Potential future of major British Columbian park land forest tree species and the effects of climate change on park tree health

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Abstract:

Parks and protected areas in British Columbia are responsible for the protection and maintenance of biological diversity, natural ecosystems, and species at risk while integrating these goals with outdoor recreation opportunities for the public. Parks have been criticized for not meeting stated goals of ecological integrity, and for taking little action to ensure the conservation of ecological integrity. Management plans are dated and incomplete and there are concerns that efficacy of park networks and management in meeting the stated ecological integrity goals will be degraded further under a changing climate. In recognition of these criticisms B.C. Parks have stated strategies which involve the use of scientific research and technologies in their decision making processes. Mortality of trees due to direct and indirect effects of changing climate will have an impact both on goals of ecological integrity and quality outdoor recreation opportunities for the public. An approach developed by Coops et al. (2011) that uses empirical and process based (3-PG) data for tree species range change in B.C. was applied to 14 widespread coniferous B.C. species. Future predicted ranged under the intergovernmental panel on climate change emission scenarios A2 and B1 were produced at 3 future timesteps. This predicted data was then used to produce maps of stressed area of each species current range within B.C. parks. These data were subdivided by B.C. ecoprovince ranges. Creation of stressed park range areas was highly variable between species (0%-73% of current protected park ranges) and ecoprovinces (2%-55% of current protected species ranges). Parks in the Southern Alaska Mountains and Northern Boreal mountains had the greatest stress proportions. Whitebark pine showed the most stress area under climate change, and amabilis fir the least. A2 scenario conditions had higher rates of stress range production than B1 for most species and ecoprovinces. The results show that resistance of parks to the effects of climate change is dependent on the species present. As parks increase their efforts to meet stated goals of ecological integrity studies such as this will be necessary if the decision making process is to remain relevant in a changing climate.

Key words: parks, protected lands, climate change, species range, stress, model, British Columbia, disturbance

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Introduction:

The Intergovernmental Panel on Climate Change (IPCC) has concluded that climate change is occurring and is being accelerated by anthropogenic processes which increase the concentrations of greenhouse gasses such as CO_2 and CH_4 in Earth's atmosphere (Nakicenovic et al., 2001). Changes in climate may include temperature increases as well as redistribution of precipitation both temporally and spatially. These changes are expected to occur at a higher rate relative to naturally occurring climate change processes, with measurable changes already having been documented. Changes in regional climate may cause plant and animal species which were once well adapted to become closer to the boundaries of their realized niche or result in species living outside of their current range of tolerance (Aitken et al. 2008; Luckman & Kavanagh, 2000). In contrast some these changes in climate may be beneficial in other regions of the same species' range, or make new ranges available to be colonized. Parks and protected areas (parks) in British Columbia (B.C.) are not immune from the effects of climate change and to accomplish their goals of conservation they will need to use species prediction data in order to capture the species diversity and species communities in the future(Scott & Lemieux, 2005; Ministry of Environment, 2008; McAffee, 2005; Scott & Lemieux, 2005; Scott, Malcolm, & Lemieux, 2002). This study uses the realized niches of 14 British Columbian tree species and predicts their future stressed ranges.

The parks and protected areas of British Columbia are largely charged with the responsibility of conserving biological diversity and entire ecosystem types (Parks Canada, 2009; Hannah et al., 2002). In response to the negative results of the Report of the panel on Ecological Integrity of Canada's Parks in 2000, Parks Canada has reaffirmed that its first goal is ecological integrity which is defined as the state at which an ecosystem has it's native components (including plant and animal species) and processes intact(Parks Canada, 2009). The 2007-2012 BC Parks Program Plan also states ecological integrity as part of its number one goal. The strategies provided in the BC Parks Program Plan to accomplish this goal include utilization of technology and research to guide decisions, as well as implementation of management strategies that will "increase the resiliency and adaptability of the parks and protected areas system with respect to climate change."(Ministry of Environment, 2008). These difficult goals face a number of environmental challenges, many of which will be imposed by changing climate.

The fundamental niche of a species is described by Whittaker, Levin and Root (1973) as "an *n*-dimensional hypervolume, at every point in which environmental conditions would permit the species to exist indefinitely" (Whittaker, Levin, & Root, 1973). In this case, *n* represents the number of potential limiting factors on the species, such as soil moisture or air temperature in the case of forest trees. At the edges of this hypervolume limiting factors are inducing stresses on species, although the species can persist under these stresses in the absence of disturbance and competitive pressures from biotic and abiotic sources. Situations where external pressures do not exist are rare, and the low vigour of an individual living at the edge of its realized niche does not promote its ability to remain in these conditions. The range that we see species existing within is called the realized niche of the species. As described by Whittaker *et al*. (1973) we use the realized niche to describe the range of the fundamental niche which is actually occupied by the species in nature and excludes the regions of the hypervolume that the species is not found in nature due to interactions with disturbance vectors. The realized niche is the range of the limiting factors that we observe the species occurring in natural settings, and therefore these ranges provide the abiotic data that we can use to predict species range.

Currently standing trees and their descendants will face new disturbance regimes which they cannot escape (Aitken et al., 2008; Ayres & Lombardero, 2000; Scott, Jones, & Konopek, 2007). Trees already in habitats that are at an edge of their realized niches may be the most heavily affected either in a positive or a negative way depending on the changes to its growth limiting factors such as frost timing or soil water content. Changes in these purely climatic deterministic variables can be modeled using climate change predictions, however it is important to remember that because we are modeling the realized niche of the species, it does not mean that the new range maps created by the model represent the only areas that the species can live. We describe existing trees that are not within the modeled realized niche in our future projections to top be experiencing stressed conditions because they are no longer in climatic conditions we considered ideal according to empirical data on the current range.

Indirect climate change pressures on trees include insect pest damage, wildfire potential, drought, and forest pathogens, the extent of the effects of any of these are difficult to predict(Aitken et al., 2008; Ayres & Lombardero, 2000; Campbell & Antos, 2000; Garrett et al. 2006; Johnson & Larsen, 1991). Insect damage has received much attention in BC due to mountain pine beetle's (*Dendroctonus ponderosae*) massive effects on forestry economics (Snetsinger, 2005). Increased winter temperatures leading to higher overwintering survival rates are given part of the credit for the pine beetles increased success (Hicke et al. 2006)(Carroll et al. 2004). Warmer climates also promote faster rates of insect pest development and a reduction in the length of time to reach breeding stage which leads to more generations per season and quicker adaptation to host defenses (Ayres & Lombardero, 2000; Porter, Parry, & Carter, 1991). Blue stain fungus (*Grosmannia clavigera)* ensures the death of the beetle attacked trees by blocking the trees nutrient transporting phloem layer (Ballard et al., 1984). Fungal pathogens can increase in effect without assistance from an insect vector for many of the same reasons as insect pests including better overwinter survival and quicker reproductive cycles(Campbell & Antos, 2000)(Woods, Coates et al., 2005). Interactions between biotic and abiotic disturbances can increase tree mortality. A management concern in this respect is increased fire risk due to higher fuel loads caused by biotic disturbances induced mortality (Johnson & Larsen, 1991).

