

# Forested Ecosystems

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Karen Price and Dave Daust



## Introduction

Climate shapes disturbance regimes, species distributions and ecological communities. As climate change continues in BC, temperatures will increase, patterns of precipitation will change, seasons will shift, and climatic variation—including the likelihood of extreme events such as storms and droughts—will increase (Chapter 2a). With warmer temperatures, the intensity and frequency of disturbances, particularly those due to fire, insects and pathogens, will increase, and interactions among different disturbance types may become more common (Chapter 2c). With these changes, some species within existing communities will become maladapted to local conditions (Johnson et al. 2010) as emerging climatic and disturbance conditions exceed environmental tolerances and change competitive advantages.

Species faced with a changed environment can die out, move, or adapt to the new conditions (Pojar 2010). Most species, especially those with long inter-generational periods (e.g. trees) and poor dispersers, will not be able to migrate quickly enough to keep pace with suitable climatic conditions (Aitken et al. 2008, McLachlan et al. 2005). Species can adapt by taking advantage of existing phenotypic plasticity or by evolving, however, most species will not be able to evolve quickly enough to cope with climate change (Parmesan 2006). The species most capable of movement and with the highest level of plasticity will be generalist, “weedy” species that have evolved to colonise disturbed sites. These weedy species are least likely to be extirpated and most likely to move into newly-disturbed areas.

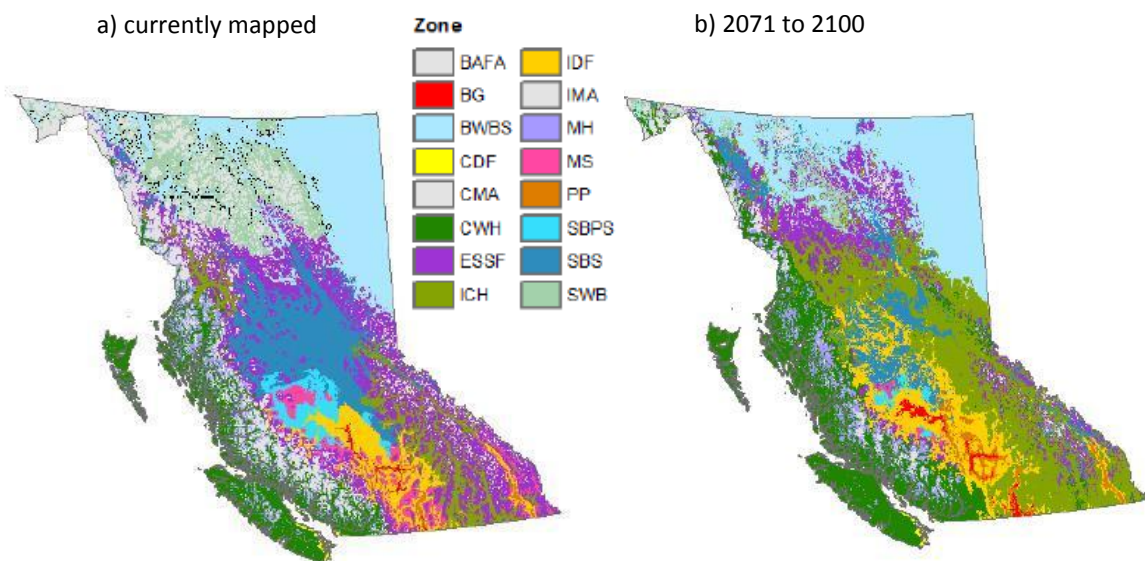
Communities will reassemble, often into novel combinations, as established species decline or disappear, new species colonise and interactions among species change (Pojar 2010). Species complexes can decouple because interdependent species may differ in sensitivity to change or in use of climatic cues that govern interaction (e.g. caribou rely on day-length to time calving while their forage plants respond to temperature; Post and Forchhammer 2008). With reassembly, ecosystem function and resilience may change (Hooper et al. 2012, Reich et al 2012, Peterson et al. 1998). Some ecosystems may remain relatively intact, with species moving in parallel upslope; others may change gently, retaining essentially the same functional capacity, for example with different dominant conifer species but a similar disturbance regime. But some ecosystems will undergo “regime shifts” to new disturbance regimes, successional pathways and dominant species (Folke et al. 2004). Regime shifts can occur slowly, for example as woody vegetation encroaches on sub-boreal grassland, or quickly following a disturbance event. Sudden changes in ecosystem type (e.g. from forest to grassland following fire) represent the greatest risk to current ecosystem function and ecosystem services (Chapin 2009, Biggs et al. 2009, Scheffer et al. 2009, Carpenter 2003). Potentially irreversible catastrophic regime shifts are associated with intense disturbances, particularly when invasive species colonise after disturbance and block historical successional pathways (Chapin 2009, Folke et al. 2004). Even without a regime shift, loss of biodiversity will adversely impact ecosystem function and certain ecosystem services (Cardinale et al. 2012).

