Projected Climate Change Impacts in the Nadina Forest District

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Overview of global climate change

Climate and greenhouse gases

Climate refers to patterns of weather, described by variables such as temperature, precipitation and wind, over a specified time period (e.g., often a longer period such as 30 years) and region (based on IPCC[1] 2007 Glossary). "**Climate change** refers to any change in climate over time, whether due to natural variability or as a result of human activity" (IPCC 2007 Glossary). **Anthropogenic climate change** or anthropogenic warming refers to climate change attributable to human activities.

Greenhouse gases in the atmosphere trap heat and influence climate. The concentration of greenhouse gases have increased dramatically since about 1750—the start of the industrial era (Figure 1). This simple trend lies at the root of climate change (Gayton 2008).

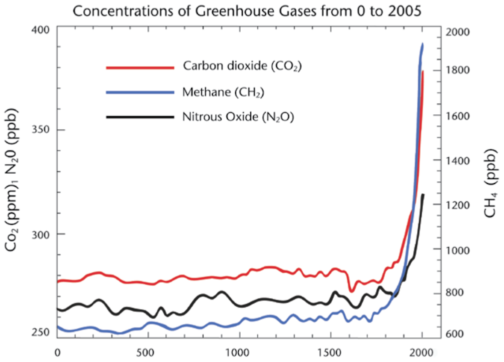

Figure 1. Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Concentration units are parts per billion (ppb). Originally from Forster et al. 2007. Available on the internet[2] ; see also Gayton 2008.

Climate models and emissions scenarios

Global climate models calculate climate variables (e.g., temperature, precipitation) as a function of greenhouse gas concentration in the atmosphere and other factors (e.g., heat absorbed by ground cover). Greenhouse gas concentration depends on assumptions about future global emissions (described as emissions scenarios).

Several "standard" emissions scenarios (referred to as IPCC Special Report on Emissions Scenarios or SRES) have been defined to facilitate comparison of results among models (IPCC 2000). These scenarios describe assumptions about global population, economic growth and technological development which translate into estimates of global CO_2 emissions over time (Figure 2). Emissions scenarios can be associated with different concentrations of greenhouse gas in the atmosphere (Table 1). Some scenarios lead to stable concentrations, others do not.

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[1] Intergovernmental Panel on Climate Change.

[2] http://CO2now.org/Know-the-Changing-Climate/Climate-System/ipcc-faq-human-natural-causes-climate-change.html

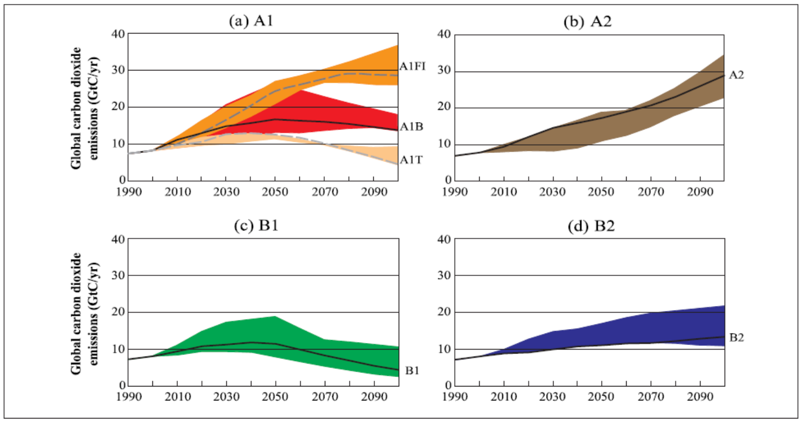
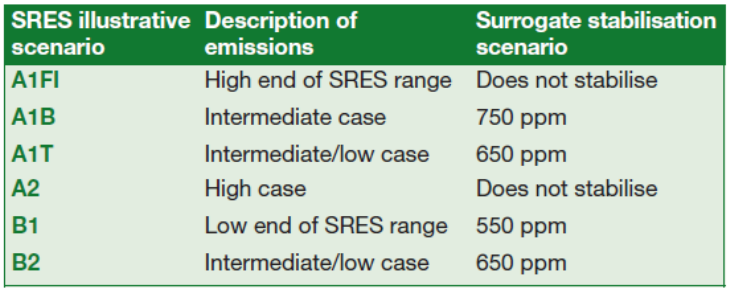


Figure 2. Total global annual CO_2 emissions from all sources (energy, industry, and land-use change) from 1990 to 2100 (in gigatonnes of carbon (GtC/yr)) for different emissions scenarios. Solid and dashed lines show illustrative examples; coloured bands show ranges of emissions. Retrieved from IPCC 2000.

Table 1. Standard emission scenarios (SRES) and the most similar stablisation scenarios (described by parts per million CO_2). Retrieved from Carter et al. 2007.



SRES illustrative scenario	Description of emissions	Surrogate stabilisation scenario
A1FI	High end of SRES range	Does not stabilise
A1B	Intermediate case	750 ppm
A1T	Intermediate/low case	650 ppm
A2	High case	Does not stabilise
B1	Low end of SRES range	550 ppm
B2	Intermediate/low case	650 ppm

Global climate models use a coarse spatial resolution (e.g., 135 km x 135 km[3]). To apply these models to a smaller region such as the Nadina, model results are "downscaled" to create finer resolution climate projections (e.g., 90 m x 90 m) by accounting for regional topography and available climate station data (see ClimateWNA software[4]).

Projected global temperature

Globally, climate change projections are usually expressed in terms of average global temperature change. Projected temperature change varies with emission scenario (Figure 3). Significant negative impacts due to climate change, such as sea level rise, desertification and mass extinction are expected to increase as global temperature increases. A two degrees Celsius increase, associated with about 450 ppm CO_2 in the atmosphere, has been considered as a threshold that should not be exceeded. Exceeding this threshold could trigger large scale climatic events such as deglaciation of western Antarctica. (Schneider et al. 2007).