Using empirical methods as well as a process based productivity model (the 3-PG model) the realized niche boundaries of B.C. forest conifer species have been mapped (Coops et al. 2011). By using historical climate data combined with the 3-PG productivity model we were able to create a predictive model for each desired species. Previous models have also employed empirical data to determine importance of climate variables (Hamann & Wang, 2006; Iverson & Prasad, 2001) and have utilized regression tree models to determine variables of importance and their weightings (Iverson & Prasad, 2001). Mechanistic approaches such as provenance tests have also been used historically to determine species range viability (Aitken et al., 2008; Stape et al., 2004). Our model combines the empirical regression tree techniques with the process (3-PG) model allowing us to distinguish which climatic factors affect species vigor the most. The 3-PG model has the ability to show non-linear biological response of the tree species where purely empirical models do not by predicting photosynthesis responses (Landsberg et al., 2003). Our technique allows us to define increases in species ranges that are created by climatically facilitated photosynthesis increase and also to find areas of the species range that will be located in increasingly stressful conditions due a reduction in photosynthetic capacity or introduction of competition and disturbance forces.

Although attention is often be focused on modeling potential new range and the challenges related to species capacity to reach these areas, the management challenges found for species that are becoming stressed in their current range is often a low priority. It should not be assumed that because the climatic envelope of an ecosystem changes, that all of the individual species of that ecosystem type are able to migrate at the same pace or remain in the historical range. The ability of species to relocate or adapt is highly variable and dependent upon mobility, genetic diversity, generation length, genetic plasticity, and fecundity (Aitken et al., 2008; Hamann & Wang, 2006). In this paper the focus is on tree species where natural adult migration is a non-factor. These adult trees often have long life spans on the order of hundreds of years and throughout their lifespan will experience new climatic conditions (Forest Practices Branch, 2008).

The goals of this paper are: 1) to predict future areas of stress for selected species, 2) to relate the changes in species range to parks and protected lands in British Columbia with emphasis on management challenges and the achievability of stated goals, 3) to show that the model can be used as a valid management tool for B.C. Parks.

Methods:

Study area:

This extent of this study is limited to British Columbia. We look specifically at parks (Provincial and National), ecological reserves, conservancies, and protected areas within the province which for this study we will collectively call parks (Ministry of Environment, 2008). The parks network consists of 1013 unique protected areas represented by 1080 polygons in the map shapefile (Webb & Ogborne, 2004) (Figure 1). To produce meaningful results we used another publically available B.C. map of Ecoprovinces to divide the provincial landbase into 10 sub-provinces (Figure 2, Table 1). Ecoprovinces were chosen because they are produced at a 1:2,000,000 scale and are designed for provincial state of the environment reporting (Demarchi, 1996). Ecodivisions (6 terrestrial divisions) are coarser and provide less information and Ecoregions (43 regions) were finer than necessary for the scope of this study.

