CITY OF PRINCE GEORGE:
THE EFFECTS OF CLIMATE CHANGE ON
NATURAL AREA ECOSYSTEMS

FINAL REPORT

Prepared for:

CITY OF PRINCE GEORGE
City Environment

Attention:
Dan Adamson
Environment Manager
dadamson@city.pg.bc.ca

Prepared by:

Ecora
Resource Group Ltd.

And

Hardy Griesbauer, MSc, RPF

January 2012
January 16th, 2012

The City of Prince George
City Environment
Prince George, BC

Attention: Dan Adamson, Environment Manager

Subject: Climate Change on Natural Areas Ecosystems - Final Report

Dear Dan:

Please find enclosed the final report for the Climate Change on Natural Areas Ecosystems. This project is the culmination of work by several individuals including Craig DeLong, Hardy Griesbauer, Dave Myers, Dan Bernier and Shikun Ran all of whom contributed to this project. This report accompanies the following additional deliverables:

- Base Risk Map (2011) (baserisk.pdf);
- Sensitive Ecosystem Risk Map (seirisk.pdf);
- Leading Species Risk Map (sp1risk_allspecies.pdf);
- Spruce Risk Map (spruce_risk.pdf); and
- Douglas Fir Risk Map (dougfir_risk.pdf);

We would like to thank the City of Prince George staff, specifically you, Jocelyn and Lauren for your ongoing contributions and support through this project. Please do not hesitate to call if you have any questions on the report or associated work.

Yours Truly,

Jay Greenfield, RPF
Senior Resource Analyst

Prince George, BC
jay.greenfield@ecora.ca
(250) 614-8171
EXECUTIVE SUMMARY

An increased understanding of risk and vulnerabilities of local ecosystems is an important component of an adaptive management strategy for maintaining important values of local ecosystems with the limits of City of Prince George. The recent mountain pine beetle epidemic and increases in Douglas-fir bark beetle are a few indicators of recent changes that may be attributed to climate change. Drought is anticipated to be one of the leading causes of climate change induced impacts to ecosystems. This report focuses on a project to predict site-level climate related changes to soil moisture and its potential impact on forest mortality and sensitive ecosystem resilience.

The project uses a recently developed model to assign soil moisture classes to polygons from recently ecosystem mapping of the City. Soil moisture class was then estimated for future climates (2020, 2050, 2080) based on generally accepted climate-change scenarios for BC. An ecosystem level drought risk was calculated for each polygon as well as tree-specific risk based on soil moisture deficit tolerance (i.e., drought tolerance) of the species.

Significant changes in soil moisture availability are predicted over time with a large proportion of the study area shifting from slightly dry to moderately dry or drier between 2011 and 2080. As conditions become drier more and more species will reach their moisture regime tolerance and suffer mortality. No attempt was made to predict shrub and herb species decline but for tree species, deciduous species appear to be at most risk but also spruce and lodgepole pine in some areas.

In order to make accurate predictions of future impacts of climate change it is critical that the base mapping of ecosystems and their associated site and soil features that relate to moisture availability be accurate. We undertook an assessment of the current mapping and will be making recommendations for remedial action.

This project serves a good basis for determining impacts of climate change on ecosystems within the limits of the City of Prince George. Now it is important to focus on impacts to important ecosystem features that are of particular concern to City of Prince George managers and residents and develop tools to assist planners and other staff to be able to understand and interpret the climate change impacts in order to find optimum solutions to reducing or ameliorating their impacts. One of the key components of climate change adaptation will be a monitoring system focusing on land areas that are estimated to be at most risk from climate change impacts.
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standard error of the mean. Red stars denote months with significant (p<0.05) mean differences between climate stations.

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Figure 12: Geographic points selected for input to ClimateWNA. Thick red lines denote BGC units.
1 INTRODUCTION

1.1 Global and Local Context

Forests and natural areas are an integral part of the city of Prince George and provide many values, such as recreation, aesthetics, wildlife habitat, and ecological functions such as slope stability and structural diversity. Forests are also important from a wildfire management perspective; this is especially important in a city like Prince George with a substantial urban-wildland interface. Adaptive management strategies will be required to maintain the values currently provided by natural areas and forests around Prince George (Picketts et al. 2009a), and these strategies will rely in part on an increased understanding of risks and vulnerabilities of local ecosystems and forests to climate change (Millar et al. 2007).

There is increasing evidence that climate change is having discernable impacts on forested and other terrestrial ecosystem processes, structure and function across British Columbia; examples include the mountain pine beetle epidemic (Carroll et al. 2006) and widespread increases in tree mortality rates related to changes in soil moisture and drought (van Mantgem et al. 2009). Climate-induced changes in forest disturbances such as wildfire, disease, and insect outbreaks could result in rapid and dramatic changes in forest ecosystems (Kurz et al. 2008). For example, recent outbreaks of Dothistroma needle blight in lodgepole pine in northwest BC have been attributed to climate change (Woods et al. 2005) and have now been found in pine stands near Prince George. An increase in warmer and wetter summers could result in a rapid expansion of this disease. As well, Douglas-fir bark beetle populations appear to be increasing in the dry Douglas-fir forests along the Nechako River within city limits (Burrows, pers. comm.), and this may be related to drought stress from events such as the summer drought of 2010.

1.2 Summary and History of Previous Phase

This project builds upon the previously completed Terrestrial Ecosystem Mapping (TEM) and Sensitive Ecosystem Inventory (SEI) developed for the City of Prince George, as well as the two reports prepared by the city in partnership with the Pacific Climate Impacts Consortium and the University of Northern British Columbia (Picketts et al. 2009a, 2009b). From 2010 to 2011, the city of Prince George completed an inventory of ecosystems within city limits (Bio-Geo Dynamics Ltd. 2011). This work was completed in two stages. First, major terrain features and topographic enhancements were identified through Lidar elevation modeling, air photo interpretation, and other sources. Bioterrain maps produced from this stage were then used to aid ecosystem identification and TEM. Ecosystems were identified using the Biogeoclimatic Ecosystem Classification system (Pojar et al. 1987). There are three Sub-Boreal Spruce (SBS) climatic units found in Prince George: 1) the Moist Hot Sub-Boreal Spruce Subzone (SBSmh), 2) the Mossvale Variant of the Moist Cool Climatic Subzone (SBSmk1) and 3) the Stuart variant of the Dry Warm Subzone (SBSdw3) (Figure 1). Site series within these units are described and mapped, along with management-related site modifiers such as aspect and soil texture. Ecosystem classification was to be completed following
standard procedures that included air photo interpretation and field sampling, and conformed to provincial standards for TEM (RIC 1999).

