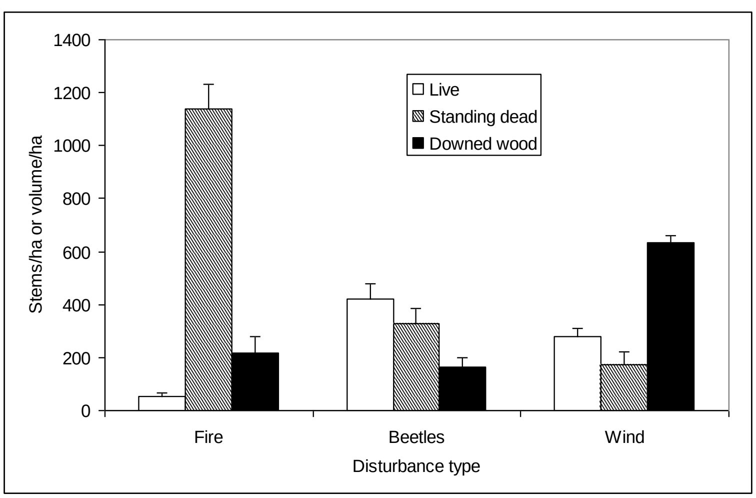

Figure 3. Number of standing live and dead trees and volume of downed wood remaining within the first decade after disturbance by fire, beetles and wind (bars are standard error) in SBS and ESSF ecosystems. Based on Lloyd et al. 2007.

Projected changes in natural disturbance before 2100

Changes in disturbance regimes reflect changes in climate means and extremes. For example, changes in mean climatic conditions support range expansion of forest pests that are currently limited by climate (Woods et al. 2010). Globally, abiotic disturbances are expected to increase with projected increases in extreme weather events. It is likely that rain storms will increase and very likely that heat waves will increase; there is medium confidence that drought will increase (IPCC 2012). Rain and wind storms influence flooding, landslides and windthrow; heat waves and drought influence fire hazard and drought stress (making trees more susceptible to insects and disease); fewer cold snaps in winter facilitate outbreaks of mountain pine beetle and other insects.

Seemingly small increases in mean values of climate variables (e.g., mean rainfall per rain event), can substantially increase the probability of an extreme event (e.g., increasing the mean by one standard deviation can lead to a 10 to 100 fold increase in extremes; Wigley 2009). Also, changes in underlying climate mechanisms may increase the variability around the mean (Hansen et al. 2012).

Below we provide an overview of projected trends in disturbance, based primarily on reviews addressing one or more disturbance agents (Haughian et al. 2012, Sturrock et al. 2012, Woods et al. 2010, Pojar 2010, Kliejunas et al. 2009, Pike et al. 2008, Geertsema et al. 2006, Williams et al. 2000). Please read these reports for additional detail.

Most types of disturbance are expected to increase in BC, including insects and disease, fire, drought, wind, mass movement and flooding (discussed in specific sections below). Disturbance agents vary in their importance regionally and projected increases in disturbance vary across BC (Table 2). Disturbance may decrease for some species in some regions.

Table 2. Projected changes in factors influencing disturbance risk in different regions (Ecoprovinces) of BC before the end of the century. Grey shading highlights the largest changes. Climate data taken from Plan2Adapt, Sept 12, 2012. Disturbance risk data are based on Figure 1, 2 and 3 in Haughian et al. 2012. See the latter for details.

Ecoprovince	Fire[A]	Wind[B]	SB[C]	MPB[D,E]	Summer Precip.[F]
Georgia Basin	↑↑↑	↑↑↑	↑↑	↓	-17%
Coast Mountains	↑↑	↑↑↑	↑↑↑	--	-20%
Northern Boreal Mountains	--	↑↑↑	↑↑	↑↑↑	+3%
Sub Boreal Interior	--	↑	↑↑↑	↑	+1%
Central Interior	↑	--	↑↑	↑	-5%
Southern Interior	↑↑↑	↓	↑↑	--	-11%
Southern Interior Mountains	↑↑	--	↑↑	--	-7%
Boreal Plains	--	--	↑↑↑↑	↓↓	0%
Taiga Plains	--	--	↑↑↑↑	↓↓↓	+1%