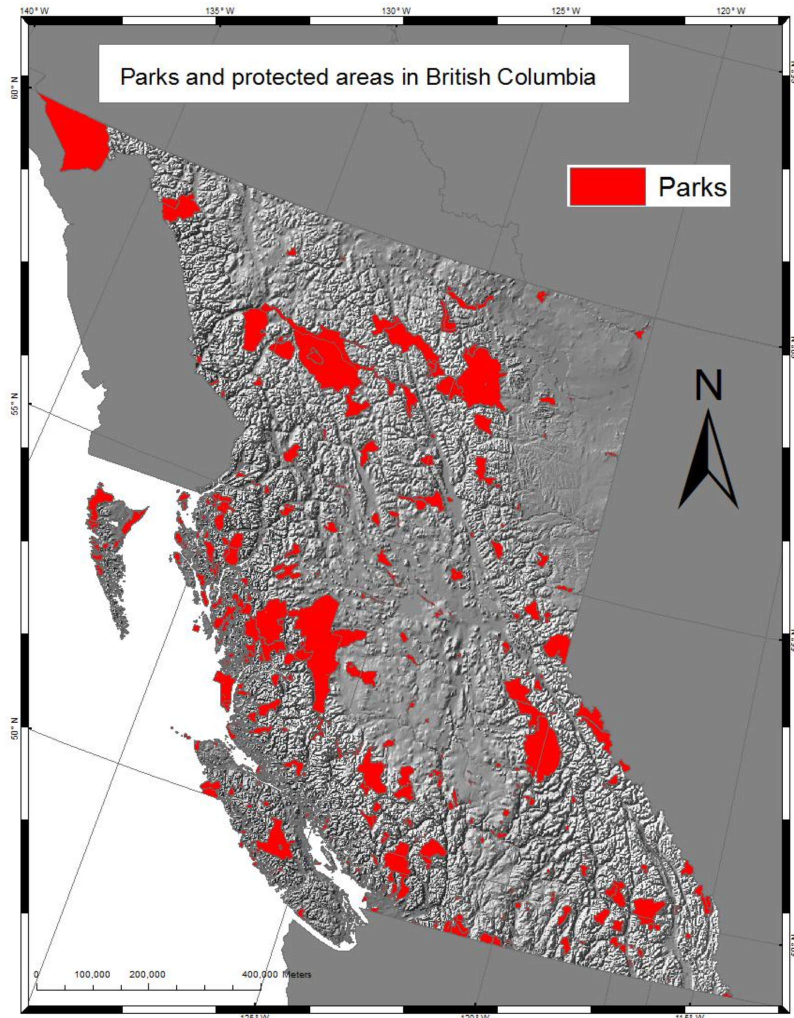

Figure 1: Map showing parks and protected areas in British Columbia

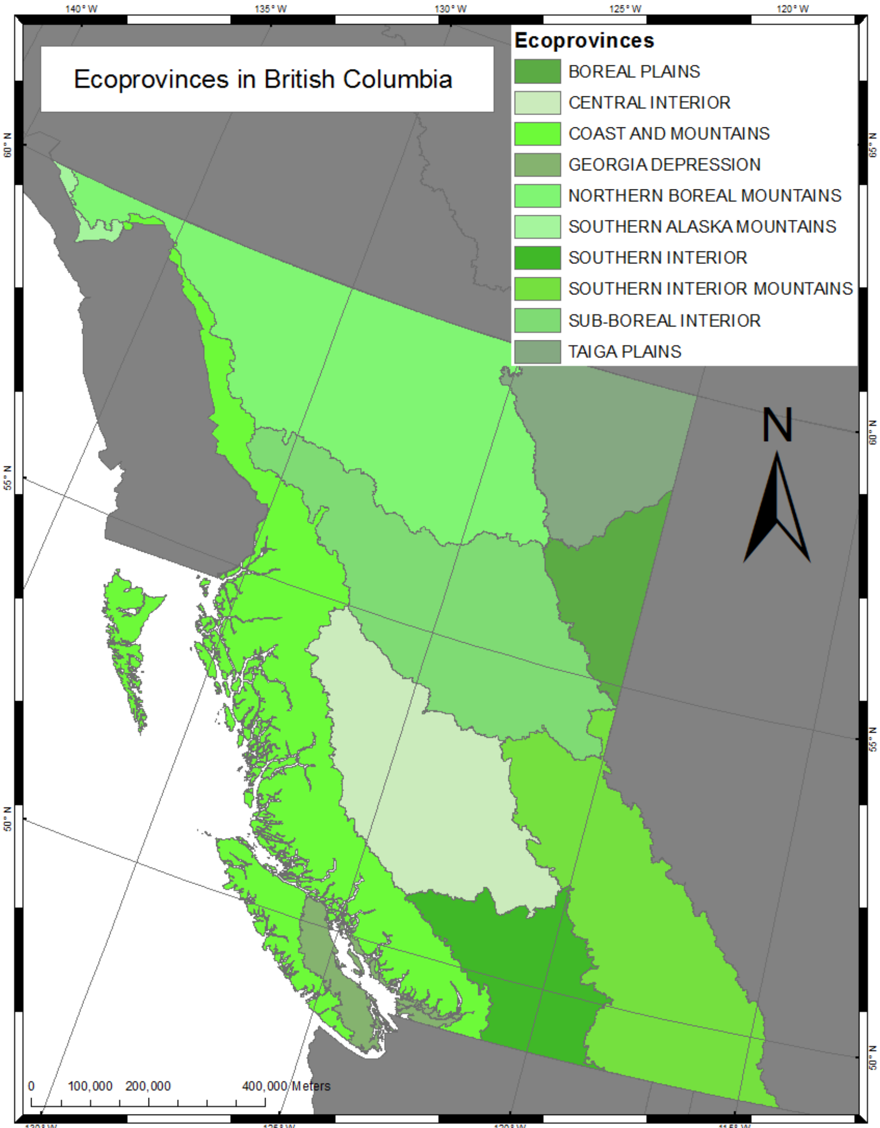

Figure 2: Map showing the boundaries of ecoprovinces in British Columbia

Table 1: Ecoprovince name, abbreviation, area, park area in ecoprovince, and percentage of ecoprovince that is park land

Ecoprovince name	Abbreviation	Ecoprovince area (km2)	Ecoprovince park area (km2)	Ecoprovince park %
SOUTHERN ALASKA MOUNTAINS	SAL	3528.6	3528.6	100%
NORTHERN BOREAL MOUNTAINS	NBM	188988.6	39493.7	21%
TAIGA PLAINS	TAP	69519.4	1448.9	2%
BOREAL PLAINS	BOP	37935.6	329.7	1%
SUB-BOREAL INTERIOR	SBI	138786.3	9078.6	7%
SOUTHERN INTERIOR MOUNTAINS	SIM	138692.9	20360.7	15%
SOUTHERN INTERIOR	SOI	56463.0	5125.1	9%
COAST AND MOUNTAINS	COM	182274.9	35321.6	19%
GEORGIA DEPRESSION	GED	18332.6	2144.7	12%
CENTRAL INTERIOR	CEI	111356.7	17433.0	16%

Focus Species:

14 of the most common forest canopy coniferous tree species were analyzed in this study. These include Douglas-fir (*Psuedotsuga menziesii*), Grand fir (*Abies grandis*), Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), mountain hemlock (*Tsuga mertensiana*), ponderosa pine (*Pinus ponderosea*), amabalis (pacific silver) fir (*Abies amabalis*), subalpine fir (*Abies lasiocarpa*), Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), western larch (*Larix occidentalis*), whitebark pine (*Pinus albicaulis*), western red cedar (*Thuja plicata*), and yellow cedar (*Chamaecyparis nootkatensis*). They were chosen on the basis of their frequency of occurrence in plots and species modeling accuracies. Many of these species are of high economic value and can be dominant species making up a large portion of canopy composition (Forest Practices Branch, 2008).

Modeling approach:

For this study we used the model created by Coops et al. (2011). For this model, climate data was input into the 3-PG model for the wide spread Douglas-fir (*Psuedotsuga menziesii*) to create continuous "generic tree" maps showing the relative effects of each climate variable on the tree's productivity. Using empirical data on tree species presence or absence gathered from the United States Forest Service Forest Inventory and Analysis program plots (Bechtold & Patterson, 2005), and British Columbian data from the Provincial Ecology Program plots (Forest Science Program, B.C. Ministry of Forests, 2001) weightings were extrapolated for each variable using the Decision Tree REGression model (DTREG) (Sherrod, 2003). These weightings show which climatic factors are limiting each species' range. Species maps based on historical climate data, intended to represent current species ranges were used to validate the accuracy of the model. The weights produced by the regression program for each species were then applied to climate scenarios and predicted distributions for the species were produced.

Two of the IPCC's four climate change scenarios (A2 and B1) were chosen for use in this paper (Nakicenovic et al., 2001). These scenarios where chosen to display the sensitivity of the models and to show differences in the degree of range change prediction between two highly researched, plausible futures. Both of these climate projections include increased global average temperatures. The A2 emissions scenario represents a world where global issues of climate are not addressed due to inward looking geopolitical regions. Fuel usages vary regionally depending on technology and wealth. The A2 scenario predicts some of the highest temperature increases of 2.0-5.4°C by year 2100. In contrast the B1 emissions scenario represents increased environmental and social consciousness leading to sustainable practices of development. This represents the best scenario with temperature increases of 1.1-2.9°C projected by 2100. Three timesteps were applied at thirty year intervals for years 2020, 2050, and 2080.

Analysis:

ArcMap™ was used to produce, modify, and analyze the predicted species range data layers produced (Environmental Systems Research Institute, 2011). A total of 98 species range layers were imported into the ArcMap program. 14 of these were the species ranges representing the current extent of the species. The first step in the analysis was using the Raster Calculator tool to subtract each range prediction layer from the full species ranges leaving a layer that shows where the species is currently present, but expected to be outside of its realized niche at the future time (stressed). 84 of these layers were produced corresponding to the 14 species each with 2 climate scenarios and 3 timesteps.

Secondly, from these stress layers, new map layers were produced to show the extent of the stress within parks and thirdly, the amount of within-park stress in each ecoprovince. These were created by first using the Merge tool to merge the Ecoprovince layer with the Parks layer, resulting in a layer with the spatial extent of Parks that had the attributes of both parks and ecoprovinces. The Zonal

Statistics tool was then used with each of the 84 stress layers to produce thematic map layers displaying sums of stress area within parks and sums of park stress area grouped by ecoprovince. Sum of park stress area by ecoprovince was identified from these final layers. Sum terrestrial areas for ecoprovinces, parks, and park groupings within each ecoprovince were produced to compare stress areas and create stress proportions (Table 1).

Data generated in ArcMap™ was entered into Microsoft® Excel® 2010 for organization and analysis. Sums of stress area for each species and ecoprovince were calculated for the timesteps of each scenario. Proportions of total historic B.C. park species range stressed were produced, subdivided by ecoprovince. Proportions of total B.C. park range that becomes stressed for each species were also calculated.

Results:

Scenarios:

The A2 scenario showed larger stress areas for 10 species at every model time over all of B.C. compared to the B1 scenario (Table 2). Ponderosa pine was the only species that consistently did not follow this trend. Stress area sums in B.C. for this species were higher in B1 at each model time by 24, 133, and 19km^2 for 2020, 2050, and 2080 respectively. Douglas fir in 2020 and 2080, Lodgepole pine in 2020 and 2050, and Grand fir in 2020 also showed greater stress areas in the B1 vs. A2 scenarios. The other 10 species had lower stress areas in the B1 scenario by a range of 8 to 16739km^2. Large proportional differences (over 200% of B1 stress) between scenarios are shown in yellow cedar, Engelmann spruce, mountain hemlock, subalpine fir, and western red cedar. Other species such as Sitka spruce also showed large proportional differences at some modeling times, but their low stress area totals mean these results are more difficult to interpret.