![Pie chart showing area by biogeoclimatic zone, subzone, and variant.]

**Figure 1:** Area by Biogeoclimatic Zone, Subzone and Variant.

The SEI identifies sensitive ecosystems within the City and includes terrestrial, wetland, and aquatic ecosystems that are listed as either rare or endangered by the British Columbia Conservation Data Centre. Sensitive ecosystems also include specific forest types such as mature Douglas-fir and deciduous stands, or ecosystems that provide important wildlife habitat values. TEM and SEI data were used to provide information on wildlife habitat for selected wildlife species such as grizzly bear, long-billed curlew, and mule deer.

### 1.3 Project Objectives

The objective of this project is to build upon the previous TEM and SEI work and investigate potential impacts of climate change on natural area ecosystems within Prince George. This project focuses on predicting climate-related changes in soil moisture at the site series level, and evaluating the impacts of these changes on forested ecosystem processes. Projections of sustained temperature increases for this region of BC (Picketts et al. 2009a) may result in a net reduction of available soil moisture in terrestrial ecosystems (Pike et al. 2008a). Soil moisture is a critical driver of terrestrial ecosystem processes; a reduction of available soil moisture associated with climate change will lead to a wide range of changes in forests and other terrestrial ecosystems. As previously mentioned, an increase in forest mortality rates in many parts of BC has been partly attributed to temperature-mediated changes in soil moisture (van Mantgem et al. 2009), and this can be exacerbated by drought events, which have been projected to increase in frequency and intensity as a result of climate change (Easterling et al. 2000). Ultimately, reductions in soil moisture may lead to changes in forest productivity, lowered resistance to disturbance, mortality, shifts in plant communities, and other effects. It is important to note that many vulnerability studies in BC have focused on “zonal” sites – ecosystems with average soil and site conditions. However, because ecosystem sensitivity to soil moisture varies by site conditions, it is important to consider all site conditions and identify at the site series level those ecosystems that may be particularly vulnerable.
The specific objectives of this project are to:

1) Identify current soil moisture regimes at the site series level using a soil-moisture driven climate change risk analysis tool developed by DeLong et al. (submitted) applied to the Prince George terrestrial ecosystem maps developed in the previous phase.

2) Project future soil moisture regimes using a suite of global circulation models and scenarios that represent a range of future emissions and global populations.

3) Predict risk of forest mortality and maladaptation using forest inventory polygons overlaid on soil moisture regime.

4) Use outcomes from objectives 1-3 to make specific management recommendations to the City of Prince George around future vulnerabilities and adaptive strategies.

The study area for this project is defined based on the extent of the previously completed TEM / SEI project for the City of Prince George.
2 METHODS

The following sections detail the methods and approach used in assessing and quantifying the potential impacts of climate change on ecosystems and existing vegetation within the natural areas of the City of Prince George.

2.1 TEM / SEI

As the first phase of this initiative, Bio-Geo Dynamics was contracted by the City of Prince George to complete a TEM / SEI for the natural areas within the City. The TEM inventory forms the foundation for all climate change projections and is used throughout this project. As part of the TEM / SEI project, Bio-Geo Dynamics produced the summary report, Terrestrial Ecosystem Mapping (TEM) and Sensitive Ecosystem Mapping (SEI) for the City Of Prince George (2011) which provides an overview of the actions taken to complete this inventory.

A Quality Assurance (QA) of the TEM / SEI was undertaken as part of this project. The findings of this QA are documented in a separate report entitled Quality Assurance of Terrestrial Ecosystem Mapping and Sensitive Ecosystem Inventory For the City of Prince George (Ecora. 2012).

2.2 Actual Soil Moisture Regime (ASMR)

The TEM products identify the relative soil moisture regime (RSMR) for all site series in the study area. RSMR categorizes available soil moisture of a site series relative to that of other sites within a climatic unit (e.g., within the SBS mk1 Zone). RSMR cannot be directly compared between climatic units (e.g., between SBSmk1 and SBS mh), and therefore cannot be used to compare and evaluate risks from drought and soil moisture deficit across the city of Prince George. To address this, RSMR was converted to actual soil moisture regime (ASMR). ASMR is a classification system based on the number of months that rooting-zone groundwater is absent during the growing season and is defined by the ratio of actual evapotranspiration to potential evapotranspiration. ASMR provides an absolute measure of soil measure that can be compared between climatic units.

ASMR predictions have been previously calculated for all site series in the Prince George Timber Supply Area (DeLong et al. submitted) using the Tree and Climate Assessment model (TACA; Nitschke and Innes 2008b). TACA is a mechanistic model that analyses the response of trees to climate-driven phenological, biophysical, and edaphic variables, and provides ASMR estimates based on user-input soil conditions (rooting depth, soil texture, coarse fragment %) and daily climate data. Daily climate data was input into the model from Environment Canada climate stations located in each of the three climatic units located within Prince George city limits.

2.3 ASMR Projection

The TACA model also predicts future ASMR by using climate change scenarios to adjust the daily climate data. We used TACA to predict changes in ASMR for three time
periods (2020, 2050, and 2080), using three different climate change scenarios. These scenarios were chosen to represent a range of possible future emissions and population scenarios, as recommended by Vanessa Foord, Regional Climatologist in the BC Ministry of Forests, Lands and Natural Resource Operations (Foord, pers.comm.). The three scenarios used were the A2 scenario implemented through the Canadian Global Circulation Model, version 3 (CGCM3), of the Canadian Centre for Climate Modeling and Analysis (Flato et al. 2000), The B1 scenario implemented through the Hadley Centre Coupled Model, version 3 (HadCM3) (Johns et al. 2003), and the A1B scenario implemented through the Hadley Centre Global Environmental Model, version 1 (HadGEM1) (Johns et al. 2006). Future ASMR projections were calculated using the ClimateWNA model (Wang et al. 2006).

2.4 Risk Class Mapping

There are two different forms of risk class mapping that have been defined and described for this project: 1) base risk that assesses the risk of a particular ecosystem or site to potential impact of climate change based on the risk of multiple species reaching their drought tolerance limits and 2) individual tree species risk that assesses the likelihood that a particular tree species occupying a particular polygon is likely to experience drought-induced stress and potential mortality.