While the overall projected trend towards increasing temperature is well supported, variation among individual model projections is high. Much of this variability is due to differences in

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[3] Explained at http://news.bbc.co.uk/2/hi/science/nature/6320515.stm
[4] http://www.genetics.forestry.ubc.ca/cfcg/ClimateWNA_web/

scenarios (different dots in Figure 3), while some is due to uncertainty about model structure and parameterization (bar widths in Figure 3).

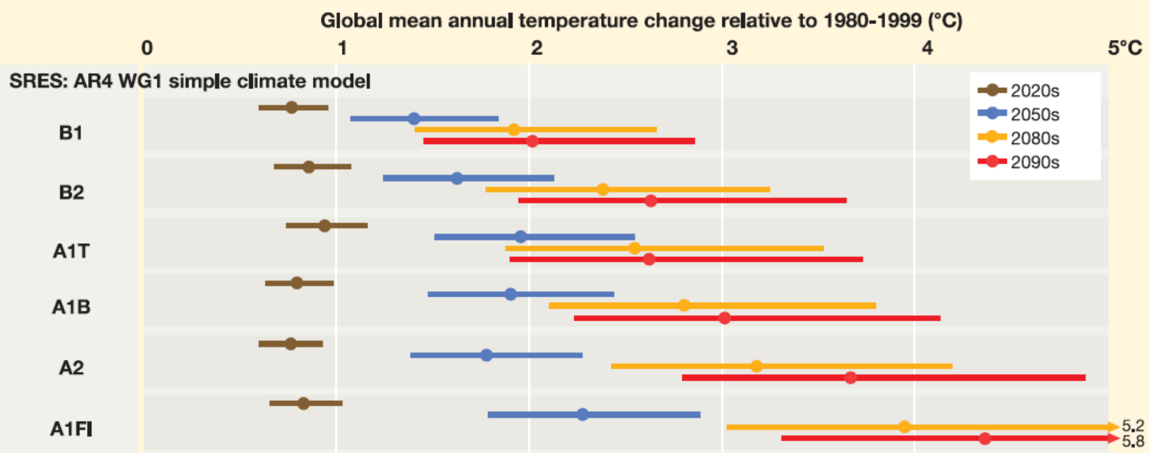

Figure 3. Projected ranges of global mean annual temperature change during the 21st century for the six illustrative SRES scenarios. See details in Figure 2.8 of Carter et al. 2007.

Projected global impacts

Recent Climate-related Changes

The IPCC Fourth Assessment provides a summary of recent climate-related changes in the natural and human environment over the globe (IPCC 2007; Rosenzweig et al. 2007). Data series are available from 765 physical systems and 28,671 biological systems. The great majority of studies come from Europe, with a large number also in the western United States. Of the observed significant physical and biological changes, 94% of the physical changes and 90% of the biological changes are consistent with warming. The IPCC Assessment concludes that “physical and biological systems on all continents and in most oceans are already being affected by recent climate changes” (Rosenzweig et al. 2007). Evidence indicates that these changes are related to 30 years of anthropogenic warming.

Changes to frozen physical systems include increased instability in permafrost, increased rock slides in mountains, and changes to Arctic and Antarctic ecosystems. Changes to hydrology include earlier spring peak discharge and increased runoff in glacier-fed streams, and decreases in water quality associated with warming in lakes and rivers. Changes to terrestrial ecosystems include shifts in timing (e.g. earlier leaf-out and egg-laying), and shifts in range for a variety of plants and animals. Changes to marine and freshwater ecosystems include changes in algal, plankton and fish abundance and range, as well as ocean acidification.

Projected Impacts to Human Activities

These changes to physical and biological systems are projected to impact human activities over the next century. Impacts vary geographically and with level of climate change (Figure 4). Available water is projected to increase by 10 – 40% in high latitudes and wet tropical areas, and decrease by 10 – 30% in some dry regions. There will be more drought and more heavy precipitation events, which will affect crops. Glacial water will decline, reducing water for one-sixth of the world population. Ecosystems will likely lose their resilience due to a variety of factors. Over the century, net carbon uptake will decrease and may reverse. With an increase in global mean temperature of above 1.5 – 2.5C, about 20 – 30% of plant and animal species will face an increased chance of extinction. At this temperature, ecosystem structure and function will change with severe consequences for biodiversity and ecosystems services (e.g. water, food). Ocean acidification will reduce coral formation, and increased sea temperature will lead to widespread coral mortality. Fish distribution will change, with adverse effects for fisheries. Forest management will change due to altered fire and pest disturbance regimes. Agriculture will change due to extreme weather events and changed growth seasons. Hunting and travel potential in the Arctic will change. Coastal regions will flood. Extreme weather events will have vastly increased economic and social costs. Human health will change: malnutrition will increase, climate-related mortality due to heatwaves, floods, droughts and associated disease will increase, disease vector distribution will change.