Table 2: Park stress areas for all of B.C. by species showing differences in stress area between A2 and B1 scenarios. Positive differences bolded and shaded.

Species	Stress areas in km^2 for all of B.C.								
	A2 2020	B1 2020	Difference	A2 2050	B1 2050	Difference	A2 2080	B1 2080	Difference
GRAND FIR	2438	2475	**37**	4197	3068	-1129	7835	4693	-3142
DOUGLAS-FIR	382	1110	**728**	126	47	-79	109	838	**729**
ENGELMANN SPRUCE	2148	1003	-1145	4273.5	1220	-3053.5	6616	2038	-4578
LODGEPOLE PINE	8451	10330	**1879**	9307	9659	**352**	15455	13607	-1848
MOUNTAIN HEMLOCK	5941	4628	-1313	10891	7221	-3670	18374	7193	-11181
PONDEROSA PINE	428	452	**24**	253	386	**133**	276	295	**19**
AMABILIS FIR	13	0	-13	9	0	-9	49	0	-49
SUBALPINE FIR	4789	4385	-404	8086	5750	-2336	21334	8968	-12366
SITKA SPRUCE	404	11	-393	245	16	-229	129	35	-94
WESTERN HEMLOCK	222	7	-215	63	7	-56	15	7	-8
WESTERN LARCH	411	302	-109	428	290	-138	933	454	-479
WHITEBARK PINE	19417	17629	-1788	28940	21938	-7002	41607	24868	-16739
WESTERN RED CEDAR	221	26	-195	110	51	-59	156	19	-137
YELLOW CEDAR	149	109	-40	617	148	-469	1179	430	-749

Table 3: Park stress area for ecoprovinces showing differences in stress area between A2 and B1 scenarios. Positive differences bolded and shaded

Ecoprovince	Stress area in km^2 for all species								
	A2 2020	B1 2020	Difference	A2 2050	B1 2050	Difference	A2 2080	B1 2080	Difference
SOUTHERN ALASKA MOUNTAINS (SAL)	400	335	-65	483	463	-20	631	502	-129
CENTRAL INTERIOR (CEI)	5163	5303	**140**	9054	5657	-3397	18805	8151	-10654
GEORGIA DEPRESSION (GED)	1274	1055	-219	2151	1316	-835	3426	1631	-1795
SOUTHERN INTERIOR (SOI)	2556	2727	**171**	3930	3067	-863	8201	4058	-4143
SOUTHERN INTERIOR MOUNTAINS (SIM)	10603	9858	-745	13732	11531	-2201	23240	14135	-9105
SUB-BOREAL INTERIOR (SBI)	2685	2721	**36**	3781	3006	-775	5403	3639	-1764
BOREAL PLAINS (BOP)	69	62	-7	30	48	**18**	108	50	-58
TAIGA PLAINS (TAP)	11	4	-7	15.5	15	-0.5	59	26	-33
NORTHERN BOREAL MOUNTAINS (NBM)	6728	5967	-761	8702	6772	-1930	11858	8861	-2997
COAST AND MOUNTAINS (COM)	16034	14435	-1599	25814	17926	-7888	42522	22392	-20130
TOTAL (BC)	45523	42467	-3056	67791	49801	-17990	114346	63445	-50901

Greater stress area for the A2 scenario was also seen in the ecoprovince divisions (Table 3). Again there were a few exceptions with CEI, SOI, and SBI showing greater total stress across all species in B1 2020, and BOP having greater stress in B1 2050. Stress area differences by ecoprovince between scenarios ranged from 7 to 20130km^2. Because the park area in each ecoprovince varies considerably, proportions of stress change (A2/B1 stress area) can be used to compare between ecoprovince responses. Proportionally CEI, GED, SOI, TAP, and COM ecoprovinces showed the largest stress differences between scenarios at all timesteps. Some high values can also be found for ecoprovinces where stress area totals are small, but as with species stress proportions these low area ecoprovinces should be looked at critically.

Species:

Percentage of park range that becomes stressed is highly variable between species for the same timestep and scenario (Table 4 in appendix). The species which develops the largest proportion of stressed area is whitebark pine with 73% of B.C. park range stressed in 2080 using the A2 scenario whereas amabilis fir shows no future stress in its current range. Four species exceeded 20% park range stressed by 2020 in both the A2 and B1 scenario. Three species in the A2 scenario and 4 species in the B1 scenario do not show any loss of park habitat range with climate change.

Time:

A strong trend can be seen in the summed percentages of stressed park range for tree species in the A2 scenario where stress area becomes a larger percentage of B.C. park area or does not decrease at later timesteps for 9 of 14 species (Figure 3). Exceptions to this trend (by >1%) include Douglas-fir,ponderosa pine, Sitka spruce, and to a lesser degree, western hemlock and western red cedar (Table 4). Similar exceptions where seen in the B1 scenarion where 3 species did not show highest stress at the 2080 timestep (Table 4). At the ecoprovince level stress area sums increased with each timestep for all

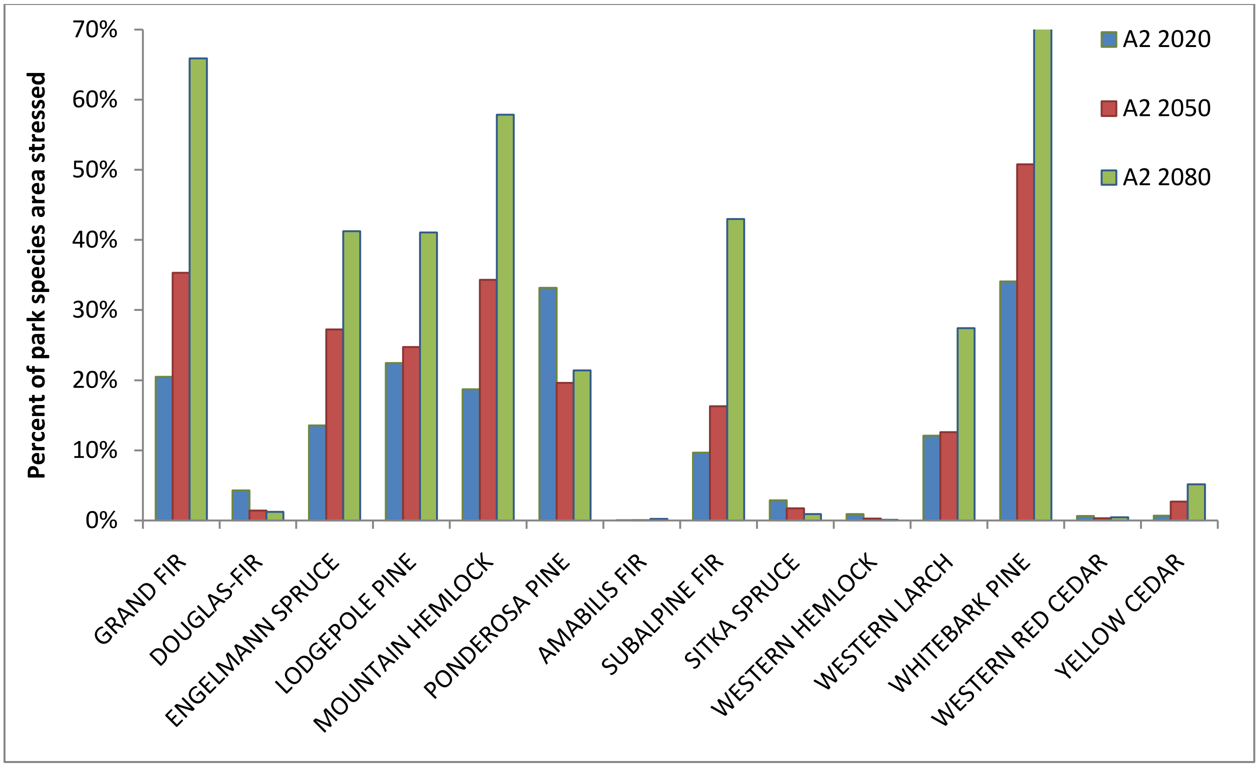

Figure 3: Percent of tree species park range stressed in British Columbia in the A2 scenario