[A] Change in seasonal mean severity rating, relative to historic baseline; each arrow represents one point of severity.
[B] Change in mean speed of high-wind events (top ten percent of wind events) for season with the highest change; each arrow represents approximately 5%.
[C] Spruce beetle: change in generation time (each arrow is ~ 10% change in adaptive seasonality; Haughian et al. 2012).
[D] Mountain pine beetle: change in generation time (as above).
[E] Despite decreasing adaptive seasonality in the Taiga and Boreal Plains, damage from mountain pine beetles may increase because outbreaks have been constrained by cold survival and cold survival is expected to improve substantially (10 to 15%) in Northern Boreal Mountains, Sub-boreal Interior, Boreal Plains and Taiga Plains Ecoprovinces.
[F] Summer precipitation influences drought risk; precipitation projections have low certainty; based on ensemble projections from Plan2Adapt: http://pacificclimate.org/tools-and-data/plan2adapt.

Insects and disease

Insects and diseases adapt quickly and could respond to climate change faster than their long-lived hosts (Spittlehouse 2008, Altizer et al. 2003, Kliejunas et al. 2009). Pest species are expected to expand, contract and shift their ranges; the number and variety of forest pests is expected to increase and pest outbreaks are expected to be more common (Pojar 2010 and references therein; Williams et al. 2000). New pests may emerge. Species that have not caused damage in the past could be released from climatic controls and become pests (Williams et al. 2000, Kliejunas et al. 2009). Exotic invasive species tend to come from warmer climates and will be favoured by climate change (Woods et al. 2010). Similarly, dwarf mistletoes appear to be limited by temperature and could expand their range as the climate warms (Kliejunas et al. 2009). The extent of damage to forests may be greatest when pests first expand their range into large tracts of susceptible host species—where ecosystems have not co-evolved with immigrant disturbance agents (e.g., Carroll et al. 2006).

The warmer, drier climate projected for parts of BC favours increased fecundity, growth and survival of many insect pest species, although these projections do not adequately account for the full complexity of ecological interactions (Haughian et al. 2012 and references therein). However, projected increases in tree growth rates over longer growing seasons may increase a tree's defensive capacity.

The severity and extent of bark beetle outbreaks are expected to increase (Haughian et al. 2012 and references therein) with climate change. For example, most of BC is expected to become climatically favourable for mountain pine beetle over the next 50 to 100 years, reducing the chance of overwinter mortality due to extreme cold and increasing the likelihood that a generation can be completed in one year instead of two (Haughian et al. 2012 and references therein). Other bark beetle species are expected to show similar trends. Large outbreaks of mountain pine beetle and spruce beetle have already occurred in BC and Yukon respectively. Southern, historically-optimal portions of the mountain-pine beetle range may become less suitable due to hot summers (Carroll et al. 2006).

While projections have not been made for many species, other insects could also expand in importance (Haughian et al. 2012 and references therein). Outbreaks of western spruce budworm could increase due to warmer surface temperatures. White pine terminal weevil could expand its range to include all areas of BC that currently contain the white spruce host species. Tent caterpillars, in conjunction with drought, could defoliate aspen-dominated forests in central and northeastern BC, promoting conversion to grassland. Of particular ecological importance, willows (*Salix spp.*) will continue to decline as the introduced willow stem borer (*Cryptorhynchus lapathi*) spreads northward and upward in elevation and intensifies its attacks (Pojar 2010). Ecological consequences are unknown, but willows play key ecological roles in the functioning of wetlands, shrublands, riparian habitats and other ecosystems.

In general, forest pathogens are expected to show increased frequency and duration of infection as the climate warms (Woods et al. 2010, Sturrock et al. 2012, Kliejunas et al. 2009). The effect of moisture varies by species of pathogen. Some root rots, blights and rusts are expected to cause more damage where climatic conditions become warmer and wetter; where conditions become drier, damage from these organisms may decrease or remain the same. Other pathogens that are primarily opportunistic, relying on poor host vigour, may expand in areas where trees face increased drought stress (Sturrock et al. 2011, Kliejunas et al. 2009). Currently information is inadequate to quantify the effect of pathogens (Kliejunas et al. 2009).