2.4.1 Base Risk Class

Ranges in ASMR or AET/PET representing relative soil moisture availability were assigned a number as well as descriptive class, the numerical value being necessary in order to calculate tree species specific risk. Base risk provides an overall level of ecosystem risk due to drought (see section 3.2). Maps showing base risk are also included with this report. Base risk also contributes to the assessment and mapping of tree species vulnerability as discussed below. Where more than one site series was present in a polygon, ASMR was calculated using the dominant site series (i.e., the site series that occupied the largest portion of polygon area).

<table>
<thead>
<tr>
<th>AET/PET Ratio</th>
<th>ASMR Category</th>
<th>Base Risk Number</th>
<th>Base Risk Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0.55</td>
<td>Excessively dry (ED)</td>
<td>&gt;5</td>
<td>Extremely high</td>
</tr>
<tr>
<td>≤0.65 and &gt;0.55</td>
<td>Very dry 1 (VD1)</td>
<td>4-5</td>
<td>Very high</td>
</tr>
<tr>
<td>≤0.75 and &gt;0.65</td>
<td>Very dry 2 (VD2)</td>
<td>3-4</td>
<td>High</td>
</tr>
<tr>
<td>≤0.85 and &gt;0.75</td>
<td>Moderately dry (MD)</td>
<td>2-3</td>
<td>Moderately High</td>
</tr>
<tr>
<td>≤0.95 and &gt;0.85</td>
<td>Slightly dry (SD)</td>
<td>1-2</td>
<td>Moderate</td>
</tr>
<tr>
<td>≤1.0 and &gt;0.95</td>
<td>Fresh (F)</td>
<td>0-1</td>
<td>Low</td>
</tr>
<tr>
<td>≥1.0</td>
<td>Moist (M), very moist (VM), or wet (W), depending on soil characteristics.</td>
<td>&lt;0</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

Table 1: Actual Soil Moisture Regime and Associated Base Risk Class.
2.4.2 Tree Species Risk

Risk of tree mortality and maladaptation from climate change is estimated by modifying the base risk with species-specific modifiers based on accumulated field data and experienced ecologists' estimates of tree sensitivity to drought (Table 2). Like the base risk number, the tree species modifiers increased with sensitivity/risk. Tree species risks were calculated for each polygon using the three leading tree species from the Vegetation Resources Inventory layer. Figure 2 shows the area distribution by leading tree species for the entire study area. A blended polygon risk was also calculated using specific risks for the three leading species in each polygon multiplied by their percent cover in that polygon. Where more than three species were present, the percent cover of the first species was increased respectively.

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Modifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas-fir</td>
<td>0.0</td>
</tr>
<tr>
<td>Trembling aspen</td>
<td>0.5</td>
</tr>
<tr>
<td>Western larch</td>
<td>0.5</td>
</tr>
<tr>
<td>Spruces</td>
<td>1.0</td>
</tr>
<tr>
<td>Paper birch</td>
<td>1.0</td>
</tr>
<tr>
<td>Western red cedar</td>
<td>1.0</td>
</tr>
<tr>
<td>Western hemlock</td>
<td>1.5</td>
</tr>
<tr>
<td>Subalpine fir</td>
<td>2.0</td>
</tr>
<tr>
<td>Black cottonwood</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Figure 2: Existing Leading Tree Species
3 RESULTS

As described above a number of measures have been developed to quantify and assess the potential risk due to climate change. The following sections show the distribution of these measures across the study area and how certain measures are projected to change over time.

3.1 Actual Soil Moisture Regime (ASMR)

As described above, actual soil moisture regime is the base measurement upon which risk classes are based. This attribute is projected through time to assess the impacts of climate change in 2020, 2050, and 2080 (Figure 3).

![Figure 3: Projecting Actual Soil Moisture Regime Into the Future.](image)

Table 3 and Figure 4 show the projected changes in ASMR over time. As temperature’s increase over time, evapotranspiration increases, resulting in a decrease in soil moisture (especially if precipitation does not increase proportionally). The most substantial projected increase is between 2011 and 2020 where approximately 12,000 ha move from slightly dry to moderately dry. Overall, by 2080, approximately 17,000 ha are projected to move from slightly dry and below (more moist) to moderately dry and drier – a substantial shift in the soil moisture availability on the land base as a whole.
Table 3: Projected ASMR Change Over Time.

<table>
<thead>
<tr>
<th>ASMR Class</th>
<th>Area (ha)</th>
<th>2011</th>
<th>2020</th>
<th>2050</th>
<th>2080</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Moist</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>Moist</td>
<td>798</td>
<td>798</td>
<td>481</td>
<td>481</td>
<td></td>
</tr>
<tr>
<td>Fresh</td>
<td>1,066</td>
<td>1,066</td>
<td>1,066</td>
<td>1,066</td>
<td></td>
</tr>
<tr>
<td>Slightly Dry</td>
<td>16,683</td>
<td>4,795</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Moderately Dry</td>
<td>501</td>
<td>12,378</td>
<td>16,900</td>
<td>15,604</td>
<td></td>
</tr>
<tr>
<td>Very Dry 1</td>
<td>-</td>
<td>-</td>
<td>19</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Very Dry 2</td>
<td>19</td>
<td>31</td>
<td>601</td>
<td>1,580</td>
<td></td>
</tr>
<tr>
<td>Extremely Dry</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>318</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19,160</td>
<td>19,160</td>
<td>19,160</td>
<td>19,160</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Projected ASMR Change Over Time.

3.2 Base Risk Class

As described above, base risk class was developed to provide an overall assessment of the risk of a particular ecosystem to drought-related impacts from climate change. As shown in Table 4 and Figure 5, the majority of the land base is classed as having a moderate risk in 2011. The amount of area in higher classes of risk increases through time. These relative measures of risk allow us to differentiate individual ecosystems and areas based on their relative risk. Using this information we assess individual ecosystems and plant communities based on risk and begin to develop management strategies, indicators and measures for monitoring at this site series or ecosystem level.
### Table 4: Area by Base Risk Class.