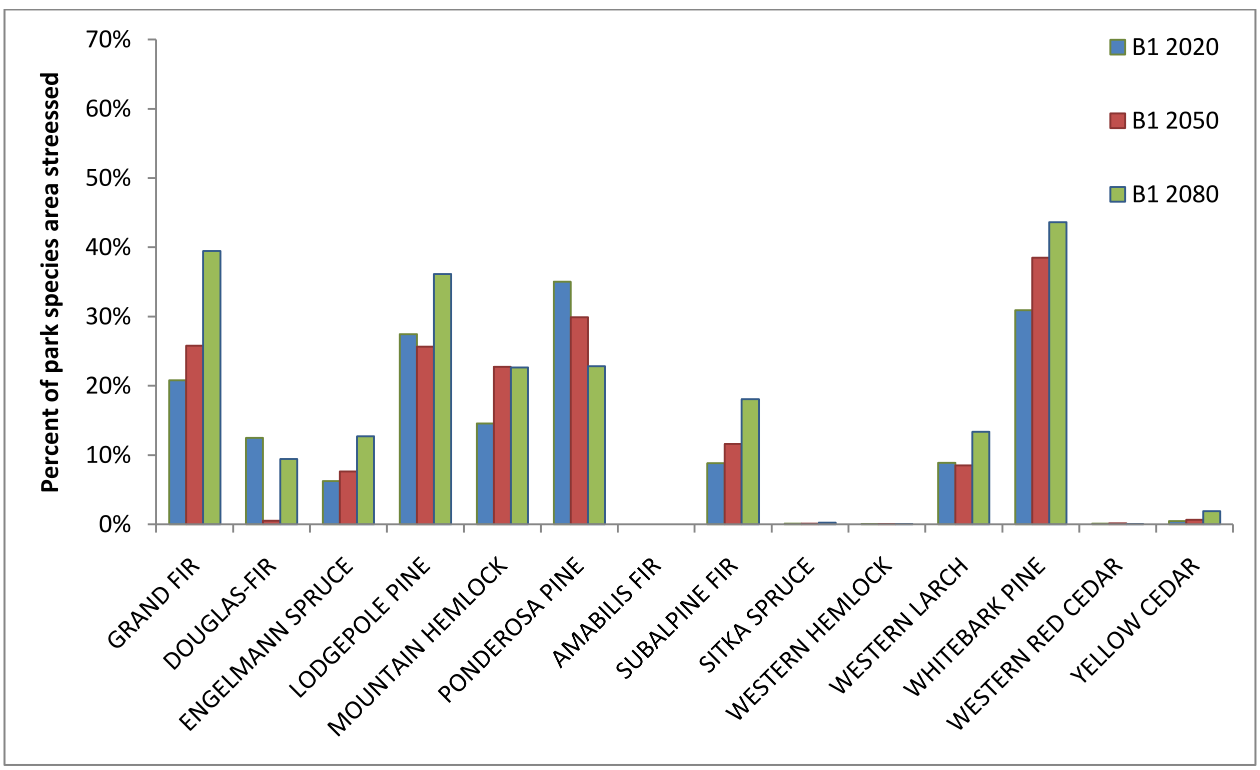

Figure 4: Percent of tree species park range stressed in British Columbia in the B1 scenario

ecoprovinces with the exception of BOP in A2 which had a drop in 2050 because of low lodgepole pine stress area relative to 2020 (Figures 5,6).

Ecoprovince:

Greatest park stress area summed across all species is found in the COM ecoprovince for both scenarios at each time step (Figures 5,6). As a percent of the ecoprovinces park range the NBM and SAL ecoprovinces have the most stressed park area due to large losses of whitebark pine and lodgepole pine range in both scenarios, and a large (1352km^2) increase in subalpine fir range loss at the 2080 time step of the A2 (Figures 7,8). This is especially significant in the NBM ecoprovince because it contains the largest park area of any ecoprovince (Table 1).

Discussion:

Scenarios:

As expected from its greater climate change amplitude, the A2 scenario had a greater effect on tree species ranges than the B1 scenario. Exceptions to this general trend with ponderosa pine were surprising, but we believe our findings are analogous to those of Hamann and Wang who saw the largest percent habitat loss in their first timestep (2025) and constant decrease in habitat loss in later timesteps (Hamann & Wang, 2006). It is important to remember that our data is of a subset (parks) of the range used by Hamann and Wang (B.C.) and some of the differences in proportion data may be a result this. Because the A2 scenario should have similar climate to later timesteps in the B1, it is intuitive that the climate change effects that are reducing stress over time in the B1 scenario are magnified in the A2. The only other species in the study by Hamann and Wang that this trend occurred in was bitter cherry (*Prunus virginiana*) although decreases in habitat loss area at one timestep occurred in 7 other tree species. Two of these 7 are species that make up a dominant portion climax forest canopy: Douglas-fir