Several reports detail current knowledge of potential impacts to BC’s ecosystems as climate change unfolds (e.g., Pojar 2010, Gayton 2008, Wilson and Hebda 2008, Hamann and Wang 2006, Wang et al. 2012). The following section summarises portions of these materials, looking at lines of evidence for ecological change based on climate envelopes.

## Predicted Ecosystem Changes

### Trends for BC

Climate modeling predicts the geographic location of “climate envelopes” or “ecosystem niches” that are associated with particular ecosystems (Hebda 1997, Hamann and Wang 2006, Wang et al. 2012). All projections indicate a high potential for a substantial shift in the distribution of ecosystem niches over the next century; some suggest that almost a quarter of BC has *already shifted* to climates suitable for a different ecosystem (comparing 1970s to 2001 – 2009; Wang et al. 2012). By the end of the century, the shift in ecosystem niches is projected to affect all but small areas of the province (Figure 1). The projected combination of warming, changed hydrology, decreased snowpack, and increased disturbance intensity and frequency means that all present-day ecosystems “will undergo ecological upheaval and some will unravel” (Pojar 2010, p 25).



**Figure 1. Geographic distributions of climate envelopes associated with BEC zones for currently mapped (a) and predicted for 2080s (b), based on consensus predictions with the best-model agreement among 20 selected climate change scenarios (Wang et al. 2012). See Table 1 for zone names.**

At a provincial scale, the level of loss of currently-suitable climate provides a first approximation of the relative impact to ecosystems. Wang et al. (2012) predict that alpine and subalpine ecosystems (MS, BAFA, IMA) and sub-boreal spruce ecosystems (SBPS, SWB, SBS) will lose suitable climate from over 80% of their current range, while rainforest and the low-elevation boreal ecosystems may lose little area (Table 1).

**Table 1. Predicted decrease in the area of each mapped Biogeoclimatic zone over time. Shading shows 20% loss classes. Modified from Table 5 Wang et al. 2012.**

BEC*	BEC	Area	Loss of climate habitat (% of current)		
			2020s	2050s	2080s
Zone Name	Acronym	(x 1,000ha)			
Montane Spruce	MS	2,800	64	90	96
Sub-boreal Pine Spruce	SBPS	2,300	67	86	93
Spruce Willow Birch	SWB	8,000	36	71	88
Boreal Altai Fescue Alpine	BAFA	7,600	48	66	81
Interior Mountain-heather Alpine	IMA	1,200	54	76	81
Sub-boreal Spruce	SBS	10,300	19	52	80
Engelmann Spruce Subalpine Fir	ESSF	17,200	34	59	74
Mountain Hemlock	MH	3,600	33	70	74
Coastal Mountain-heather Alpine	CMA	4,400	29	44	60
Bunchgrass	BG	300	38	43	49
Ponderosa Pine	PP	400	25	37	41
Interior Douglas-fir	IDF	4,500	13	22	39
Coastal Douglas-fir	CDF	200	15	19	22
Boreal White and Black Spruce	BWBS	15,700	3	7	10
Interior Cedar Hemlock	ICH	5,600	7	6	10
Coastal Western Hemlock	CWH	10,800	2	0	2

\*Biogeoclimatic Ecosystem Classification

Climate envelope models also predict that some ecosystem niches will expand (Table 2). The climate envelopes for dry ecosystems (BG, PP, IDF) as well as the diverse moist conifer forests of the ICH are projected to more than double, with the ICH ecosystem niches becoming the most common climate type in 2080 (Wang et al. 2012). These analyses suggest that coastal ecosystems and the BWBS of northeastern BC are the least vulnerable, although analyses that include non-BC ecosystems predict shifts in the BWBS to climates suitable to ecosystems currently in southern Alberta or the central US (Mbogga et al. 2010, Rehfeldt et al. 2012).