<table>
<thead>
<tr>
<th>Base Risk Class</th>
<th>2011</th>
<th>2020</th>
<th>2050</th>
<th>2080</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>2,271</td>
<td>2,271</td>
<td>1,953</td>
<td>1,953</td>
</tr>
<tr>
<td>Low</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Moderate</td>
<td>16,683</td>
<td>4,795</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Moderately High</td>
<td>501</td>
<td>12,378</td>
<td>16,583</td>
<td>15,604</td>
</tr>
<tr>
<td>High</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Very High</td>
<td>19</td>
<td>31</td>
<td>601</td>
<td>1,580</td>
</tr>
<tr>
<td>None</td>
<td>13,519</td>
<td>13,519</td>
<td>13,856</td>
<td>13,856</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>32,993</td>
<td>32,993</td>
<td>32,993</td>
<td>32,993</td>
</tr>
</tbody>
</table>

### Figure 5: Base Risk Class Changes Over Time.

#### 3.3 Sensitive Ecosystems

Overall, the TEM / SEI project identified approximately 2,067 ha of sensitive ecosystems. Using base risk class we can assess the potential risk of these ecosystems to climate change. Of these areas, approximately 1,597 ha (77%) is classed as having high or very high potential risk of impact from climate change. The high percentage of sensitive ecosystems at risk is understandable as many of these ecosystems exist at the extreme dry end of the edatopic grid (e.g., rock outcrops) where minor reductions in soil moisture may result in significant mortality.
However, being a rare or endangered ecosystem is not by itself a reason for conservation or special management. Further refinement of the definition of sensitive ecosystems is required to ensure that these definitions capture specific values of interest and ultimately reflect areas and ecosystems that should be considered for conservation and/or special management consideration.

Table 5: Sensitive Ecosystem Risk Class.

<table>
<thead>
<tr>
<th>SEI Class</th>
<th>Risk Class</th>
<th>Total Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLUE</td>
<td>Low</td>
<td>156</td>
</tr>
<tr>
<td>BLUE</td>
<td>High</td>
<td>1,136</td>
</tr>
<tr>
<td>BLUE</td>
<td>Very High</td>
<td>454</td>
</tr>
<tr>
<td>RED</td>
<td>Low</td>
<td>313</td>
</tr>
<tr>
<td>RED</td>
<td>Very High</td>
<td>7</td>
</tr>
<tr>
<td>Not Sensitive</td>
<td>NA</td>
<td>30,926</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>32,993</strong></td>
</tr>
</tbody>
</table>

![Table 5: Sensitive Ecosystem Risk Class](image)

3.4 Tree Species

In many cases the tree species that exist on a particular stand represent a considerable portion of the value attributed to an ecosystem or area. Trees usually occupy the largest percentage of cover in an area, have the largest visual impact and provide structural diversity and contribute to maintaining slope stability. Therefore, the potential risk of
individual trees species to climate change is of particular interest to land managers and planners.

As described above, tree species risk has been assessed by applying individual tree species modifiers to the base risk class calculations. Table 6 and Figure 7 show that birch, cottonwood and aspen are the species at highest risk to climate change. Of the coniferous species, some lodgepole pine, and white spruce stands are at a high risk class. Douglas-fir is well adapted to dry conditions and therefore represents the lowest risk of the species currently reflected on the land base. Further work should be undertaken to understand the particular ecosystems in which species are at risk and develop strategies for mitigation of this risk.

Table 6: Area by Leading Tree Species Risk Class

<table>
<thead>
<tr>
<th>Leading Species</th>
<th>No Rating</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>Moderately High</th>
<th>High</th>
<th>Very High</th>
<th>Extremely High</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>7,586</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7,586</td>
</tr>
<tr>
<td>Birch</td>
<td>196</td>
<td>136</td>
<td>167</td>
<td></td>
<td>2,558</td>
<td>36</td>
<td>3</td>
<td></td>
<td>3,097</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>302</td>
<td>3</td>
<td>289</td>
<td></td>
<td>44</td>
<td>219</td>
<td>45</td>
<td></td>
<td>8,673</td>
</tr>
<tr>
<td>Aspen</td>
<td>757</td>
<td>284</td>
<td>418</td>
<td></td>
<td>7,028</td>
<td>174</td>
<td>13</td>
<td></td>
<td>6,378</td>
</tr>
<tr>
<td>Lodgepole Pine</td>
<td>3,568</td>
<td>44</td>
<td>87</td>
<td></td>
<td>2,577</td>
<td>102</td>
<td></td>
<td></td>
<td>1,015</td>
</tr>
<tr>
<td>Subalpine Fir</td>
<td>154</td>
<td>121</td>
<td>78</td>
<td></td>
<td>660</td>
<td>2</td>
<td></td>
<td></td>
<td>3,814</td>
</tr>
<tr>
<td>White Spruce</td>
<td>1,245</td>
<td>179</td>
<td>235</td>
<td></td>
<td>2,136</td>
<td>20</td>
<td></td>
<td></td>
<td>1,405</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>287</td>
<td>45</td>
<td>966</td>
<td></td>
<td>107</td>
<td></td>
<td></td>
<td></td>
<td>121</td>
</tr>
<tr>
<td>Black Spruce</td>
<td>83</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>14,178</td>
<td>810</td>
<td>988</td>
<td>1,256</td>
<td>15,147</td>
<td>335</td>
<td>232</td>
<td>49</td>
<td>32,993</td>
</tr>
</tbody>
</table>
Figure 7: Leading Tree Species Risk Class.
4 DISCUSSION AND RECOMMENDATIONS

4.1 Ecosystems / Species at risk

Ran et al. (in press) review potential climate change implications to the forested ecosystems of the Sub-Boreal Spruce biogeoclimatic zone, which encompasses the city of Prince George. Bioclimate envelope studies (Hamann and Wang 2006) project that by 2085, most of the SBS climate will change to IDF climate in dry SBS areas, and will change to ICH climate in wetter SBS areas. The city of Prince George has both dry and moist SBS subzones. Long-term climatic shifts in the SBS (and Prince George) could result in Douglas-fir gaining suitable habitat in the area, although hybrid spruce and subalpine fir will continue to be important species on the landscape (Ran et al. in press). Process-based models such as the TACA (Tree and Climate Assessment) model (Nitschke and Innes 2008) can help forest managers anticipate site-level climate-induced impacts to forests and make strategic decisions (DeLong et al. submitted).