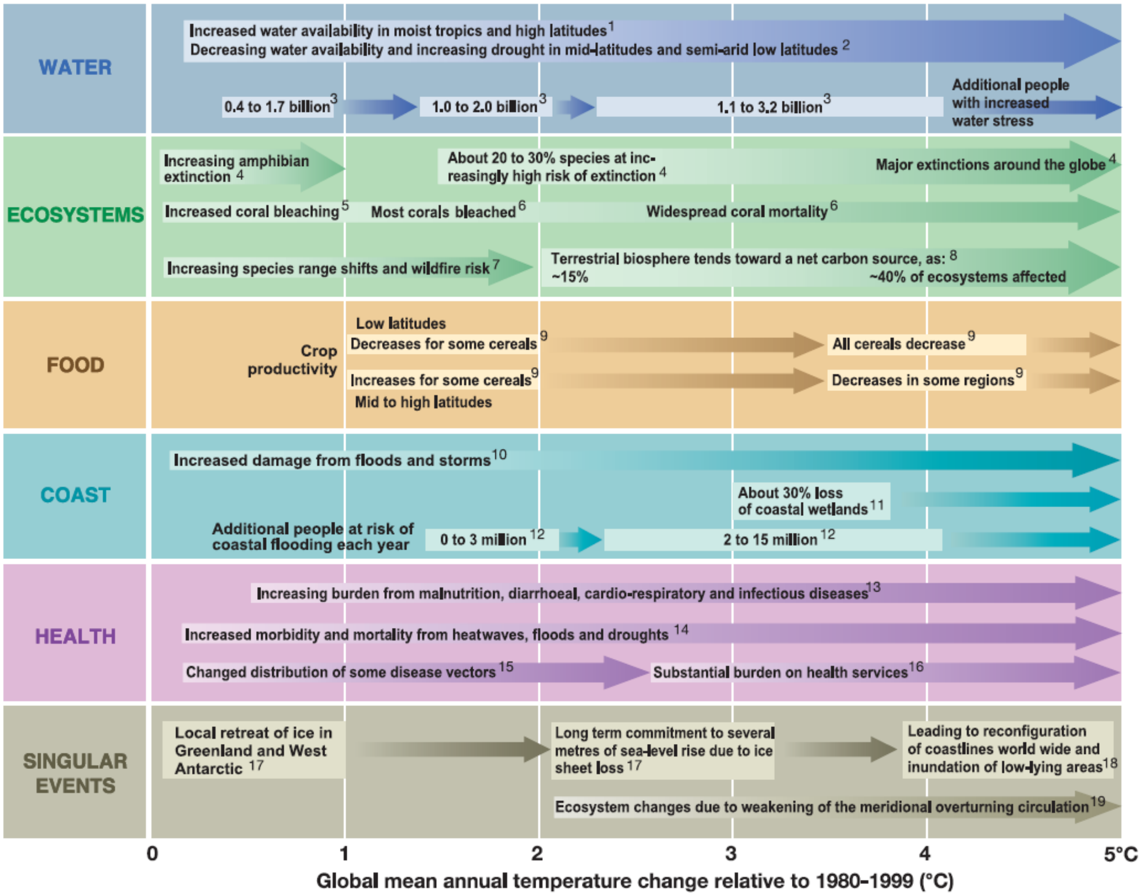

Figure 4. Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. All entries are from published studies in the chapters of the IPCC 4th assessment. See Table 20.8 in Yohe et al. 2007.

Overview of Nadina climate change

Physiography and climate of the Nadina Forest District

The Nadina falls within the Fraser Plateau hydro-climatic region (Figure 5), bordering the North Coast region on the west side. The western portion of the Nadina is relatively mountainous, with exposed bedrock and incised streams. It is heavily influenced by coastal climate and includes the Coastal Western Hemlock (CWH) and Mountain Hemlock, as well as the Engelmann Spruce Subalpine Fir (ESSF), Biogeoclimatic zones. For the purposes of considering climate change, we treat the eastern plateau portion of the Nadina, including the Sub-Boreal Pine Spruce, Sub-Boreal Spruce (SBS) and ESSF Biogeoclimatic zones, separately from the western mountains. The eastern plateau contains many small streams and wetlands on shallow, low-relief glaciated terrain.

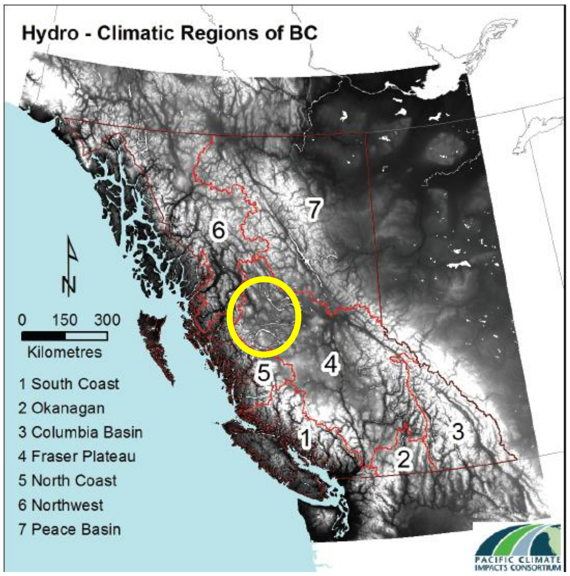

Figure 5. Hydro-climatic regions of BC (from Rodenhuis et al. 2007). Nadina falls within yellow circle.

Projected climate trends in the Nadina

Climate in the Nadina is expected to get warmer and wetter, on an annual basis, with temperature and precipitation in winter increasing more than in summer (Table 2). A higher proportion of fall/winter/spring precipitation will fall as rain instead of snow, and some of that rain is expected to occur during rain-on-snow events. Spring snowpack water equivalents will decline by 5 to 20% in the eastern plateau and by 20 to 40% in the western mountains (Rodenhuis et al. 2007).

Across the Nadina, summer precipitation may either increase or decrease (see range of change, Table 2). Rainfall in the western mountains may increase while rainfall in the eastern plateau may decrease. Climate projections show an increasing proportion of wetter zones (Interior Cedar Hemlock (ICH)and CWH) in the western mountains and of drier zones (Interior Douglas Fir (IDF)) in the interior plateau (Wang 2010). The projected location of the boundary between the wetter and drier zones varies with climate model projection. Climatic trends over the past century also support the projected shift towards a warmer, wetter climate (Rodenhuis et al. 2007).