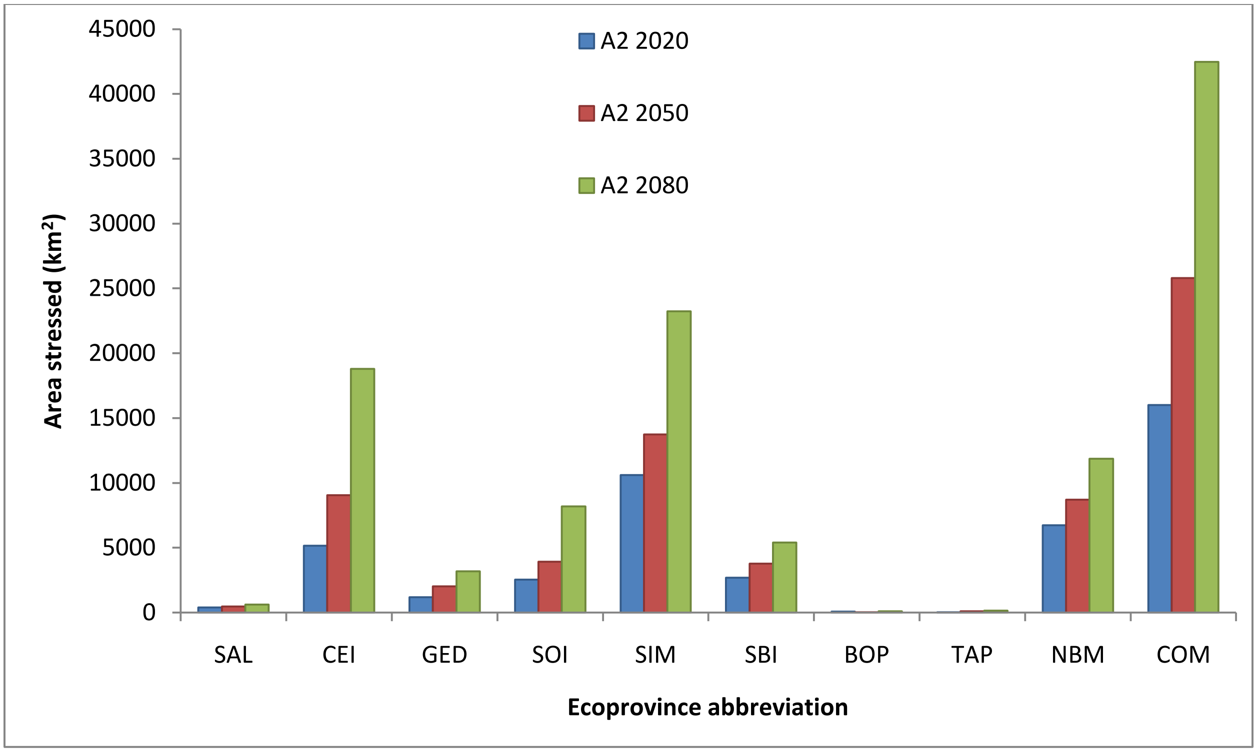

Figure 5: Sum of all species stress ranges by ecoprovince in the A2 scenario (km^2)

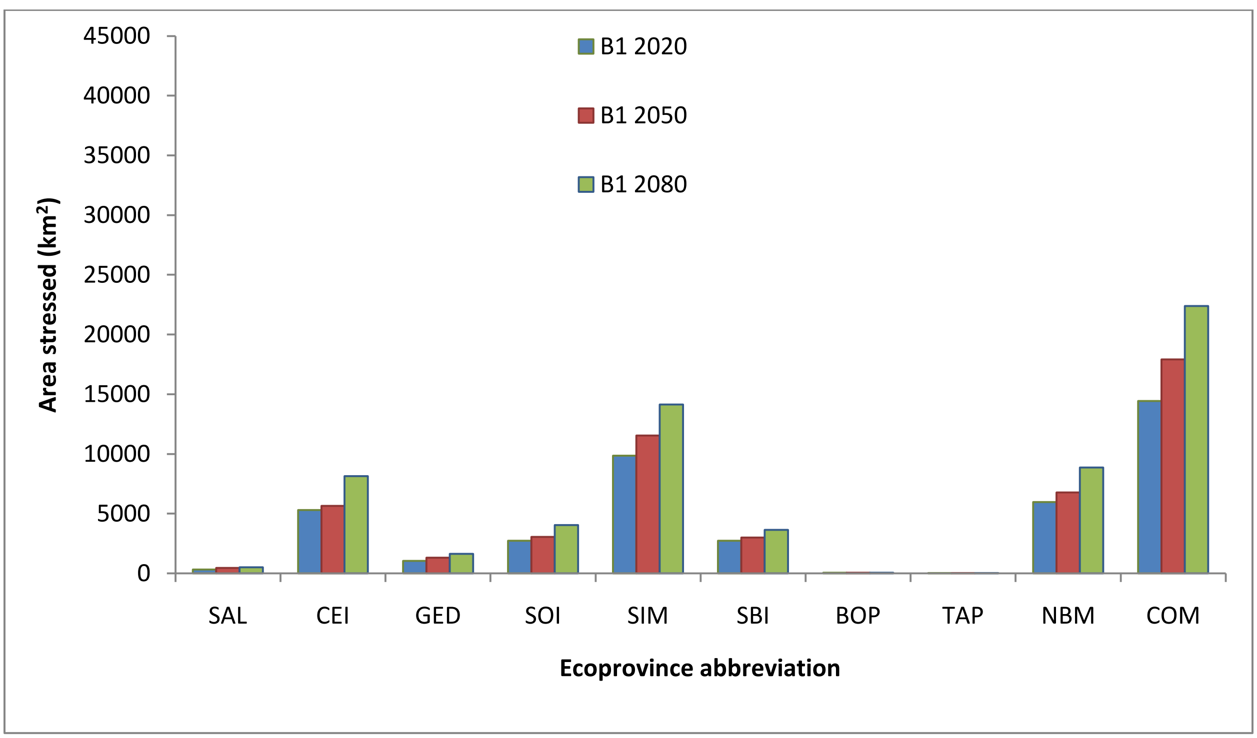

Figure 6: Sum of all species stress ranges by ecoprovince in the B1 scenario (km^2)

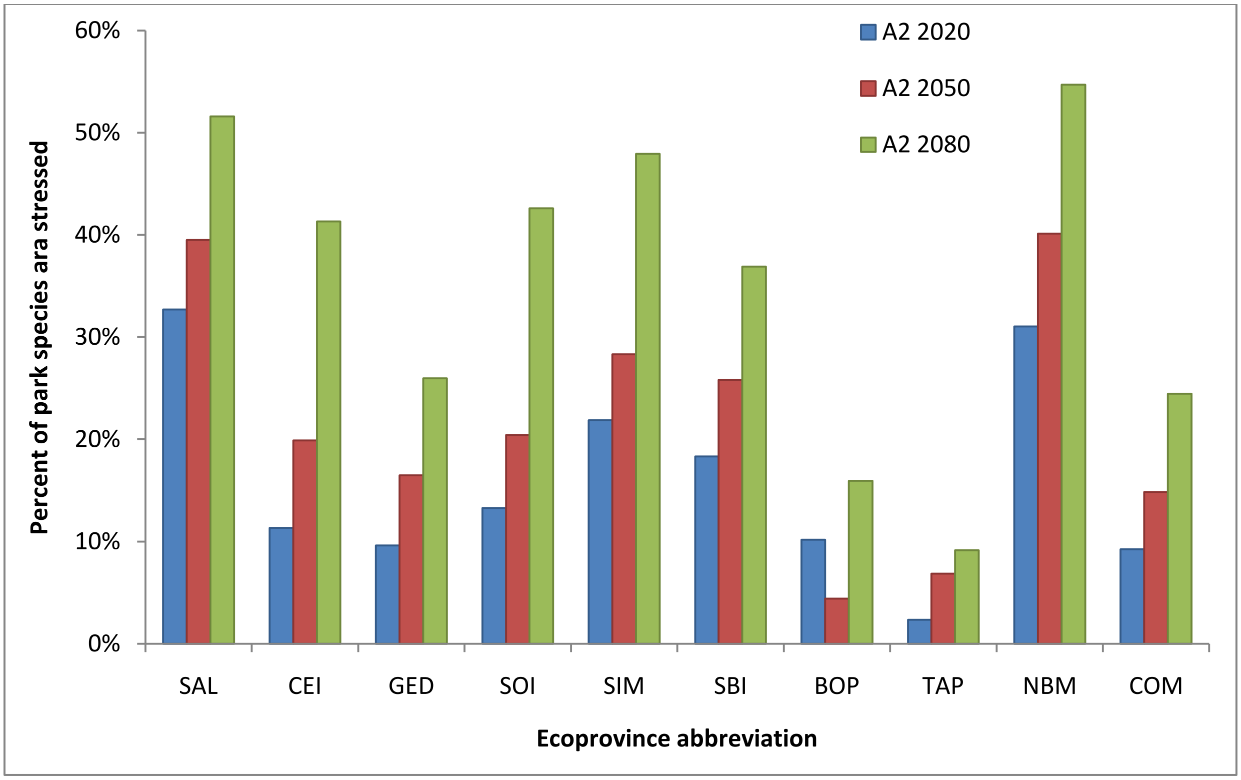

Figure 7: Sum of all species stress area for the A2 scenario as a percent of current ecoprovince area for all species