Climate change projections for BC indicate that climate regimes will become warmer over the next century. Daniels et al. (2011) suggest that soil moisture is sensitive to even slight changes in temperature; it is therefore likely that available soil moisture will decrease in many forested ecosystems around Prince George. Wet ecosystems appear to be buffered from future climate change, whereas dry ecosystems may be particularly vulnerable. In addition, tree and plant species will show differential responses to future drought and soil moisture reductions. Species like Douglas-fir may be better adapted to survive drought than deciduous species or co-occurring conifers such as subalpine fir. Over time, site and species differences will express themselves through species declines and community shifts. Tree species mortality from climate change and climatic events such as droughts will likely occur primarily through complex interactions between trees, climate, and disturbance agents such as bark beetles. For example, Douglas-fir populations growing on dry ecosystems along the Nechako River appear to be increasingly susceptible to Douglas-fir bark beetle attack; this is likely occurring in conjunction with drought-induced stress.

4.2 Other Risks

Climate-mediated changes in wildfire behavior will remain a critical risk to the natural areas of Prince George, particularly with respect to the wildland-urban interface. It is important that fire mitigation measures such as those outlined in the Filmon (2003) report (http://bcwildfire.ca/History/ReportsandReviews/2003/FirestormReport.pdf) are implemented to ensure public safety with respect to wildfires. More research into the relationship between temperature trends and wildfire activity in central BC is also required in order to better predict and anticipate seasonal fire behavior. Ocean-atmosphere climatic interactions such as the El Nino/Southern Oscillation and the Pacific Decadal Oscillation show some promise in predicting seasonal fire behaviour in central BC (Foord, pers. comm) and represent an area of potential future research. In general, as soil moisture decreases and existing tree species become stressed they are more susceptible to mortality which can increase fire hazard through the introduction of dead and dry biomass into the stand and onto the forest floor. Furthermore, as has been
witnessed throughout British Columbia, massive mountain pine beetle induced mortality of lodgepole pine has had a dramatic affect on fire hazard. The connection between the provincial mountain pine beetle epidemic and climate change cannot be over looked.

Climate change may increase risks to endemic plant and animal species from invasive species. Some invasive plant and animals are able to rapidly respond to novel climate conditions and outcompete native species that adapt more slowly. This problem is increasing globally, and wide scale displacement of native species can have serious economic, social, and ecological implications. In the Prince George area, invasive plants such as marsh thistle and orange hawkweed have been documented; organizations such as the Northwest Invasive Plant Council will be important partners in identifying and mitigating risks from these and other invasive species in the area.

### 4.3 Uncertainty

Uncertainty may be one of the primary challenges facing the management of natural areas and ecosystems in Prince George (Millar et al. 2007). One of the key areas of uncertainty is around future climate, especially over the next few decades. Although most global circulation models are unanimous in projecting sustained temperature increases over the next century, it is important to recognize that there will be considerable variation around temperature and precipitation trends; in the central interior of BC, this is due in part to the influence of quasi-periodic climate oscillations such as the Pacific Decadal Oscillation and the El Nino/Southern Oscillation. Further, the frequency and severity of extreme climate-related events such as drought and windstorms have been projected to increase, which will lead to increased uncertainty around future climate. Adaptive management strategies must consider and reflect this uncertainty, both through planning for a range of possibilities, as well as continuously updating plans and objectives to reflect improved knowledge and information.

### 4.4 Management Strategies

Given the considerable uncertainty and complexity of forest responses to climate change and resultant future conditions (Millar et al. 2007), it is now widely recognized that ecosystem and forest management paradigms need to change to maintain or increase resiliency to future changes (Ran and Swift in press, Spittlehouse 2005, Puettman et al. 2008). Approaches that increase diversity across multiple spatial, structural, and biological scales will help mimic natural forest processes and increase forest resiliency to climate-related disturbances (Ran and Swift in press, Puettman et al. 2008). More deterministic approaches such as facilitated migration may help match tree species and genotypes to anticipated future climates and reduce maladaptation (Ukrainetz et al. 2011). For example, long-term climatic shifts in the SBS BGC zone (and Prince George) could result in Douglas-fir gaining suitable habitat in the area, although hybrid spruce and subalpine fir will continue to be important species on the landscape (Ran et al. in press). Western red cedar and western larch are currently absent from Prince George forests at a landscape scale, but may be productive under projected climates (Rehfeldt and Jaquish 2010, Ran et al. in press), and are thus suggested as potential candidates for facilitated migration (Ran et al. in press). Measures such as facilitated migration have inherent risk and require careful consideration of many site- and landscape-level
factors; decisions should be made by experienced ecologists with strong local knowledge (Puettman et al. 2008, Ran and Swift in press, Ran et al. in press).

4.5 Recommendations

The following sections provide a summary of recommendations for moving forward with the development of management strategies that consider climate change for the natural areas within the City of Prince George.

4.5.1 Review TEM / SEI Quality Assurance

The accuracy of any forecasts of potential climate change impacts rely on the quality of existing ecosystem mapping. A quality assurance of the TEM / SEI product has been conducted as part of this project. This QA was undertaken after much of the climate change modeling had been completed and therefore these results should be viewed in light of this report. Before proceeding with Phase III of this project a thorough review the finding of the TEM / SEI Quality Assurance Report should be undertaken to:

1. Assess the degree to which deficiencies in the TEM / SEI affect Phase II and Phase II results
2. Develop and implement a plan to address any issues in the TEM / SEI that will affect the outcomes of Phase II and III.

This project utilizes the extent of the TEM / SEI data as its project boundary. This boundary should be reviewed and critically assessed to ensure that it captures all natural areas within the city boundary. A precise definition of natural areas should be developed to guide the establishment of this boundary. Natural areas should be classified into one of three categories based on ownership: private, provincial government (crown), municipal park and municipal (not park). This will allow for a clear delineation of the project boundary and natural area categories will help guide future management strategy development.

4.5.2 Data Simplification and Delivery

TEM and SEI products are designed to be used by individuals with experience and training with ecological data and complex data base structures. In order to be used effectively by those without specific training, ecological data and management direction should be simplified and delivered in an easy to use interface such as the City's PGMap online mapping tool.

