Nadina Case Study

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Study Region

The Nadina Forest District covers about three million hectares in central British Columbia, reaching from Babine Lake in the North to Ootsa Lake in the south and from west of the town of Houston to east of the town of Burns Lake (Province of BC 2000; Province of BC 2007; Pacific Analytics et al. 2004) . It falls within the Bulkley-Nechako Regional District. The Nadina is sparsely populated (~14,000). Forestry dominates primary economic activity, but tourism, agriculture/ ranching and mining also occur. Land use plans for the Nadina identify objectives related to terrestrial and aquatic ecological integrity and for economic and recreation values.

The western portion of the Nadina is relatively mountainous, with exposed bedrock and incised streams. These western mountains are headwaters to both the Fraser and Skeena river systems. The eastern plateau portion contains many small streams and wetlands on shallow, low-relief glaciated terrain.

The western Nadina is influenced by coastal climate and dominated by the Engelmann Spruce Subalpine Fir (ESSF) Biogeoclimatic zone. For the purposes of considering climate change, we treat the eastern plateau portion of the Nadina, dominated by the Sub-Boreal Spruce and ESSF Biogeoclimatic zones, separately from the western mountains.

Projected changes in climate and disturbance

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 1). 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 may decline by 5 to 20% in the eastern plateau and by 20 to 40% in the western mountains (Rodenhuis et al. 2009). Across the Nadina, summer precipitation may either increase or decrease (see range of change, Table 1); rainfall in the western mountains may increase while rainfall in the eastern plateau may decrease. Climatic trends over the past century also support the projected shift towards a warmer, wetter climate (Rodenhuis et al. 2009). Climate variability (and hence weather extremes) is also expected to increase. The Pacific Decadal Oscillation and the El Niño/La Niña Southern Oscillation create variability in the Nadina climate and may mask climate change trends (Daust and Price 2011).

Predicted proportions of each BEC climate envelope vary substantially with climate projection (Table 2). Two of three climate projections show a near-total loss of SBS climate envelopes (mainly dk and mc2) from the Nadina; all three show a near-total loss of the ESSF (mainly mc; Table 2; Price and Daust 2012). Climate projections show an increasing proportion of wetter zones (Interior Cedar Hemlock [ICH] and Coastal Western Hemlock [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 (Wang et al. 2012).

Table 1. Historic median and weighted standard deviation of climate variables (for approximate location of Nadina from http://pacificclimate.org/tools-and-data/regional-analysis-tool); and projected median and range (90% of outcomes) of change for circa 2055 (2040 to 2070) 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).

Climate Variable	Historic Median ± W. Std. Dev.	Median Projected Change	Range of Projected Change
Annual mean temp (°C)	1.8 ± 0.9	+1.8 °C	+1.3 °C to +2.7 °C
Summer mean temp (°C)	11.8 ± 1.1	+1.6 °C	+1.2 °C to +2.8 °C
Winter mean temp (°C)	-8.7 ± 0.7	+1.8 °C	+0.6 °C to +2.8 °C
Annual precipitation (mm/day)	1.7 ± 0.8	+9%	+2 to +16%
Summer precipitation (mm/day)	1.7 ± 0.3	+2%	-7 to +11%
Winter precipitation (mm/day)	2.0 ± 1.3	+11%	-2 to +21%
Winter snowfall (mm)	167 ± 108	+7%	-4 to + 16%
Spring snowfall (mm)	51 ± 46	-52%	-68 to -10%
Growing degree days > 5 °C (degree-days)	864 ± 161	+213 (deg x days)	+127 to +394
Frost free days	216 ± 12	+18 days	+11 to +29

Table 2. Proportion of existing BEC Zone covered by projected climate envelopes (2055) for different scenarios. Hot and wet, hot and dry, and warm refer to the CGCM3_A2_R4, HadGEM_A1B_R1 and HadCM3_A2_R1 projections, respectively.

Existing Zone →	**ESSF** (476,000 ha)			**SBS** (1,890,000 ha)		
Scenario →	**Hot + wet**	**Hot + dry**	**Warm**	**Hot + wet**	**Hot + dry**	**Warm**
Projected Envelope ↓						
CWH	0.48	0.12	0.02	0.06	0.01	0.01
ESSF			0.11	0.00		
ICH	0.37	0.39	0.05	0.57	0.14	0.03
IDF	0.03	0.43	0.00	0.36	0.82	0.00
MS	0.04	0.01				
PP					0.03	
SBS	0.06	0.05	0.81	0.02		0.95

Climate drives disturbance regimes by affecting insect and disease populations and the probability of extreme weather (Table 3). Disturbance may be worse in the short and mid-term (a transition period) as disturbance agents spread into high densities of susceptible hosts (e.g., recent mountain pine beetle outbreak) or, conversely, worse in the long-term as climate change becomes more pronounced.