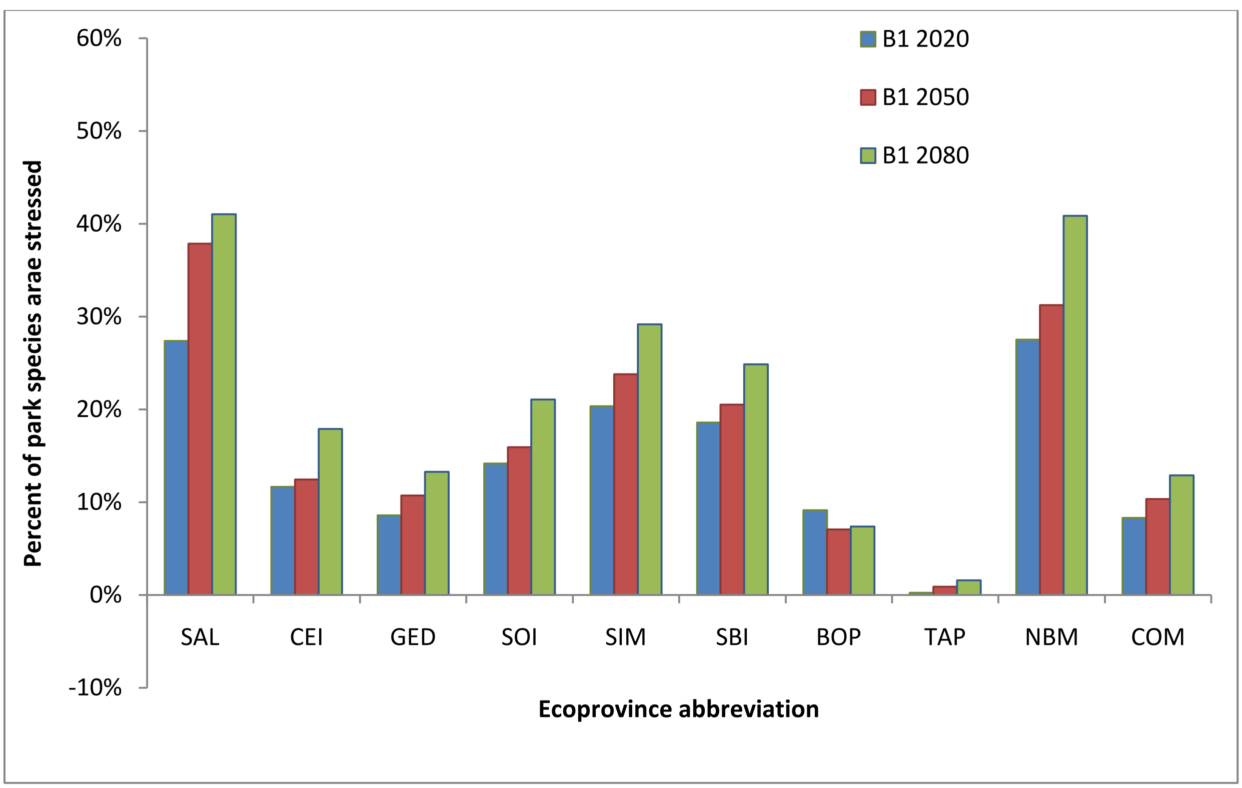

Figure 8: Sum of all species stress area for the B1 scenario as a percent of current ecoprovince area for all species

and Western hemlock. Douglas-fir was another species in our study that showed greater stress in some B1 scenarios compared to the same timestep for A2 scenarios. Hamann and Wang did not comment on potential reasons for decreased loss of current habitat with time or the negative elevation shifts seen in the interior Douglas-Fir (IDF) biogeoclimatic (BEC) zone at 2055 and montane spruce (MS) BEC zone at 2025 and 2055.These BEC zones have a large component of Douglas-fir (IDF and MS) and ponderosa pine (IDF) (Hope et al., 1991; Hope et al. 1991) so the reasons for negative elevation shifts and reduced stress at the species level may be linked. Explaining the mechanism of the model is not the aim of this paper, but the only reason we can suggest that links the results seen in these species are that they all have a large soil water component in their range variable weightings and all often grow in dry environments (Coops et al. 2010). Our study supports modeling and range study suggestions that small differences in temperature can have broad ecological effects (Iverson & Prasad, 2001; Luckman & Kavanagh, 2000; Parmesan & Yohe, 2003).

Species and time:

Our data show that species stress response was highly variable with climate change effects and sensitive to changes in climate change amplitude over time. This result reflects the variable percentages of habitat loss presented by Hamann and Wang. In the model used for this study the variability of stress can be explained by the results of the decision tree regression analysis (Coops et al., 2010; Coops et al., 2011). Species that had the greatest or least stress percentages appear to be those that had a large or small proportion of their distribution dictated by temperature variables (e.g. whitebark pine and amabilis fir respecitvely). In terms of park management concerns, we have found that large stress areas for many species will occur in park lands across B.C. For ecological integrity conservation concerns whitebark pine, mountain hemlock, and subalpine fir appear to be the hardest hit when considering both percentage of range lost and the area affected. These may require the largest and most intensive management inputs to ensure retention in parks. From a park safety and public utility standpoint concern may focus on low-lying species that are found in frequently used camping and recreation areas. These species may in these areas vary with park location, but could be identified from our data. An example of management for public safety concerns is mountain pine beetle attack caused lodgepole pine mortality which is already being managed for public safety by removing trees within falling distance of infrastructure and camping araes in some parks such as Monkman Park, and E.C. Manning Provincial Park (Blackwell & Needoba, 2008).

Ecoprovince:

Subdividing park tree species stress data in B.C. by ecoprovince allowed us to see on a coarse scale which regions of B.C. suffer the most. Ecoprovinces don't attempt to outline ecosystem types specifically, but contain a subset of ecosystem types (Demarchi, 1996). Proportions of the park range affected by stress standardized losses between areas containing large and small park areas. The regionally based analysis provided a more generalized response for park tree species. Amount of stress range created in an ecoprovince appears to be dependent on current species ranges in the ecoprovince and the responses of those species, rather than the richness or diversity of species in that ecoprovince.

Conclusions and management implications:

Although models do not predict extent of future range that will be realized by a species and are innacurate in that they not including dispersal abilities, genetic plasticity, and all biotic interactions(Aitken et al., 2008; Pearson, 2006; Wang et al., 2010), their value lies in providing ideal future distributions and showing where current ranges will be in peril (Pearson & Dawson, 2003). Our study focused solely on the stressed range and avoids the confounding factors of species dispersal abilities and other abiotic factors although we still do not account for genetic plasticity and adaptability, or the competitive abilities of various species. This model also does not predict insect pest or pathogen outbreaks although increasing densities of both in B.C. have been suggested to be linked to the effects of climate change including dothistroma needle blight fungus(*Mycosphaerella pini),* and mountain pine beetle(Woods et al., 2005; Carroll et al., 2004). A relevant topic for future study may be whether if this model accurately predicts past disease outbreaks.