4.5.3 Developing Management Strategies

This analysis assesses the climate change risk based on individual tree species, ecosystems as a whole, and sensitive ecosystems irrespective of management objectives for these values. Phase III of this project should focus on climate change risk based on specific values of interest within the context of the City’s current and future planning objectives for natural areas and sensitive ecosystems. Through dialog with City Planners, specific values and management objectives should be identified and
defined. With this information, the principles and processes defined through this project can be applied to specific and quantifiable land base values. Through an understanding of how climate change might affect specific values we can begin to establish targets and management strategies in an effort to mitigate any potential adverse impacts from climate change.

4.5.4 Establishing Monitoring Framework

The City should consider the development of a monitoring framework for management objectives potentially impacted by climate change. Monitoring allows for continual feedback on whether projected impacts and risks are occurring as planned and ensures that management strategies are having the desired affect on the values identified. Ongoing monitoring combined with a critical assessment of management assumptions allows us to adjust management decisions and strategies as a greater body of knowledge is built. This is of particular importance when addressing an issue with considerable uncertainty such as climate change.

The monitoring framework should reflect an adaptive management approach, integrating continual learning into an ongoing review of management strategies, objectives as well as modeling assumptions.
APPENDIX I – LITERATURE REVIEW
5 LITERATURE REVIEW

5.1 Introduction

A literature review was completed to determine the state of knowledge regarding climate change and related effects on forested ecosystems and tree species. We focused on studies that were relevant to Prince George. The literature review is broken into three main topics: 1) climate change (including potential modifiers of Prince George climate), 2) climate change impacts on forested ecosystems and tree species, and 3) forest management and climate change. A brief summary of the state of knowledge is provided for each topic along with a list of the literature reviewed. It should be noted that the body of literature around climate change and forest ecosystems is very large and expanding quickly; therefore, the list is representative but not entire. Also, note that some references appear in more than one section.

5.2 Climate change

Picketts et al. (2009) summarized baseline climate and streamflow data for Prince George, and quantified the effects of synoptic patterns of ocean-atmosphere interactions (El Nino/Southern Oscillation and the Pacific Decadal Oscillation) on short- and mid-term climatic variability. Historical long-term climate trends were also analyzed and projected using a range of climate scenarios and global circulation models. Generally, Picketts et al (2009) found that temperatures in Prince George are projected to increase at a rate faster than the global average, consistent with other projections for British Columbia (Rodenhuis et al. 2007, Pike et al. 2008a) and northern latitudes (IPCC 2007). Precipitation changes are difficult to project accurately (IPCC 2007); many models suggest that winters in Prince George will become wetter (although snowpacks may decrease) and summers may become drier (Picketts et al. 2009). Over the short and mid-term time horizons (annual to decadal), climatic variability is expected to increase, potentially resulting in increased frequency and magnitude of climate-related events such as droughts, floods, and wildfires (Easterling et al. 2000, Kurz et al. 2008).

Griesbauer and Foord (unpublished data) have analyzed climate-related parameters and extreme climate events in Prince George using the RClimdex software developed by the Climate Research Branch of Environment Canada (Zhang and Yang 2004). Unpublished results from this analysis show that temperature-related climate events such as cold nights, frost events, and diurnal temperature range have decreased significantly over the past 69 years (1942-2010). Growing season length in Prince George has increased significantly by 16 days from 1942 to 2010. These findings are consistent with other analyses of historical extreme climate in Canada (Vincent and Mekis 2006). Precipitation-related events such as extreme rainfall events, rainfall intensity, and meteorological droughts (i.e., consecutive dry days) show no significant trends over the past 60 years. Historical changes in extreme precipitation show high spatial, interannual, and seasonal variability across Canada and BC, and extracting trends can be difficult (Burn et al. 2011, Vincent and Mekis 2006, Rodenhuis et al. 2007). It should be noted that rising temperatures in conjunction with stable or decreasing precipitation are projected to reduce soil moisture and effectively cause drought-like conditions in British Columbia forests (Pike et al. 2008, Christensen et al. 2007).
5.2.1 Reference list


5.3 Potential modifiers of Prince George climate

5.3.1 Urban island heat effect

Significant temperature difference between cities and surrounding undeveloped areas have been well documented in many areas of the world (Yow 2007), and are commonly termed the urban heat island (UHI) effect (Landsberg 1981). This effect has important atmospheric, biological, economic, and human health impacts (Yow 2007, Zhou and Shepherd 2010). The UHI effect has been detected at northern latitudes (Hinkel et al. 2003) and in cities with populations as low as 10 000 (Karl et al. 1988); therefore, it is likely that Prince George experiences this effect to a degree (also see our baseline climate analysis for more details). The largest temperature differences associated with the UHI are at night, partly because materials such as concrete and asphalt absorb heat energy during the day and release it at night (Karl et al. 1988). Nighttime temperature differences may be especially pronounced during vegetated months (i.e., during the growing season) because plants redistribute much of the heat energy absorbed during the day through evapotranspiration, therefore, heat absorbed by plants in undeveloped areas is not reflected back into the air (Yow 2007). UHI varies significantly with atmospheric changes such as cloud cover and wind speed, as well as urban characteristics such as materials, building sizes and shapes, and many other factors (see Yow 2007 for a review).
The temperature gradient between warm urban areas and cooler rural areas is often steep (Oke 1987), with a gradual change within an urban area (i.e. urban cores are often warmest, and suburban areas are intermediate in between urban core and rural areas). From an ecological perspective, therefore, the UHI will pertain generally to city parks and urban forests within and adjacent to the developed areas of Prince George. The UHI effect can exacerbate heat stress during periods of high ambient temperatures (Zhou and Shepherd 2010), and may cause higher nighttime evapotranspiration in plants. Mitigation strategies include increasing albedo (reflectivity) and vegetation cover; urban forests can play a critical role in mitigating this effect (Zhou and Shepherd 2010).

5.3.2 River influence on local climate

The effects of large bodies of water on land precipitation patterns are well known (e.g., Kristovich and Laird 1998). The effects of the Nechako and Fraser rivers on city climatic conditions (particularly river fog in the fall) are well known to residents, however, there appears to be very little study or documentation of these effects on local climate. However, the classification of the land adjacent to the two rivers in Prince George as having a SBS moist and hot climate may partly reflect the influence of water and large south-facing river banks on temperature and precipitation. This effect is likely localized.