Even-aged lodgepole pine plantations are especially vulnerable to a wide range of foliar diseases and stem rusts that are expected to expand over the coming decades (Woods et al. 2010; Sturrock et al. 2011). Increased prevalence of pine needle blight (*Dothestroma septosporum*) has already been linked to climate change (Woods et al. 2005). In response to increased warmth and spring precipitation, this blight could expand into much of BC's northern interior and shift to include mature pine hosts.

White-pine blister rust, an introduced species, has killed a high proportion of western white pine and whitebark pine in North America (Sturrock et al. 2011). It requires cool, wet conditions for spore dispersal so its importance may decrease in the Southern Interior and increase in northwestern BC (Haughian et al. 2012). Ecological consequences are potentially significant because whitebark pine is a keystone species that facilitates the spread of forest vegetation into alpine ecosystems and provides an important food source for several species, including Clark's nutcracker and grizzly bear (Tomback and Resler 2007).

Fire

Climate change affects the probability of fires starting and spreading (see cautions regarding attributing ignition to climate change in Woolford et al. 2010). Lightening ignitions are expected to increase due to a warmer moister atmosphere (Price and Rind 1994; AFTAU 2012). The length of the fire season is expected to increase from 30 to 52 days across BC; fire season is already starting earlier (Haughian et al. 2012 and references therein). Seasonal drought indices and hence fire risk is projected to increase (Table 2; see Haughian et al. 2012 for details). The correlation between area burned and drought indices varies with forest type (Haughian et al. 2012).

Projected changes in fire regime vary by region. Southern and Central BC are expected to become warmer and drier and hence to experience more frequent, severe and extensive fires, leading to more area burned (Spittlehouse 2008, Hawkes 2005). The Southern Interior is expected to experience the most significant increases in fire-related weather indices: by 2070 in the North Okanagan, a warming of 4 °C could increase fire frequency by 30% (due to a longer fire season), increase mean fire size by a factor of 2.4 (to 19,000 ha) and increase fire severity by 30 to 95% (Nitschke and Innes 2008).

Northwestern BC is expected to become wetter and could experience decreased fire frequency (Spittlehouse 2008).

Northeastern BC could experience minor to substantial increases in fire. Area burned is projected to increase by 200 to 300% in the Boreal Plains ecozone and 50 to 100% in the Taiga Plains, but projections for the Boreal Plains are relatively uncertain (Flannigan et al. 2005, Haughian et al. 2012). Other climate models and analyses have shown much more modest increases (0-25%) for the Boreal Plains or substantial increases (5-fold) for the boreal forest of western Canada and Alaska (Haughian et al. 2012 and references therein).

Forest management practices influence fire risk at stand and landscape scales and thus have the potential to mitigate or exacerbate climate-induced changes in fire regimes (Lindenmayer et al. 2009). Effects of logging vary by forest type (i.e., particularly moist versus dry forests) and management must be tailored to the specific ecological context and disturbance regime (Lindenmayer et al. 2009, Noss et al. 2006), however available guidance for managers is weak—further research is needed.

Drought

The frequency and duration of summer drought events are expected to increase over much of southern BC (Haughian et al. 2012). Drought can lead to shifts in tree species composition, shifts of forested ecosystems to parkland, and shifts from parkland and savannah to scrub or grassland (Haughian et al. 2012, Holt et al. 2012).

Wind

In general, climate warming is expected to increase the intensity of atmospheric convection processes, leading to an increased frequency of intense windstorms (Pojar 2011, Haughian et al 2012; Lambert and Fyfe 2006).

The average speed of intense wind events (i.e., top 10% of wind events), those with potential to damage forests, is expected to increase by up to 14% in coastal BC and in the Northern Boreal mountains (Table 2). Moderate increases in wind speed are expected in the Sub-Boreal Interior and Southern Interior Mountains. Earlier thawing of soils in northern forests may increase their susceptibility to wind damage (Haughian et al. 2012).