Table 2. Median and range (90% of outcomes) of climate variables projected for 2055 in the Bulkley-Nechako Regional District (which includes the Nadina and area to the north and east) from multiple runs of different climate models using different emissions scenarios ("ensemble" runs). Source: http://plan2adapt.ca

Variable	Median Change	Range of Change
Mean temp (annual)	+1.8 °C	+1.3 °C to +2.7 °C
Mean temp (summer)	+1.6 °C	+1.2 °C to +2.8 °C
Mean temp (winter)	+1.8 °C	+0.6 °C to +2.8 °C
Precipitation (annual)	+9%	+2 to +16%
Precipitation (summer)	+2%	-7 to +11%
Precipitation (winter)	+11%	-2 to +21%
Snowfall (winter)	+7%	-4 to + 16%
Snowfall (spring)	-52%	-68 to -10%
Growing degree days	+213 (deg x days)	+127 to +394
Frost free days	+18 days	+11 to +29

Historic climatic variability in the Nadina

Climate models do not currently simulate climate oscillations that have historically caused substantial variation in temperature and precipitation among years and decades.

Three scales of climate variability will influence the future climate of the Nadina. Long-term climate trends, such as climate change, act over centuries. Within long-term trends, decadal climatic oscillations and yearly "events" (short duration oscillations) cause variability. Climatic oscillations have different temperature and precipitation patterns associated with their alternate phases. At least two oscillations are particularly relevant in the Nadina. The Pacific Decadal Oscillation (PDO) and the El Niño/La Niña Southern Oscillation (ENSO) strongly influence the Nadina climate. The PDO has an approximate 50-70 year period (i.e. about 30 years in each phase). The ENSO is a quasi-periodic climate pattern, that is El Niño or La Niña years are interspersed with "normal" years[5]. El Niño events occur every two to seven years and last from a half a year to two years. La Niña events are of similar duration but somewhat less frequent. Ideally, climate models should create projections that account for climate oscillations.

The warm phases of the PDO and ENSO lead to warmer temperatures, particularly in winter and spring (Table 3). Synchrony between the warm PDO and warm ENSO correlates with increased wildfire (Heyerdahl et al. 2008). The warm phase of the PDO increases spring precipitation (Table 4). We are currently probably in a negative (cool) phase of the PDO. The last positive (warm) phase spanned approx. 1977 to 2002 and was preceded by a cool phase from 1947 to 1977. The cool PDO may mask some of the temperature and precipitation increases associated with climate change in the Nadina.

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[5] Wikipedia: http://en.wikipedia.org/wiki/El_Ni%C3%B1o-Southern_Oscillation

Table 3. Temperature in warm phase of climatic oscillation relative to cool phase, in Nadina (based on Rodenhuis et al. 2007). Arrows show magnitude of difference (three arrows represent roughly 2^{0} C). Winter is December, January, February.

	Winter	Spring	Summer	Fall
El Niño (warm ENSO)	↑↑↑	↑↑	↑	—
Positive (warm) PDO	↑↑	↑↑	↑	—

Table 4. Precipitation in warm phase of climatic oscillation relative to cool phase, in Nadina. Arrows show magnitude of difference (two arrows represent roughly 20% of mean precipitation; arrows in brackets show weak trends). Winter is December, January, February.

	Eastern Plateau				Western Mountains			
	Winter	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**
El Niño (warm ENSO)	↓	—	(↑)	(↑)	(↓)	—	—	(↑)
Positive (warm) PDO	(↑)	↑↑	—*	—	↑	↑↑	—*	—

*August tends to be ↓.

Effects on hydrology in the Nadina

In general, the Nadina follows the climatic trends and related hydrological impacts projected for BC (Table 5).

Table 5. Projected changes in winter weather, storm impacts and streamflow in BC (from Pike et al. 2008a, b).

Winter	Summer	Storms and their impacts	Streamflow
Temp ↑	Temp ↑	Frequency & magnitude ↑	Snowmelt → hybrid rain/snow driven
Precipitation ↑	Precipitation ↓ ↑	Landslides ↑	Rain on snow events ↑
Rainfall ↑	Evaporative demand ↑	Avalanche ↑	Earlier freshet
Snowfall ↓	Plant transpiration ↑	Erosion ↑	Peak flow ↑ ↓
Snowpack ↓	Moisture deficits ↑	Sedimentation ↑	Summer low flow ↓
Snowline up & north	Stream/lake temp ↑	Big log jams ↑	Low flow period ↑
Extreme weather ↑	Risk to salmon ↑	Channel stability ↓	Perennial stream → intermittent*
		Log supply (long term) ↓	

*where snowmelt not stored in ground water

In the Nadina, increased winter temperatures, increased precipitation and reduced snowfall in the spring (i.e., more precipitation falls as rain; Table 5) will likely shift the hydrological regime from snowmelt driven to hybrid rain/snow driven, leading to more frequent rain on snow events and smaller spring snowpacks. While these changes will affect sediment loads and channel stability, the most obvious ecological effect may be reduced summer flow levels and a longer low flow period, with consequent increased risk to fish.

Effects on ecosystems in the Nadina

Climate is one of the main “drivers” controlling the structure (e.g., species composition) and function (e.g., productivity, decomposition, nutrient cycling) of ecosystems. Climate influences species directly. In particular, many species’ ranges are limited by temperature extremes. Climate influences site moisture and nutrient conditions, affecting plant distributions. In turn, plant communities, along with temperature, exert a large influence on invertebrate and vertebrate species distributions. Climate drives disturbance regimes by affecting insect and disease populations and the probability of extreme weather.

Across BC, the climatic conditions historically associated with major forest types ("BEC climate envelopes") are expected to shift substantially over this century (Hamann and Wang 2006), with implications for forestry. BEC climate envelopes will shift northward and upward and may have little if any overlap with their historic range. Many BEC climate envelopes will contract, while others expand. Of the BEC zones found in the Nadina, several face high risk at the provincial scale: AT and SBPS climate envelopes may contract the most, followed by SBS and MH at the provincial scale (Table 6). Within BEC zones, impacts will likely vary by site type (e.g., Haeussler 2009).

Table 6. Current BEC zone composition of Nadina and predicted province-wide expansion or contraction of BEC zones by 2085, expressed as percent of 1990 province-wide BEC zone area (from Table 3, Hamann and Wang 2006).