Table 3. Estimated increase in tree mortality from different disturbance agents due to climate change (rough estimates based on expert opinion: Daust 2010; Daust and Morgan 2011).

Agent	**Target**	**Projected mortality (relative to historic)**
Disease (e.g., Dothistroma, Commandra)	Mainly young stands	5 to 10 x
Insects (e.g., bark beetles)	Mainly mature stands	1.5 to 2 x
Fire	All stands	1 to 2 x
Drought	Establishment phase	5 to 10% loss of historic forest area
Extreme weather (e.g., ice storms)	All stands	expected to increase

Vulnerabilities

Hydrology and aquatic ecosystems

Aquatic ecosystems contribute to biodiversity and ecological integrity; they provide fish habitat and clean water. In general, the Nadina follows the climatic trends and related hydrological impacts projected for BC (see Hydrology and Aquatic Ecosystems).

Impacts to aquatic ecosystems arise from climate-induced changes to hydrological regimes (e.g., changes in the amount and timing of peak flows and low flows; Tables 4 and 5). Increased winter temperatures, increased precipitation and reduced snowfall in the spring (i.e., more precipitation falls as rain) 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. The main impacts to aquatic ecosystems, in approximate order of importance, include increased stream temperatures, increased instream erosion/scour (related to peak flow and landslides) and increased risk of landslides. Erosion and landslides can add sediment to streams, affecting aquatic communities and spawning beds. Increased peak flows and landslides also pose risk to infrastructure. In the Nadina, some salmon stocks and bull trout are particularly sensitive to increased water temperature. Studies of the Fraser River system indicate that increased water temperatures could pose a significant risk to salmon before the end of this century (Morrison et al. 2002).

Table 4. Estimated, climate-induced ecological changes that influence hydrology and aquatic ecosystems. Magnitude of change rated as low, moderate or high (L,M,H), with intermediate categories. Adaptation shows change in magnitude due to management.

Ecological Change	Location	Magnitude	Adaptation
Summer water temp ↑	temperature sensitive watersheds (similar in other watersheds)	H	→ H?
Spawning bed quality ↓	overall	H	→ MH
Peak flow ↑	western mountains eastern plateau	MH LM	→ M
Landslides and surface erosion ↑	overall	LM	→ L
Flood risk ↑ (but uncertain)	overall	L	→ L
Overland flow ↑	overall	L	→ L

Table 5. Estimated, climate-induced changes in ecosystem services relevant to fisheries and forestry. Adaptation shows change in magnitude due to management.

Ecosystem Service Change	Initial vulnerability	Adaptation
Risk to fish ↑	H	→ M
Risk to infrastructure due to increased peak flow and decreased slope stability ↑	L*	

* Infrastructure standard already increased to account for increased peak flows.

Forest and range ecosystems

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 (e.g., species vary in their tolerance to extreme cold or heat); it favours spread of weedy invasive species. Climate influences site moisture and nutrient conditions, affecting plant distributions. It influences disturbance regimes, determining seral stage and the associated plant community. In turn, plant communities, along with temperature, exert a large influence on invertebrate and vertebrate species distributions (Hunter 1990, Bunnell et al. 1999). This section focuses on changes in tree biomass and in stand age. The section on biodiversity and wildlife below discusses changes in plant communities.

Trees are both foundation species supporting biodiversity and an important source of wood fibre for local mills. Across a landscape, tree/timber stock and seral stage distribution depend on the rate of tree growth within each stand and on the probability of trees and stands surviving to old age.

Tree species vary in their ability to tolerate climate-driven environmental conditions (e.g., minimum temp, available moisture, minimum growing days, chilling period). Trees in the Nadina seem fairly resilient: existing tree species face minor risk of widespread establishment failure due to abiotic conditions (Daust 2011, Nitschke 2010). Although Engelmann spruce (*Picea engelmannii*) faces high risk, interior spruce (*Picea engelmannii x glauca*) does not. Within the SBS, dry sites are least resilient: water deficits in the growing season are expected to increase in drier subzones, particularly on dry site types. Douglas-fir (*Pseudotsuga menziesii*) will likely benefit from climate change, but lodgepole pine (on drier sites) and interior spruce (on mesic to moist sites) will likely remain dominant in higher elevation and frost-prone areas (Nitschke 2010). Black cottonwood (*Populus balsamifera ssp. trichocarpa*) may increase substantially on moist sites in the ESSF.