Areas already prone to wind damage may be most vulnerable to future wind events because storm tracks are projected to remain relatively stable (Haughian et al. 2012; Lambert and Fyfe 2006) and because enduring features—topography and soil—have a large influence on susceptibility to wind damage (Mitchell 1998, Zielke et al. 2010). Areas of Coastal BC, including northern Vancouver Island, Haida Gwaii and the central and northern mainland coast are most exposed to big winds. The frequency of catastrophic blowdown in these areas could increase substantially to approximate the current wind disturbance regime of southeast Alaska, with return intervals of less than 300 years (Pojar 2010). In particular, Haida Gwaii, the North Coast and the Alaska Panhandle may experience the greatest increase in intense storm events (Haughian et al 2012 and references therein).

Mass movement

Increased precipitation is expected to compromise slope stability and increase the frequency of landslides (Haughian et al. 2012 and references therein). A relatively small increase in precipitation may generate a large increase in landslides. For example, projections for the Georgia Basin suggest that a 10% increase in precipitation by the 2080s could lead to a 165% increase in landslides. Northwestern BC and coastal areas are expected to experience substantial increases in precipitation (Rodenhuis et al. 2009): annual precipitation is projected to increase 6 to 26% in parts of northern coastal BC; storm-mediated precipitation is projected to increase 40 to 60% on the southern coast and 100 to 150% in the Northern Caribou Mountains (Haughian et al. 2012 based on Salathe 2006).

Other aspects of climate change also influence mass movement. Melting permafrost will result in more frequent earth slumps and landslides in northern BC (Pojar 2010, Haughian et al. 2012). Changes in the rate and timing of snowmelt could also saturate soils and trigger mass movements. Melting of glacial buttresses will increase the incidence of rock slides in high alpine areas (Geertsema et al. 2006). Decreased water can also have an effect. In the Southern Interior, an increased incidence of droughts and forest fires is expected to reduce the erosion-protecting and water-transpiring cover of hillslopes and lead to more mass movement (Pierce et al. 2004)

Susceptibility to mass movement is largely determined by topography and soils, thus areas already vulnerable to mass movements are likely to face increased hazard while most of the province will remain at “low risk” or “no risk” (Haughian et al. 2012).

Flooding

Warming may lead to earlier spring and summer peak flows and increase winter flood risk in many parts of BC, although changes in flows and flood risk will vary substantially among watersheds (Haughian et al. 2012). A projected increase in the frequency and magnitude of storm events will lead to an increased frequency and magnitude of storm-driven peak flows in watersheds with rain-dominated hydrological regimes (Pike et al. 2008). Some watersheds in coastal BC that typically receive both rain and snow in winter (hybrid regimes) will become more susceptible to flooding from rain on snow events if deep snowpacks decline and lose their capacity to buffer rainfall (Pike et al. 2008).

Invasive plants

Several lines of reasoning suggest invasive species will be favoured by climate change (Dukes et al. 2009, Vila et al. 2007, Simberloff 2000). Invasive plant species are generalists, adapted to exploiting disturbed sites: they are able to tolerate a wide range of environments and climates; they can disperse rapidly; they can evolve rapidly. Invasive species from warmer regions are better adapted to survive and grow in future climates than native species. Invasive species may benefit more than native species from increased $C0^2$ (Vila et al. 2007). Any change in historical disturbance regimes creates opportunities for invasive species (Hobbs and Huenneke 1992).

Ecological relevance of changes in natural disturbance

Disturbance influences vegetation and vegetation influences disturbance (Chapin 2009, Whelan 1995). Decoupling disturbance regimes from historic vegetation patterns can challenge ecosystem resilience. Vegetation may be poorly adapted (e.g., highly susceptible and/or unable to recover) to new disturbance agents. For example, large tracts of pine and spruce contributed to beetle outbreaks in BC and Yukon (Raffa et al. 2008). Similarly, dense forests are susceptible to large, high-severity fires as the local climate dries (Utzig and Holt, 2012). Ecological recovery after fire may be poor, due to a shortage of fire-adapted species. Management decisions (i.e., fire suppression) contributed to creating the landscapes with reduced resilience to climate change (Raffa et al. 2008). Limiting climate change and promoting ecological heterogeneity are two of the best options for maintaining historic ecosystem function (Raffa et al. 2008).