BEC zone	Composition of Nadina excluding Tweedsmuir (% area circa 1990)	Predicted area of BEC climate envelope in 2085 (% of 1990 province-wide area)
SBS:	70	15
ESSF:	21	73
AT:	4	3
CWH:	2	150
SBPS:	2	2
MH:	1	21

Three projections of future BEC climate envelopes have been prepared for the Nadina (Wang 2010). The projections reflect different models, different emissions scenarios and specific model runs (Table 7). They give a rough idea of how much ecological change might be expected.

Table 7. Models, scenarios and run numbers used for three illustrative climate projections in Nadina.

Label	**Model Name**	**Emission Scenario***	**Model Run**
cm	Coupled Global Climate Model, 3rd generation (CGCM3; Canada). http://www.ec.gc.ca/ccmac-cccma/	A2	No. 4
hm	Hadley Centre Circulation Model version 3 (HadCM3; U.K.) http://www.metoffice.gov.uk/climatechange/science/hadleycentre/	A2	No. 1
gm	Hadley Centre Global Environmental Model (HadGEM1; U.K.) Builds on HadCM3	A1B	No. 1

*see Figure 2 above.

The ESSF and SBS BEC zones currently dominate the Nadina. Projections suggest that the ESSF climate envelope (i.e., climatic conditions associated with the zone) will be mostly gone from the Nadina by 2050 and the SBS envelope will be mostly gone by 2080, but projections for the SBS are more variable (Figure 6).

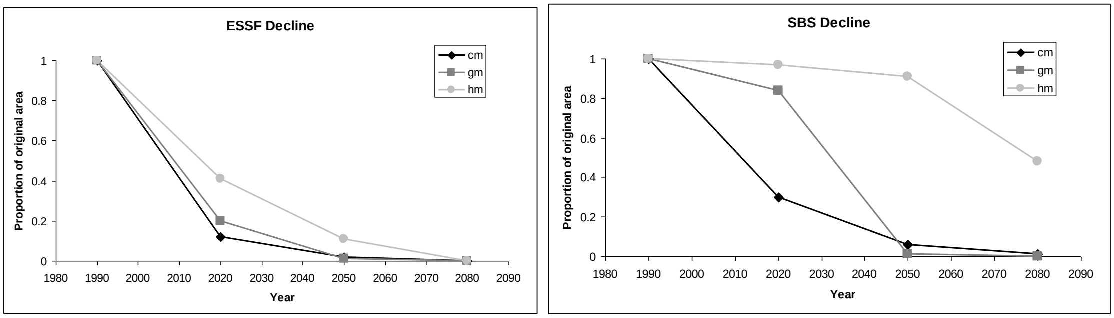

Figure 6. Decline in Nadina ESSF and SBS climate envelopes (proportion of 1990 region still covered) over time predicted by three different model runs (cm, gm, hm; Table 7).

Between now and 2080, the current ESSF zone may be replaced by some combination of ICH, CWH, SBS and IDF zones (Figure 7). The future dominance of the relatively wet ICH and CWH versus the relatively dry SBS and IDF varies by model run and also varies by location. The eastern plateau portion of the Nadina will likely have drier zones than the western mountains.

IDF and ICH climate envelopes will move into the location of the current SBS zone (Figure 8). The proportion of the current SBS zone that becomes IDF will be greater than the proportion that becomes ICH, but relative proportions vary by model run.

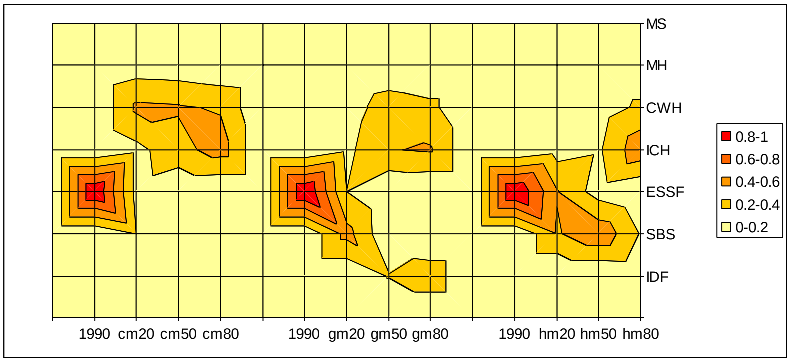

Figure 7. Proportion (shown by contour bands) of the 1990 Nadina ESSF zone covered by different climate envelopes (y-axis) versus time (1990, 2020, 2050 and 2080) for different model runs (cm, gm, hm; Table 7).

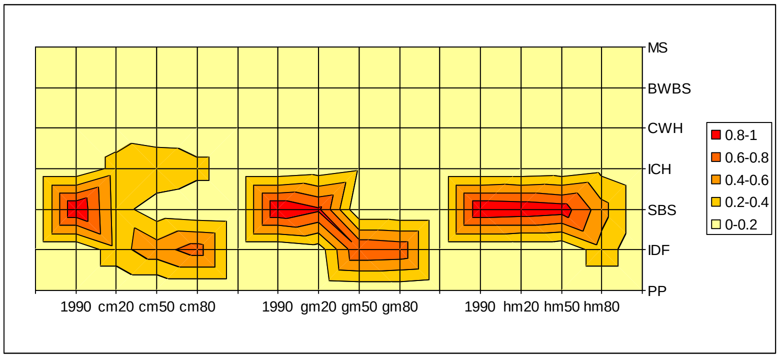

Figure 8. Proportion (shown by contour bands) of the 1990 Nadina SBS zone covered by different climate envelopes (y-axis) versus time (1990, 2020, 2050 and 2080) for different model runs (cm, gm, hm; Table 7).

Effects on trees in the Nadina[6]

Trees provide timber, a valued ecosystem service, and serve as a foundation species, providing habitat and altering the local environment (Ellison et al. 2005).