Net volume production is unlikely to increase in the Nadina during this century and could decline (Table 6). Projections of lower timber supply have also been made for BC and Canada (CNRTEE 2011). The effects of climate change on timber supply in the Nadina are highly uncertain, reflecting tradeoffs between increased growth (10 to 25%), due to longer, warmer growing seasons and increased carbon dioxide concentrations, and increased unsalvaged mortality (10 to 30%) due to increased natural disturbance from insects, disease, fire and drought (Table 7; Daust and Morgan 2011). Effects of tree mortality on timber supply depend greatly on amount salvaged, but post-disturbance harvesting is difficult to predict for two reasons. First, as disturbance increases, leading to more younger forest on the landscape, disturbed stands are more likely to be young and unmerchantable. Second, the periodic nature of disturbance can overwhelm harvesting capacity and/or market demand. In addition, future fire disturbance rates for the Nadina are highly uncertain.

Dry and fresh SBSdk ecosystems are currently used for agriculture in the Nadina plateau. Two of three projections suggest a substantial portion of the SBSdk will become drier (similar to an IDFxh climate). Agriculture may shift and/or expand. Agriculture was not a focus of the Nadina study.

The Nadina study did not explicitly examine impacts on soils. In general, workshop participants felt that nutrient regimes would take decades to respond to changes in moisture and temperature.

Table 6. Estimated climate-induced changes in ecosystem services relevant to the forest industry, prior to adaptation. Benefits of adaptation not estimated.

Ecosystem service change	Magnitude
Timber supply ↓	M-H
Percent salvage ↑	H
Plantation failures ↑	M
Road access per m^3 ↑	L
Shutdown periods ↑	L

Table 7. Estimated climate-induced ecological changes that influence timber supply and forest management costs. Magnitude of change rated as low, moderate or high (L,M,H), with intermediate categories. Adaptation shows change in magnitude due to management.

Ecological Change	Applicable subunit	Magnitude	Adaptation
Tree growth ↑	sites without moisture stress	M	
	sites with moisture limitations	L	
	overall	LM	→M
Bark beetle mortality ↑	pine component	H	
	spruce	MH	
	balsam	MH	
	overall	H	→LM over time*
Diseases of young stands ↑	pine leading plantations in SBS mc2	MH	→M
Fire mortality ↑	dry eastern plateau	H	→H?
	wet western mountains	L	
Maladaptation due to climate-stress ↑	dry sites	H	→H?
	moist and wet sites	L	
Forest-scale resilience ↓	may vary by BEC zone	M	→M

*due to natural restructuring of species and age classes and to increased plantation diversity

Biodiversity and wildlife

Climate change will affect plant community structure, with consequences for ecosystem function and resilience; it will likely lead to extirpation of some species from the Nadina (Table 8 and 9). As habitat area decreases, extirpation risk increases, especially for species that are strongly associated with particular habitats (Price et al. 2007). Extirpation risk arises from loss of climatically-suitable habitat (e.g., changes in temperature and growing season timing; climatic influences on site moisture and nutrient status) and from loss of old seral habitat, due to climate-induced disturbance. Anticipated increases in climate variability may lead to periodic extreme conditions that exceed species tolerances, even if most years remain suitable. Invasive species will also affect biodiversity in the Nadina, but the timing and magnitude of impact are difficult to determine. Currently, the cold climate in the Nadina limits the invasion of exotic species.

Based on climate projections summarized in Table 2, about 20% of plant species in the Nadina face extirpation risk (i.e., species found in the Nadina that are not associated with projected climate envelopes) in two projections (Price and Daust 2012). Future ecosystem function will also likely be compromised because many species associated with future climate envelopes do not occur in the

Nadina (about 50% in two projections) and may be unable to migrate (tree migration may not keep pace with climate change and habitat fragmentation hinders movement; Pearson 2006; McLachlan et al. 2005; Scott et al. 2009). Depauperate plant communities may impair ecosystem function and be less able to resist weedy invasive species.