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Appendix A: Overview of disturbance agents in BC

A diversity of biotic and abiotic agents is responsible for disturbance in BC. While most agents occur across the province, their importance in a region is controlled by climate, topography, substrate (parent material) and susceptible vegetation (Runkle 1985, Whelan 1995, Wong et al. 2004). For example, fires burn more area in relatively dry, warm regions (Wong et al. 2004); mountain pine beetle outbreaks are limited by cold winters (Safranyik 1978); fungal diseases use damp conditions to spread (Williams et al. 2000; Woods et al. 2010); fire spreads more easily uphill (Whelan 1995); landslides occur on steep slopes or in fine-textured soils (Geertsema et al. 2006). Insects and disease are limited by the distribution of susceptible host species, as influenced by climate, topography and parent material (Banner et al. 1993). Vegetation adapts to cope with different disturbance agents. For example, aspen stands are less flammable than conifer stands (Fechner et al. 1976). Short, spike-topped cedars with small canopies avoid windthrow (Lanquaye 2003). Subalpine fir sheds snow and ice (Smith and Brewer 1994).

Fire is one of the main disturbance agents responsible for patterns shown in Figure 2 (above). From 1950 to 2000, fires have ignited most frequently in the IDF, ICH, SBS, ESSF and CWH zones (Hawkes 2005). People are a major source of ignition, along with lightening. The probability of fires larger than 20 ha is low in the Georgia Basin, Coast Mountains and Northern Boreal Mountains relative to other Ecoprovinces (Taylor et al. 2005).

Insects of concern in BC include bark beetles, weevils and moths (Haughian et al. 2012; Abbott et al. 2008). Insects and disease can kill more tree volume than fire in some regions: between 1982 and 1987, insects and disease killed approximately 3 times as much volume as did fire in Canada (Volney and Fleming 2000).

Forest pathogens responsible for disease in trees include bacteria, viruses, fungi, parasitic plants and other organisms (Sturrock et al. 2011). In BC, pathogens of significance include several root-rot fungi, foliar diseases, stem rusts and dwarf mistletoe (Woods et al. 2010).

Wind that exceeds 100km/hr is responsible for most windthrow (Peterson 2000), although wind exceeding 62 km/hr can also cause windthrow (Zielke et al. 2010). Windstorms are more frequent on the coast than in the interior and are responsible for a greater proportion of disturbance (Pojar 2010, Franklin et al. 1987). Wind, associated with pathogens, is the primary disturbance agent responsible for gap dynamics in coastal BC (i.e., CWH). Stand-initiating windthrow is relatively rare (Wong et al. 2004). Wind is also an influential disturbance agent in the MH, ICH, BWBS and ESSF (Wong et al. 2004).

Hydro-geomorphic processes (including mass movement and floods) cause most stand-initiating disturbance in parts of the Coastal Western Hemlock zone (Wong et al. 2004). These disturbances are confined to specific locations and small areas and thus rates of geomorphic disturbance across a landscape are low. On the central coast in the CWHvm, geomorphic processes disturbed 0.02% of the area annually (5000 yr return interval) and disturbed much less in the CWHvh (Wong et al. 2004; Pearson 2003).

Human activity influences disturbance regimes. In the past, poor road-building practices increased the frequency of debris flows in harvested terrain by approximately nine times in Clayoquot Valley and 15 times on Haida Gwaii, relative to the natural rate (Wong et al. 2004 and references therein). Similarly, fire control has altered vegetation patterns, predisposing central BC to a large mountain pine beetle outbreak (Taylor and Carroll 2004) and predisposing forests in many regions to large, intense fires (Whelan 1995). Pine-biased reforestation facilitated spread of Dothistroma needle blight in west-central BC (Woods et al. 2005).