**Table 2. Predicted change in the area of each Biogeoclimatic zone over time (current range - % lost as per Table 1 + % gained from outside the current range). Shading shows change classes (more than 60% loss; 59 to 20% loss; 20% loss to 20% gain; 20 to 100% gain; over 100% gain). Modified from Wang et al. 2012.**

BEC	Area	Change in climate habitat (% loss or gain)		
		2020s	2050s	2080s
Zone	(x 1,000ha)			
MS	2,800	-44	-75	-88
SBPS	2,300	-45	-71	-85
BAFA	7,600	-47	-64	-81
IMA	1,200	-52	-74	-81
CMA	4,400	-16	-26	-45
SBS	10,300	11	-15	-44
SWB	8,000	-13	-49	-44
ESSF	17,200	-19	-21	-33
MH	3,600	-4	-7	-12
BWBS	15,700	13	12	11
CDF	200	-1	-3	19
CWH	10,800	22	40	69
IDF	4,500	42	78	91
BG	300	19	71	128
PP	400	61	115	211
ICH	5,600	76	200	325

In summary, the future climate is predicted to be similar to that experienced during the early Holocene warm/dry interval (10,000 – 7,000 years BP), when grasslands were much more widespread, with more weedy, drought-tolerant and alkali-tolerant species (Wilson and Hebda 2008). Models predict that the climate favouring the grassland, shrubland and dry forest ecosystem types common to southern BC will move north and upslope, that climates suitable for moist forests will move upslope to replace subalpine forests, and that climates suitable for boreal spruce forests and alpine ecosystems will decrease substantially (Wilson and Hebda 2008, Table 2).

While loss of climatically-suitable habitat (Table 1) can indicate potential loss or alteration of existing ecosystems, expansion of climatically suitable habitat (Table 2) cannot predict potential expansion of familiar ecosystems—because ecosystems do not move, species do (Wilson and Hebda 2008, p 23). Instead, the communities of species that make up ecosystems will reassemble. Ecosystem recovery (assuming climate stabilisation) will depend on migration of climate-adapted species. Increased migration time may result in dominance by generalist weedy species, lower diversity and lower resilience (Chapin III et al. 2000, Dukes et al. 2009, Fischer et al. 2006). Many ecosystems will likely simplify into transient ecosystems of undetermined composition with character mediated by disturbance events (Wilson and Hebda 2008).

If ecosystems change to follow the climate, regime shifts are likely as grassland and shrub-steppe replace currently forested ecosystems, perhaps as far north as Quesnel (Hamann and Wang 2006, Wilson and Hebda 2008). Although grasslands are projected to expand, these ecosystems will likely not reassemble into historical ecosystems as early seral, weedy, invasive species that spread in response to disturbance, changing conditions and human activity colonise before native species have a chance to migrate (Malcolm et al. 2005, Gayton 2004). Low elevation ecosystems in southern BC already host a variety of non-native weedy species (Harding et al. 1994, Gayton 2004).

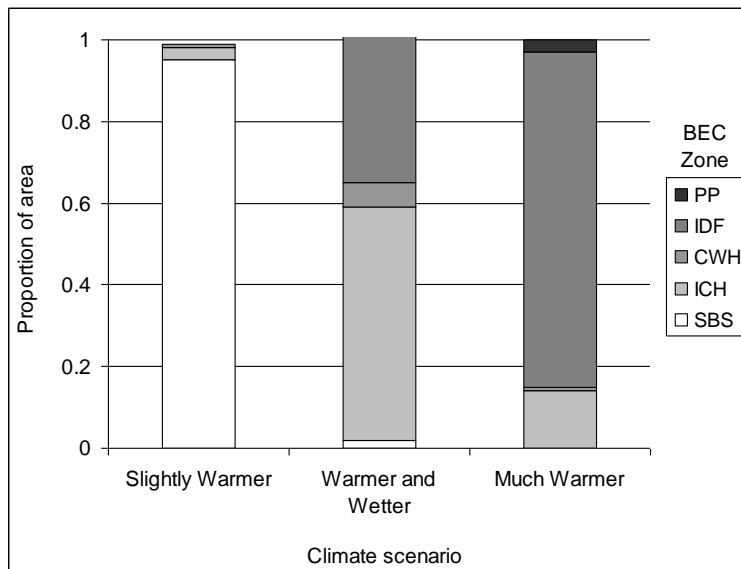
In northern BC, coniferous forests may become dominated by shrubs after fire due to post-disturbance regeneration failure, a regime shift already underway in the boreal forests of Alaska and Yukon forests (Johnstone et al. 2010, Hogg and Wein 2005). Wetlands are vulnerable to regime shifts because they are constrained by landform and sensitive to changes in water flow (Pojar 2010). Shallow interior wetlands are likely to dry up (Wilson and Hebda 2008, p. 130). Alpine tundra ecosystems are vulnerable because there is nowhere for them to move as subalpine conditions allow growth of woody plants (Pojar 2010).