Like other plants, tree distributions respond to climate directly and to site conditions and disturbance regimes determined by climate (Figure 9). Elevated CO_2 coupled with warmer temperatures will tend to increase tree growth rates, but not in all situations. Conversely, climate change will also increase maladaptation and susceptibility to natural disturbance agents, leading to reduced growth and increased mortality. Shifting BEC envelopes and increasing variability in weather patterns will create climatic conditions to which resident long-lived trees are maladapted[7].

> *When climate becomes significantly different from that in which the species evolved, maladaptation occurs. Maladaptation includes a direct climate component (e.g. the impacts of increasing temperature) and an indirect component (e.g. changes in soil moisture availability resulting from changes in precipitation and evapotranspiration). These climatic-related effects also render trees more susceptible to additional stressors, e.g. insects…, disease… and fire….* (Johnson et al. 2010)

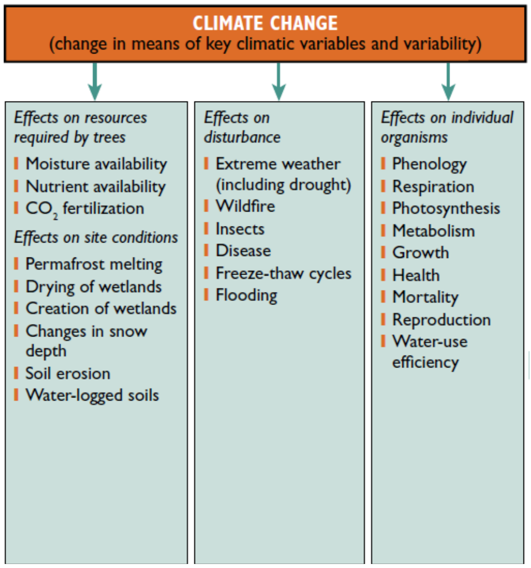

Figure 9. Pathways by which climate affects trees: via resources, via disturbance regimes and via direct effects on individuals (originally from Williamson et al. 2009, retrieved from Johnson et al. 2009).

Effects on resources required by trees

Complex interactions among responses to CO_2, temperature, light, moisture and nutrients make predicting the effects of climate change on tree growth difficult (Table 8).

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[6] The section on trees is based largely on Johnson et al. 2010 (recommended reading).

[7] Projected climate envelopes for tree species are presented in App. 3 of Hamann and Wang 2006.

Increased temperatures and longer growing seasons can increase tree growth. Similarly increased CO_2 can increase growth (25 to 75% increase in photosynthesis if CO_2 artificially doubled) and also the efficiency of water use. Growth can increase even in very old trees. To capitalize on these potential growth benefits, trees must not be limited by moisture or other nutrients. A shortage of available nitrogen often limits tree growth in northern forests, however, nutrient availability may increase if rising surface and soil temperatures stimulate decomposition of soil organic matter. The positive effects of temperature on growth may not hold for increases beyond 2^0 C. Also, in some cases, high atmospheric concentrations of CO_2 benefit soil organisms (e.g., via litterfall) rather than increasing tree growth.

In combination, increased CO_2 and temperature may either increase or decrease water stress. Increased CO_2 leads to increased water use efficiency (unit growth per unit of water used), because stomatal conductivity decreases. High temperature alone (without increased CO_2) can reduce water use efficiency, however, warmer temperatures can stimulate root growth in some species to compensate for increased evapotranspiration. While water use efficiency may increase with atmospheric changes, evapotranspiration also increases with temperature. Growth can decrease in areas with warm temperatures and limited water availability. In the Nadina, summer temperatures are expected to increase while precipitation may remain relatively constant, leading to increased evapotranspiration and summer moisture deficits.

Seasonal growth patterns

Trees are in synchrony with their historic climate.

> *Populations of forest trees become adapted to their native environments through natural selection by synchronizing their seasonal growth patterns with the average timing of local growing season conditions (favourable moisture and temperature). Despite having large distributional ranges, often encompassing large portions of continents, individual populations (i.e. provenances or 'seed sources') of most tree species can be adapted to a relatively narrow climate range.* (O'Neill and Yanchuk 2005, p. 1, cited in Johnson 2010)

As surface temperature increases with climate change, the growing season in the northern hemisphere lengthens. Most tree species can flush earlier in spring and take advantage of the longer growing season; some species, however, are tied to day length.

While a longer growing season can increase tree growth, it can also increase asynchrony between tree growth patterns and seasonal temperatures, leading to negative impacts (Table 8). Trees may become more susceptible to damage from spring and fall frosts, especially if temperatures become more variable. Elevated CO_2 levels can also increase risk of frost damage by affecting patterns of acclimation to winter weather. Elevated temperatures can lead to abnormalities and aborted vegetative buds. Tree species have a wide range of responses to changes in spring, fall and growing season temperatures.

Trees are most susceptible to unfavourable climatic conditions during the establishment phase. Older, well-established trees can tolerate climate-related stress better.

Table 8. Summary of the most common effects of increased CO_2 or temperature on physiological responses of tree species. Positive effects for tree growth and survival are shown by +, negative effects by —, and neutral effects by 0 (Reproduced from Johnson 2010).

Process	**Increased CO_2**	**Increased temperature**
Photosynthesis	+	+ or —
Respiration	+ or —	—
Shoot growth	+ or 0	+ or —
Root growth	+	+ or —
Nutrient levels	—	+
Water use	+	—
Shade vs. sun growth	+ or —	+ or —
Pollutant effects	— or 0	+ or —
Bud-burst	Earlier	Earlier
Seasonal shoot development	— or 0	+ or —
Bud-set	Earlier	Later
Senescence	+ or 0	+ or 0
Frost hardiness	—	—
Chilling	—	—
Aging	+	?
Reproduction	+	+ or —

Natural disturbance

Natural disturbance agents responsible for tree mortality in the Nadina include fire, and insects and disease.