Due to increased disturbance related to climate change, the area of old seral forest could decline to roughly 15% to 60% of historic natural abundance (i.e., abundance prior to industrial development) (Daust and Morgan 2011). Species strongly associated with old forest face an uncertain chance of extirpation, ranging from low (at 60% of natural old forest remaining) to high (at 15% of natural old forest remaining). Species strongly associated with old forest and a particular climate envelope face compounded risk.

Table 8. Estimated climate-induced changes in ecosystem services relevant to the forest industry, prior to adaptation. Adaptation shows change in magnitude due to management.

Ecosystem Service Change	Initial vulnerability	Adaptation
Simplified communities ↑	MH	→ M
Extirpation ↑	H	→ H
Ecological function/ resilience ↓	M	→ ML

Table 9. Estimated climate-induced ecological changes that influence biodiversity. Magnitude of change rated as low, moderate or high (L,M,H), with intermediate categories. Adaptation shows change in magnitude due to management.

Ecological Change	Location	Magnitude	Adaptation
Habitat			
Suitable microclimate and soil conditions ↓	bogs	H	→ M
	dry sites	MH	→ MH
	mesic to moist sites	LM	→ LM
	hydroriparian (varies by stream size, grade)	L to H	→ L to LM
Old forest ↓ and mixed-age forest ↑	SBS	H	→ M
	ESSF	MH	→ LM
Old forest connectivity ↓	hydroriparian	M	→ L
	upland	H	→ M
Species interactions			
Risk to specialized species and communities ↑	overall	MH	→ LM
Altered successional pathways (trees)	overall	LM	→ L
Invasive species ↑ (e.g., hawkweed)	SBSdk	H	→ H
	SBSmc	MH	→ M
	ESSF and BAFA	M	→ L

Recommended adaptation

The table below summarizes adaptation strategies designed to address the main climate-induced ecological changes expected to affect three types of ecosystem services in the Nadina District: trees and timber; biodiversity; hydrology and aquatic systems. Most strategies presented are not novel; however, they will need to be implemented more widely and thoroughly, with the underlying goal of learning more about their effectiveness.

Table 10. Climate-induced effects (bold) and adaptation strategies (bulleted) for hydrology and aquatic ecosystems, trees and timber, and biodiversity.

Hydrology and aquatic ecosystems
Increased stream temperature
▪ Retain riparian cover
▪ Properly maintain ditches and properly deactivate roads
▪ Avoid harvesting sites with high water tables
Increased risk of landslides and surface erosion
▪ Avoid locating roads and cutblocks on unstable terrain
▪ Design roads and drainage structures to accommodate increased peak flow and bedload transport in areas likely to become wetter
Increased peak flows (western mountains)
▪ Limit ECA[1] to 30 to 50% of THLB
Trees and Timber
Increased tree growth potential on sites with sufficient moisture
▪ Plant climatically-suited species and genetic stock
▪ Fertilize appropriate sites
▪ Partially-cut stands on dry sites
Increased tree disease virulence (mainly younger stands)
▪ Plant climatically-suited species and genetic stock
▪ Increase stand-scale species diversity
▪ Remove stumps with root disease
Increased bark beetle virulence (mainly older stands)
▪ Plant climatically-suited species and genetic stock
▪ Increase stand-scale species diversity
▪ Shorten rotations of susceptible stands
▪ Monitor and control beetle populations
Increased fire hazard (all stands)
▪ Control human access during high hazard times
▪ Reduce post-harvest fuels

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[1] Equivalent Clearcut Area: percent of basin that functions hydrologically as though it were clearcut (calculation assumes hydrological recovery of disturbed sites is a function of tree height).

▪ Leave fire-breaks
▪ Provide more and better fire-suppression equipment on site
▪ Improve access for fire suppression
Biodiversity
Loss of old forest habitat and connectivity due to increased tree mortality
▪ Create a network of reserves, corridors and wildlife tree patches; limit salvage in network
▪ Reduce disturbance from insects, disease and fire across the landscape
Loss of suitable microclimate and soil conditions following harvest (e.g., dry sites, brushy sites)
▪ Avoid harvesting sensitive sites
▪ Partially-cut stands on dry sites
▪ Retain down wood
▪ Rapidly reforest sites
Loss of young forest vigour and diversity due to species maladaptation to changing climate
▪ Retain naturally-occurring and regenerating species and plant a diverse species mix
▪ Use stand tending to influence successional pathways
▪ Plant climatically-suited species and genotypes
Increased spread of invasive species
▪ Minimize roads
▪ Minimize road use
▪ Minimize grazing
▪ Minimize site disturbance

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