The vulnerability to a changing climate varies among ecosystems and locations and is driven by a variety of factors including disturbance regime, species diversity, presence of species adapted to future conditions, connectivity, potential for shifts from downslope, and degree of human-caused disturbance among others. While it may not be possible to predict future ecosystem distributions, it may be possible to use the magnitude of the shift in potential ecosystem niches to assess relative stress among ecosystems, locations and scenarios.

## Vulnerability of SBS ecosystems in the Nadina Forest District

Determining the magnitude of ecological vulnerability requires comparing, and interpreting, current and projected conditions **in a particular area**. For example, projected future climate envelopes for the SBS in the Nadina Forest District range from mostly SBS to mostly ICH-IDF or IDF-ICH, depending on climate scenario projection (Figure 2). A shift to a dry IDF climate could more than double the frequency of fire in the Nadina SBS (i.e., fire return intervals of < 50 yr in IDF versus 125 yr in Nadina SBS; Wong et al. 2004), although suppression may limit area burned. The ICH has less frequent disturbance (~200 yr return interval for ICHmc) than the SBS, but wetter ICH-like conditions in the SBS could support outbreaks of disease that are not reflected in ICH disturbance regimes.

Plant communities in the SBSmc2 and SBSdk (current Nadina) are more similar to those in the ICHmc2 (warmer and wetter scenario) than they are to those in the IDFxh2 and IDFmw2 (much warmer scenario; Price and Daust 2012). Shifts to climate envelopes associated with similar plant communities suggest lower ecological stress. Similarly, smaller geographic distances between current and predicted ecosystems indicate a higher likelihood of migration and ecological recovery. The ICHmc2 is much closer to the Nadina SBS than the IDFxh2 and IDFmw2 (Price and Daust 2012). Geographic distance correlates with community similarity to some extent, suggesting that dissimilar ecosystems risk both depauperate communities and longer (and less likely) recovery. Overall, the “much warmer” scenario presents the highest risk because plant communities are most dissimilar, indicating potentially higher stress, because migration distance is greater, indicating poorer recovery and because disturbance may increase substantially, hastening the pace of change. The slightly warmer scenario presents the lowest risk. The warmer and wetter scenario is intermediate, however disturbance from diseases is a large uncertainty.



**Figure 2. Projected climate envelope composition of current SBS zone (~1.9 million ha), in Nadina Forest District, for three different climate scenarios. Data from Price and Daust 2012.**

## Species Impacts

Trees are “foundation species”, providing the architecture and driving many ecological functions in most of BC’s current ecosystems (Ellison et al. 2005). They are well studied. There are relatively few tree species in BC and hence low redundancy in ecological niche (Pojar 2010). Impacts to tree species have a high potential to influence all forest organisms as well as ecosystem processes.

The climate envelopes of tree species are shifting upslope and north (Hamann and Wang 2006). Predicted declines for conifers include loss of western redcedar in southern BC (Wilson and Hebda 2008, Spittlehouse 2006, Bunnell and Kremsater 2012), continued loss of lodgepole pine (*Pinus contorta*) from sub-boreal ecosystems due to mountain pine beetles (*Dendroctonus ponderosae*) and Dothistroma needle blight (*Dothistroma septosporum*; Woods et al. 2005), and loss of interior spruce (*Picea engelmannii x glauca*) due to insects, pathogens and, potentially, regeneration difficulty (Hamann and Wang 2006). On dry sites in the central interior of BC, environmental changes (e.g., moisture, nutrients, light, etc.) could exceed the tolerances of interior spruce and paper birch (*Betula papyrifera*; Nitschke 2010). The climate in central BC and parts of northern BC could become suitable for Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) over the next century, while western redcedar (*Thuja plicata*) has the potential to expand its range in the north coast and Kootenays. However, long generation times, genetic specialisation to local areas (Newton et al. 1999) and extreme climatic and disturbance events could prevent successful tree migration (Pojar 2010 and references therein). With much quicker generational times, insects and pathogens are likely to outstrip their hosts in adaptive capacity as seen in the Alaska spruce beetle (*Dendroctonus rufipennis*) and BC mountain pine beetle outbreak (Spittlehouse 2008, Werner and Holsten 1983). Deciduous trees, particularly trembling aspen (*Populus tremuloides*), will continue to be plagued by insects and pathogens (Pojar 2010 and references therein). Abiotic and biotic factors will interact as, for example, trees stressed by drought are more susceptible to bark beetles and disease (Woods et al. 2010). Likely there will be large diebacks of trees including both deciduous and coniferous species such as aspen, several pines and interior spruce that have traditionally defined much of BC’s forested ecosystems (Pojar 2010).