Fire

By the end if this century, fire disturbance (area burned) in Canada could double due to climate change (Flannigan et al. 2005), but with variation among regions. In BC, stand-replacing disturbance varies by Biogeoclimatic Zone (BC MOF and MOE 1995, Wong et al. 2003). If the western mountainous portion of the Nadina becomes wetter and CWH and ICH expand (see "Effects on ecosystems" section above), area burned by fire should decrease or remain the same. In the eastern plateau, expansion of the SBS climate envelope into the ESSF and expansion of the IDF climate envelope into the SBS should increase the frequency of fires and of area burned (based on stand replacing disturbance rates in different zones; BC MOF and MOE 1995). The IDF fire regime is complicated because it includes stand-maintaining and stand-replacing disturbance. In the current IDF zone, Douglas-fir is adapted to frequent fires. As the IDF climate envelope moves over the Nadina, frequent fire initiations will likely lead to frequent stand-replacing disturbance rather than low-severity fire because forests are not adapted to the IDF disturbance regime.

Table 9. Disturbance return intervals (BC MOF and MOE 1995) for climate envelopes projected to cover Nadina between 1990 and 2080 (based on cm scenario, Table 7).

BEC climate envelope	Subzones	Area Trend*	Disturbance return interval (years) ranked from most to least disturbance**
IDF	dk, dc, mw, ww, ww, xc, xh	↑ East	250 (4 to 50 years for low-severity, non-stand-replacing fire)
SBPS	mc	↓East	100
SBS	dk, mc, wk, dw	↓East	125
ICH	mc, mk, dw	↑West	200 (150)
ESSF	mc, mk, mv, wv	↓East/West	200 (350)
CWH	ws, ds, wm, vm	↑West	200 (250); likely underestimated
MH	mm	↑West	350
AT		↓East/West	Unknown

*shows whether zone is expanding or contracting in eastern and western portions of Nadina.

**average number of years between stand-replacing disturbance; numbers in brackets show return intervals for less common subzones.

Insects and disease

Insect virulence is expected to increase due to longer, warmer summers that favour population growth and a reduced frequency of extreme cold periods that cause high mortality (Woods et al. 2010). Warmer temperatures also allow insects and disease to expand their range into areas with greater concentrations of host species. Trees stressed by climate change are more susceptible to insects and disease.

For some insects, reproductive cycles will shorten, allowing more rapid population growth. Spruce bark beetle can shift from a two year to a one year maturation cycle as the climate warms (Logan et al. 2003). Balsam bark beetle may do the same.

Warm temperatures can accelerate drought stress and lead to regional-scale die-offs for some species (Adams et al 2009). Climate change projections suggest that moisture availability will decline in much of central and western Canada (Hogg and Bernier 2005, Lemmen et al. 2008 cited in Johnson et al. 2010).

Evidence for drought-related tree mortality and growth decline already exists. From southern BC to Arizona, background (non-catastrophic) mortality rates in unmanaged oldgrowth forests have been increasing rapidly (doubling period of 17 to 29 years) and can likely be attributed partly to climate change (van Mantgem et al 2009). Drought and insects were the main factors causing wide-spread dieback of aspen in the prairie provinces (Hogg et al 2008). Similarly, wide-spread growth declines of white spruce in Alaska are tied to drought (Barber et al. 2000).

Ecosystem patterns reflect disturbance regimes (BC MOF and MOE). As the climate changes, landscape patterns will align with a changed disturbance regime. Species and age classes that are highly susceptible to disturbance will become less frequent over time. Tree mortality will likely be highest as landscapes shaped by historic disturbance regimes equilibrate to new disturbance regimes (Peterson 2002). The next few decades represent a transition period that is unlikely to be smooth.

Mountain pine beetles

Impacts of climate change may be sudden and substantial (Scheffer 2001). Prior to the mountain pine beetle outbreak, about half of the forest in the Nadina was older than 140 years (Figure 10). Mountain pine beetles have killed a substantial proportion of pine trees in the Nadina over about fifteen years. About half of the susceptible (i.e., sufficiently old) stands are more than one third dead (Figure 11). Most survivors within stands are non-pine. The Lakes TSA is more heavily impacted than the Morice TSA (Figure 12).

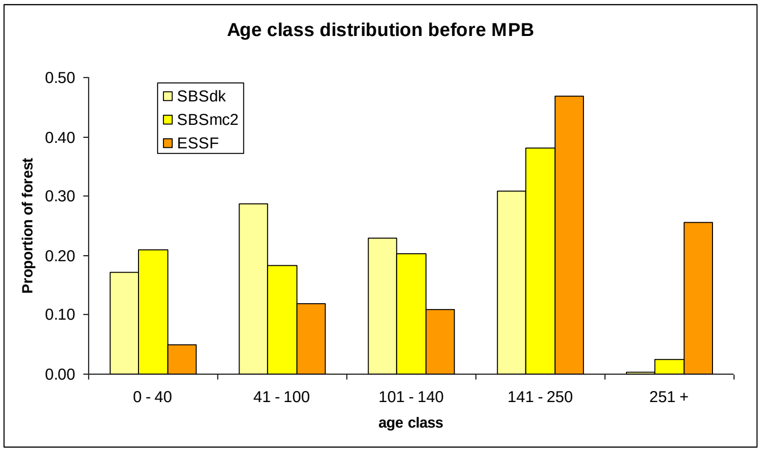

Figure 10. Age-class distribution of the three major forested subzones in the Nadina prior to the mountain pine beetle outbreak (data from 2005 BC Vegetation Resources Inventory; not updated for beetle mortality).