5.3.3 Reference list


5.4 Climate change and forested ecosystems in Prince George

There is increasing evidence that climate change is having discernable impacts on forested ecosystem processes and function across British Columbia; examples include
widespread increases in tree mortality rates related to changes in soil moisture (van Mantgem et al. 2009) and the mountain pine beetle epidemic (Caroll et al. 2006). Significant increases in possibly drought-related tree mortality have been documented across a range of ecosystems, elevations, forest types, and species in BC (van Mantgem et al. 2009), and would therefore be relevant to the forests around Prince George. Climate-induced changes in forest disturbances such as wildfire and insect outbreaks could result in rapid and dramatic changes in forest ecosystems (Kurz et al. 2008). For example, recent outbreaks of Dothistroma needle blight on lodgepole pine in northwest BC have been attributed to climate change (Woods et al. 2005) and have now been found in pine stands near Prince George.

Ran et al. (in press) review potential climate change implications to the forested ecosystems of the Sub-Boreal Spruce biogeoclimatic zone, which encompasses the city of Prince George. Bioclimate envelope studies (Hamann and Wang 2006) project that by 2085, most of the SBS climate will change to IDF climate in dry SBS areas, and will change to ICH climate in wetter SBS areas. The city of Prince George has both dry and moist SBS subzones. Long-term climatic shifts in the SBS (and Prince George) could result in Douglas-fir gaining suitable habitat in the area, although hybrid spruce and subalpine fir will continue to be important species on the landscape (Ran et al. in press). Process-based models such as the TACA (Tree and Climate Assessment) model (Nitschke and Innes 2008) can help forest managers anticipate site-level climate-induced impacts to forests and make strategic decisions (DeLong et al. submitted).

Many BC tree species show strong adaptation to local conditions and therefore, climate change may result in widespread maladaptation in tree populations (O’Neill et al. 2008); maladaptation will be expressed primarily through growth declines, lowered resiliency to other disturbances, and in severe cases, mortality (Aitken et al. 2008). Environmental-genetic interactions will result in different responses between tree species and even within a population that reflect a wide range of local-scale factors (Wang et al. 2011), likely resulting in a very complex pattern of forest responses to climate change. Studies that examine species- and population-specific responses to climate change can help elucidate the complexities underlying these patterns (e.g., Griesbauer and Green 2010, Hogg et al. 2005).

5.4.1 Reference List


5.5 Forest management and climate change

Given the considerable uncertainty and complexity of forest responses to climate change and resultant future conditions (Millar et al. 2007), it is now widely recognized that ecosystem and forest management paradigms need to change to maintain or increase resiliency to future changes (Ran and Swift in press, Spittlehouse 2005, Puettman et al. 2008). Approaches that increase diversity across multiple spatial, structural, and biological scales will help mimic natural forest processes and increase forest resiliency to climate-related disturbances (Ran and Swift in press, Puettman et al. 2008). More deterministic approaches such as facilitated migration may help match tree species and genotypes to anticipated future climates and reduce maladaptation (Ukrainetz et al. 2011). For example, long-term climatic shifts in the SBS BGC zone (and Prince George) could result in Douglas-fir gaining suitable habitat in the area, although hybrid spruce
and subalpine fir will continue to be important species on the landscape (Ran et al. *in press*). Western red cedar and western larch are currently absent from Prince George forests at a landscape scale, but may be productive under projected climates (Rehfeldt and Jaquish 2010, Ran et al. *in press*), and are thus suggested as potential candidates for facilitated migration (Ran et al. *in press*). Measures such as facilitated migration have inherent risk and require careful consideration of many site- and landscape-level factors; decisions should be made by experienced ecologists with strong local knowledge (Puettman et al. 2008, Ran and Swift *in press*, Ran et al. *in press*).

### 5.5.1 Reference list

BC MoFR. 2006. Preparing for climate change: Adapting to impacts on British Columbia’s forest and range resources. BC Ministry of Forests and Range,


6 BASELINE CLIMATE DATA

Picketts et al. (2009) summarized Prince George climate normals (1961-1990) using adjusted and homogenized temperature and precipitation data for the Environment Canada climate station at the Prince George airport, and also quantify climate normals for the same period in the Prince George region using the PRISM climate model. They analyzed climatic means as well as measures of interannual variability, such as standard deviation and coefficient of variation. They quantified the effects of the El Nino/Southern Oscillation and Pacific Decadal Oscillation on climatic variability in the Prince George region, and quantified long-term climatic trends in the Prince George and region areas.

The city of Prince George covers approximately 300km² and contains three biogeoclimatic (BGC) zones. Because BGC zones reflect different climatic regimes, there may be significant climatic variability within city limits. Additionally, the distribution of the SBS moist hot subzone in PG city limits likely reflects the modifying influence of the Nechako and Fraser rivers on local climate. The climate of Prince George’s downtown “core” may be influenced by the urban island heat (see literature review section above).

This baseline climate index expanded upon the work of Picketts et al. (2009) by summarizing baseline climate data for three Environment Canada climate stations located within or adjacent to Prince George. Each station is located within a different BGC zone, therefore, we used the climate data from the stations to infer climatic differences within the city related to the BGC units. These differences were quantified using a one-way ANOVA of monthly mean temperature and precipitation data. We also implemented three climate scenarios through the ClimateWNA model (Wang et al. 2006) to project future climates in the three BGC units in Prince George for 2050 and 2080.

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Station ID</th>
<th>BGC Unit</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m a.s.l.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prince George Airport</td>
<td>1096453</td>
<td>SBSmk1</td>
<td>53.89</td>
<td>122.67</td>
<td>680</td>
</tr>
<tr>
<td>Prince George Miworth</td>
<td>1096465</td>
<td>SBSdw3</td>
<td>53.97</td>
<td>122.93</td>
<td>610</td>
</tr>
<tr>
<td>Prince George STP</td>
<td>1096468</td>
<td>SBSmh</td>
<td>53.90</td>
<td>122.77</td>
<td>579</td>
</tr>
</tbody>
</table>
6.1 Baseline climate

Climate normals were calculated using monthly averages of daily temperature and precipitation data for the three climate stations. Climate normals are usually calculated using a 30-year period, however, data of this length and same time were not available for each station, therefore, we calculated climate normals using a 16-year period (1985-2000) common to each station. Baseline data are presented in Table 2 as well as Figures 2-4.