While tree growth will likely increase in many areas due to longer, warmer growing seasons and increased carbon dioxide in the atmosphere, potential gains in growth may not be realized because other environmental factors limit growth, because tree populations have a narrow range of temperature for optimum growth and because mortality is expected to increase due to maladaptation coupled with increased virulence of insects and disease (Johnson et al. 2010, Pojar 2010, Aitken et al. 2008, Woods et al. 2010).

A comparison of plant communities associated with historic and projected climate envelopes in the Nadina Forest District suggests that about one fifth of species in the Nadina face extirpation, that is, they are not associated with projected climates (Price and Daust 2012). About half of the species associated with projected climate envelopes are currently missing from the Nadina, indicating potentially reduced ecosystem function in the future.

## Limitations of Climate Envelope Models

Climate envelope models provide a basis for predicting the ecological impacts of climate change. The climate envelope approach draws a picture of the potential for ecosystem change in any given location, allows inference of disturbance and provides a powerful basis for developing hypotheses about levels of ecological upheaval (Wang et al 2012), but has several limitations.

- Climate envelope projections are based on global climate models that vary in formulation and in assumptions about greenhouse gas emissions. In addition, BC's tremendously diverse topography, complex climatic processes and sharp ecotones hinder precise prediction by climate models. Variation in global projections lead to climate envelope projections that range from a minor climate shift (e.g., most of original subzone extent remains) to an extreme shift (e.g., no original extent remains) for a particular time frame (e.g., Daust and Price 2011).
- Climate envelopes are based on climate averages and do not include the extreme, unpredictable events that drive disturbance and can fundamentally restructure ecosystems (e.g. mountain pine beetle). Climate variability and extreme weather events have a large effect on population and community dynamics and on species distributions (Parmesan et al. 2000, Parmesan 2006).
- Climate envelope models do not account for stand-level topographic (e.g., moisture shedding or receiving sites) or edaphic (e.g., soil texture and drainage) factors that influence species distributions, survival, and productivity at finer scales. While climate envelope models may suggest the loss or decline of a certain species from an area, that species may still persist or thrive on moister (or drier) portions of the landscape.
- Climate envelopes do not account for phenological plasticity. Some tree species may survive in remnant populations for long periods (Pearson 2006) due to high plasticity, providing a long-term dispersal opportunity.
- Climate envelopes do not include biological factors such as dispersal speed, interspecific interaction, uncoupled phenology, and the role of invasive species that determine the survival of species and of species interactions. Essentially, they cannot extrapolate beyond currently-defined ecosystems to explore novel species combinations.
- Climate envelopes do not consider barriers to movement (e.g. topography, fragmentation, soil characteristics) that determine likelihood of successful migration.
- Climate envelopes do not examine the cumulative effects of climate change and human-caused factors.

Despite their limitations, bioclimate models may provide the best available information to guide development of climate-savvy policy at this time (Pearson and Dawson 2003). Recent developments in process-based global vegetation models show promise for the future, however, accurate prediction of future ecosystem composition and distribution is fundamentally limited by the complexity of natural systems. The precautionary approach provides a means of dealing with such high uncertainty.

## Cumulative Impacts

Climate change and other anthropogenic factors can interact to increase ecological impacts. In particular, biodiversity and hence the ability of ecosystems to respond to climate change can be hampered due to human influences. For example, the CDF, PP and BG currently support high biodiversity due in part to the juxtaposition of grassland, shrub-steppe, riparian and forest habitats. However, at least 20% of organisms in these southern ecosystems are already at risk due to habitat loss, overgrazing and invasion of non-native plants (Pojar 2010). Similarly, fire suppression, grazing and invasive species interact at multiple scales, leading to grassland community shifts that can be difficult to reverse (Laycock 1991, D'Antonio and Vitousek 1992). Creating large expanses of monocultures of similar age leads to insect outbreaks (Carroll et al. 2006)

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