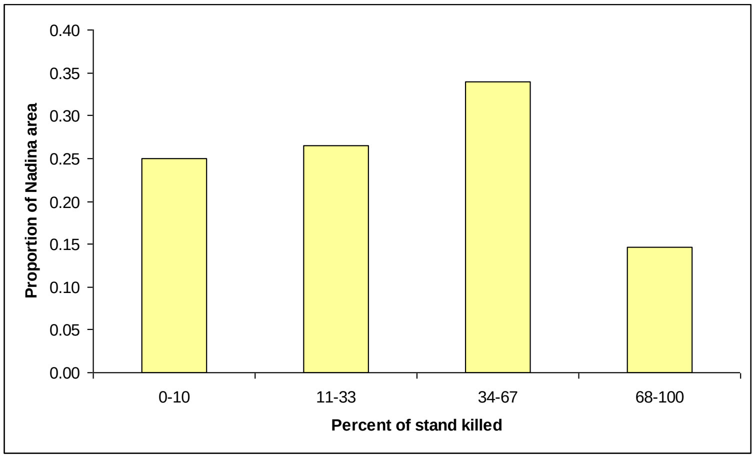

Figure 11. Proportion of Nadina forest in different mortality (due to mountain pine beetle) classes (data from Walton 2010).

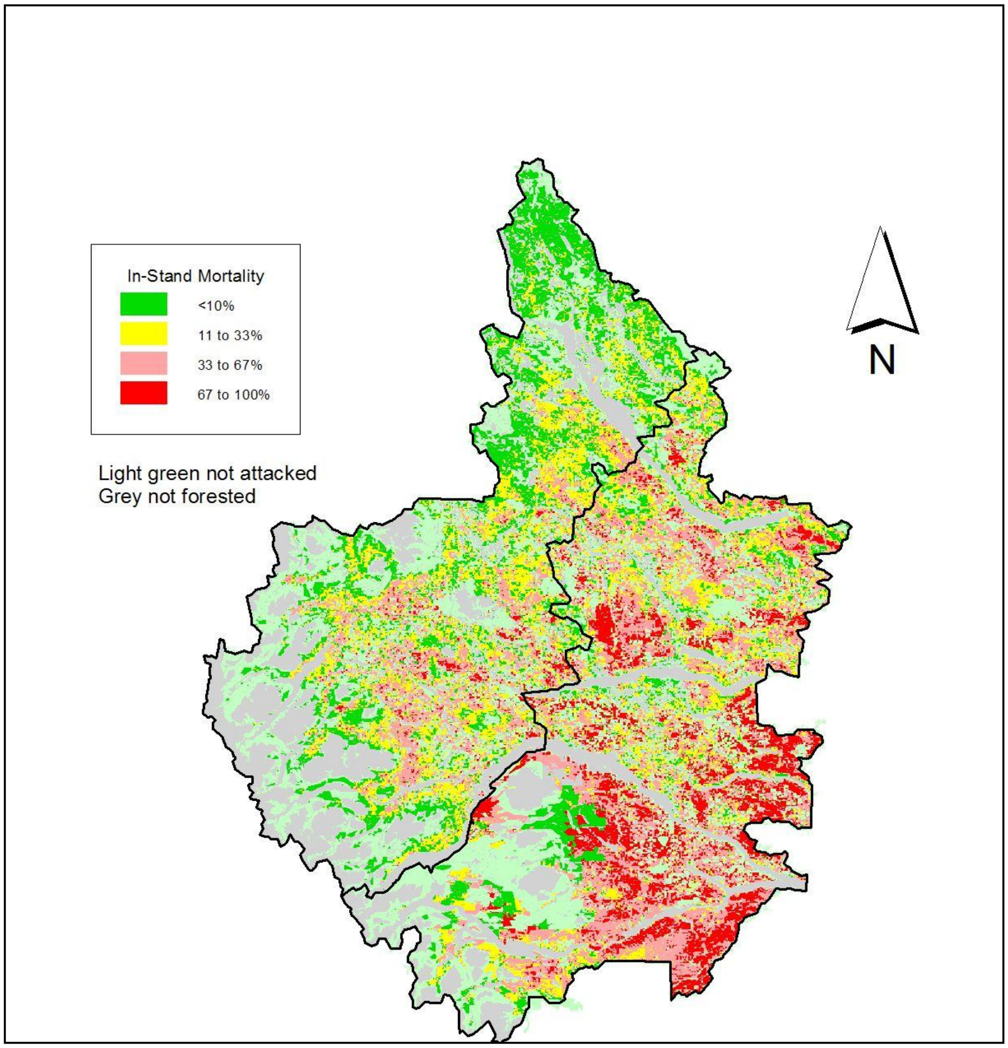

Figure 12. Mortality level in Nadina forest due to mountain pine beetle (data from Walton 2010).

Dothistroma needle blight

Dothistroma needle blight occurs in the Nadina. Historically, it infected immature pine and caused damage to plantations, mainly leading to reduced stocking. Recently, Dothistroma has become an epidemic in a portion of northwest BC, causing complete failure of 9% of pine plantations (Woods et al. 2005). It has also killed mature native lodgepole pine trees—a new phenomenon. Climate change has likely contributed to increased Dothistroma virulence.

Migration

Trees can respond to climate change by migrating to more suitable climatic conditions. Tree species have a relatively slow maximum migration rate of about 10 km per century (Aitken et al. 2008, McLachlan et al. 2005). Based on an intermediate emissions scenario (A1B), mean temperature is moving north at a rate of 11 to 43 km per century, but results vary with topography (Loarie et al. 2009). In many cases, trees will not be able to migrate fast enough to keep up with climate. Trees in mountainous terrain have less distance to migrate because large temperature changes occur over short distances, relative to flat terrain.

Barriers to movement and establishment include agricultural and urban lands and unsuitable soil conditions in the northern boreal regions and on mountain tops. As tree species try to establish in a new area, they may face novel combinations of tree species (competitors) and of pests and diseases that will inhibit colonization.

In summary, trees that manage to establish (if not maladapted) will probably grow faster (due to increased temperature and CO2) until they are killed early (due to increased disturbance).

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