Using the ecoprovinces provides an example of the potential of this study for identifying park areas of high concern, and any land classification system can be used which increases the flexibility of this model for management use. We believe that stressed species areas will have greater frequencies of tree mortality which may increase fuel loading, hazard trees, and may reduce species diversity and richness. The stressed areas shown in this study can help to guide monitoring priorities in parks and help predict the future efficacy of the current parks network for B.C. Park's goals. Parks in British Columbia are already criticized for not meeting stated goals due to incomplete program plans, management plans that are dated and incomplete, and protected area systems that are not designed to ensure ecological integrity (Doyle, 2010; Parks Canada, 2009). There are increasing concerns about continued degradation of parks abilities to meet ecological goals with climate change (Scott & Lemieux, 2005; Suffling & Scott, 2002). Parks will have to implement technology and research based science for their planning and decision making processes to remain relevant in a changing climate. We believe that even the narrow scope of this study shows viable possibilities for the implementation of technology and scientific means of parks planning and stewardship.

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Appendix

Table 4: Percent of species total current B.C. park area stressed within ecoprovinces and all of B.C. for A2 and B1 scenarios and all time steps.

	SOUTHERN ALASKA MOUNTAINS (SAL)			CENTRAL INTERIOR (CEI)			GEORGIA DEPRESSION (GED)			SOUTHERN INTERIOR (SOI)			SOUTHERN INTERIOR MOUNTAINS (SIM)		
	A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080
GRAND FIR						0%	2%	3%	6%		0%	2%		0%	1%
DOUGLAS-FIR				0%	0%	0%	0%			1%	1%	1%	2%	0%	0%
ENGELMANN SPRUCE	0%			2%	9%	11%	1%	1%	1%	1%	1%	3%	4%	5%	9%
LODGEPOLE PINE	1%	1%	1%	3%	4%	13%	0%	0%	0%	2%	4%	5%	4%	6%	8%
MOUNTAIN HEMLOCK	0%	0%	0%	1%	2%	4%	1%	1%	2%	0%	1%	2%	4%	5%	7%
PONDEROSA PINE				9%	2%	0%				12%	8%	16%	8%	7%	5%
AMABILIS FIR									0%	0%	0%	0%	0%	0%	0%
SUBALPINE FIR	0%	0%	0%	0%	1%	7%	0%	0%	0%	0%	1%	3%	1%	2%	7%
SITKA SPRUCE							1%	1%	1%						
WESTERN HEMLOCK				0%	0%	0%				0%	0%	0%	0%	0%	0%
WESTERN LARCH				5%	5%	5%				4%	6%	13%	3%	1%	7%
WHITEBARK PINE	0%	0%	0%	5%	9%	13%	0%	1%	1%	1%	2%	4%	11%	14%	23%
WESTERN RED CEDAR				0%	0%	0%				0%	0%	0%	0%	0%	0%
YELLOW CEDAR							0%	2%	3%		0%	0%			

	SOUTHERN ALASKA MOUNTAINS (SAL)			CENTRAL INTERIOR (CEI)			GEORGIA DEPRESSION (GED)			SOUTHERN INTERIOR (SOI)			SOUTHERN INTERIOR MOUNTAINS (SIM)		
	B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080
GRAND FIR							2%	2%	3%		0%	0%			0%
DOUGLAS-FIR				0%		0%	3%	0%	2%	3%	0%	3%	1%		1%
ENGELMANN SPRUCE		0%		1%	2%	2%	1%	1%	1%	0%	0%	0%	0%	0%	2%
LODGEPOLE PINE	1%	1%	1%	5%	4%	9%	0%	0%	0%	4%	3%	5%	6%	6%	8%
MOUNTAIN HEMLOCK	0%	0%	0%	1%	1%	1%	0%	1%	0%	0%	1%	0%	3%	5%	5%
PONDEROSA PINE				9%	9%	4%				13%	10%	9%	9%	8%	7%
AMABILIS FIR															
SUBALPINE FIR		0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	1%	0%	1%	2%
SITKA SPRUCE							0%	0%	0%						
WESTERN HEMLOCK				0%	0%	0%				0%	0%	0%			
WESTERN LARCH				5%	5%	5%				3%	3%	6%	1%	0%	1%
WHITEBARK PINE	0%	0%	0%	5%	6%	6%	0%	1%	0%	1%	2%	2%	10%	13%	14%
WESTERN RED CEDAR				0%	0%	0%					0%	0%			
YELLOW CEDAR							0%	1%	1%			0%			

Table 4 continued:

SUB-BOREAL INTERIOR (SBI)			BOREAL PLAINS (BOP)			TAIGA PLAINS (TAP)			NORTHERN BOREAL MOUNTAINS (NBM)			COAST AND MOUNTAINS (COM)			BRITISH COLUMBIA		
A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080	A2 2020	A2 2050	A2 2080
												19%	32%	57%	21%	35%	66%
0%			0%			0%	0%	0%				1%	0%	0%	4%	1%	1%
0%	2%	2%			0%		1%	1%	1%	3%	5%	4%	6%	10%	13%	27%	41%
2%	2%	3%	0%	0%	0%	0%		0%	7%	5%	7%	3%	4%	5%	23%	25%	41%
0%	0%	1%							0%	0%	0%	13%	25%	42%	19%	34%	58%
												3%	2%	1%	33%	20%	21%
												0%	0%	0%	0%	0%	0%
0%	0%	2%			0%				1%	1%	4%	7%	12%	20%	10%	16%	43%
												2%	1%	0%	3%	2%	1%
												1%	0%		1%	0%	0%
												0%	0%	2%	12%	13%	27%
3%	4%	5%				0%	0%	0%	6%	10%	12%	6%	10%	15%	34%	51%	73%
0%									0%	0%	0%	0%	0%	0%	1%	0%	0%
												0%	1%	2%	1%	3%	5%
SUB-BOREAL INTERIOR (SBI)			BOREAL PLAINS (BOP)			TAIGA PLAINS (TAP)			NORTHERN BOREAL MOUNTAINS (NBM)			COAST AND MOUNTAINS (COM)			BRITISH COLUMBIA		
B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080	B1 2020	B1 2050	B1 2080
												19%	24%	36%	21%	26%	39%
0%												5%	0%	4%	12%	1%	9%
		0%			0%		0%	0%	0%	0%	1%	4%	5%	6%	6%	8%	13%
2%	2%	3%	0%	0%	0%				6%	7%	6%	4%	3%	4%	28%	26%	36%
0%	0%	0%										10%	15%	15%	15%	23%	23%
												3%	3%	2%	35%	30%	23%
															0%	0%	0%
	0%	0%							0%	1%	1%	7%	9%	13%	9%	12%	18%
															0%	0%	0%
															0%	0%	0%
												0%	0%	1%	9%	9%	13%
3%	4%	4%				0%	0%	0%	6%	7%	10%	5%	7%	6%	31%	39%	44%
												0%	0%	0%	0%	0%	0%
												0%	0%	0%	0%	1%	2%