6.2 BGC Analysis

Monthly temperature and precipitation differences between the three climate stations were quantified with one-way ANOVA, with each station representing a different BGC zone. Ideally, climate analyses use data that have been adjusted and homogenized to account for different measurement techniques, station relocations, and other factors (Mekis and Vincent 2011, Vincent and Gullett 1999), however, these data are only available for Prince George A station. Thus, for this analysis, we used raw climate data.
from the stations. Climatic differences were also analyzed using a linear mixed effects model of daily data with BGC zone as the fixed effect and day as the random effect; results were virtually identical to the one-way ANOVA, and therefore are not presented.

Analysis showed that from 1985-2000, minimum (nighttime) temperatures differed significantly (p<0.05) between the three subzones. The SBSmh had significantly warmer nights than the other subzones, from March to October. For example, July and August nights in the SBSmh were almost 2°C warmer than the SBSdw3 and 1 °C warmer than the SBSmk1. Nighttime temperatures were similar between all stations during the winter months. The SBSmh climate station (Prince George STP) is located within a developed area in the “bowl”; it is possible that these nighttime differences reflect the urban heat island effect (see literature review for discussion). The lack of nighttime temperature differences between the stations during the winter months suggests that the urban heat island effect disappears during this season, possibly because of higher albedo associated with snow and cold air drainage in the bowl (Foord, pers. comm.). Generally, the SBSdw3 has colder nights than the SBSmk1, although these differences are not significant. It should be noted that the Miworth station is located relatively close to the transition between the SBSdw3 and SBSmk1 units (Figure 8); climate data from further within the SBSdw3 may result in stronger climatic differences.

Throughout most of the year, the SBSdw3 had higher maximum (daytime) temperatures than the other BGC zones, however these differences were generally not significant.

All three stations were also similar in terms of precipitation throughout the year. Summer precipitation patterns between the three stations are likely similar because of the convective nature of the majority of precipitation events (Foord, pers. comm). However, winter precipitation likely differs between the three BGC units (Foord, pers. comm.), and it is unclear why the climate data do not reflect this. Also, it is well known that the area in northern Prince George (i.e., the Hart) has a shorter growing season and longer snowpack than other areas of town. This was not reflected in the climate station data. Snowpack and growing season differences could be quantified using different approaches (e.g., analyzing growing season length using daily data).

<table>
<thead>
<tr>
<th>Station</th>
<th>Mean Temperature</th>
<th>Minimum Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jan</td>
<td>Feb</td>
</tr>
<tr>
<td>Prince George</td>
<td>mean</td>
<td>-8.7</td>
</tr>
<tr>
<td></td>
<td>std.dev</td>
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</tr>
<tr>
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<td>mean</td>
<td>-9</td>
</tr>
<tr>
<td></td>
<td>std.dev</td>
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</tr>
<tr>
<td>Miworth</td>
<td>mean</td>
<td>-7.6</td>
</tr>
<tr>
<td></td>
<td>std.dev</td>
<td>4.5</td>
</tr>
<tr>
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</tr>
<tr>
<td></td>
<td>std.dev</td>
<td>5.2</td>
</tr>
<tr>
<td>Prince George</td>
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<td>-13.5</td>
</tr>
<tr>
<td></td>
<td>std.dev</td>
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</tr>
<tr>
<td>Miworth</td>
<td>mean</td>
<td>-11.4</td>
</tr>
<tr>
<td></td>
<td>std.dev</td>
<td>5.1</td>
</tr>
</tbody>
</table>
The Effects of Climate Change on Natural Areas Ecosystems

### Monthly Temperature

<table>
<thead>
<tr>
<th>Station</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prince George</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Airport</strong></td>
<td>-4.8</td>
<td>-0.6</td>
<td>5.4</td>
<td>11.7</td>
<td>16.9</td>
<td>20.0</td>
<td>22.5</td>
<td>22.0</td>
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### Precipitation

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Figure 9: Monthly averages of daily minimum (nighttime) temperatures for three Environment Canada climate stations in Prince George from 1985-2000. Each climate station represents one of the three BGC subzones within Prince George. Black squares denote 1961-1990 climate normals for Prince George Airport station (Picketts et al. 2009). Grey error bars denote standard error of the mean. Red stars denote months with significant (p<0.05) mean differences between climate stations.
Figure 10: Monthly averages of daily maximum (daytime) temperatures for three Environment Canada climate stations in Prince George from 1985-2000. Each climate station represents one of the three BGC subzones within Prince George. Black squares denote 1961-1990 climate normals for Prince George Airport station (Picketts et al. 2009). Grey error bars denote standard error of the mean. Red stars denote months with significant (p<0.05) mean differences between climate stations.
Figure 11: Monthly sums of daily precipitation for three Environment Canada climate stations in Prince George from 1985-2000. Each climate station represents one of the three BGC subzones within Prince George. Black squares denote 1961-1990 climate normals for Prince George Airport station (Picketts et al. 2009). Grey error bars denote standard error of the mean. Red stars denote months with significant (p<0.05) mean differences between climate stations.

6.3 Climate projections

To project future climates for each of the subzones within the city, we implemented three climate change scenarios using the ClimateWNA model (Wang et al. 2006). The ClimateWNA model outputs site-specific climate projections based on user-input geographic location and elevation data. A geographic point was chosen within each BGC unit within CPG limits (Table 9 and Figure 12). Points were located well within the BGC unit to maximize the climatic differences between units. Elevation data for each point was obtained from LRDW.

The scenarios used were: 1) the A2 scenario implemented through the Canadian Global Circulation Model, version 3 (CGCM3), of the Canadian Centre for Climate Modeling and Analysis (Flato et al. 2000), 2) the B1 scenario implemented through the Hadley Centre Coupled Model, version 3 (HadCM3) (Johns et al. 2003), and 3) the A1B scenario implemented through the Hadley Centre Global Environmental Model, version 1 (HadGEM1) (Johns et al. 2006). These scenarios represent a range of possible future global population and emission outcomes, and were recommended by the Regional
Climatologist at the BC Ministry of Forests, Lands and Natural Resource Operations, Vanessa Foord (pers.comm.).

Table 9: Geographic points and elevations used as input to ClimateWNA model for projecting future climates.

<table>
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<th>BGC Unit</th>
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Figure 12: Geographic points selected for input to ClimateWNA. Thick red lines denote BGC units.
Table 10: Projected climate for three BGC units in Prince George using three climate scenarios implemented through the ClimateWNA model.

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City of Prince George: The Effects of Climate Change on Natural Areas Ecosystems

Ecora

36
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