INFORMING AND SUPPORTING CLIMATE CHANGE ADAPTATION IN FORESTS THROUGH MONITORING

Report for Phase 3

Future Forest Ecosystem Initiative Climate Change Monitoring Program

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Executive Summary

Given the large uncertainties associated with climate change, regular and systematic measurement is the primary means for understanding what changes are actually taking place and for gathering data that can be used to improve models to predict future change. Recognising this important information need, the Future Forest Ecosystems Initiative in partnership with the Forest and Range Evaluation Program of the Ministry of Forests, Land and Natural Resource Operations engaged University of British Columbia researchers to develop a strategy for monitoring forest and rangeland species and ecosystem processes in light of climate change.

From the outset a stepwise approach was planned based on a multi-phased implementation plan. Work representing Phases 1 and 2 of the project was conducted between September 2008 and June 2009. Through this work a series of recommended indicators for monitoring in light of climate change were isolated along with a list of potential data sources and suppliers for supporting the analysis of those indicators. A summary of this work, presented in Chapter 2, outlines the seventeen recommended indicators under the criteria-level headers of biodiversity (5 indicators), natural disturbance (4 indicators) and ecosystem drivers (7 indicators).

Phase 3 of the project, initiated in early 2010, effectively builds on work conducted during Phases 1 and 2, further developing the monitoring framework. Two key work activities were planned for this phase, the first of which was a Forest and Range Climate Change Adaptation Monitoring and Reporting: Information Needs Analysis Survey. This work activity sought to better identify the framework's target audience and their key

information needs and management questions with regard to climate change adaption through the use of a web based survey. Chapter 3 describes this work in detail.

The second area of work involved the development of approaches to measuring selected indicators and an in-depth analysis of current monitoring and inventory programs available to support their evaluation. This involved proposing approaches to measuring indicators examining: ecosystem distribution and composition, forest productivity, species diversity, ecosystem connectivity, fire, and insects and diseases. To the extent possible and appropriate, the data available to support the indicators was tested on a region in the south-east of BC. Chapters 4 to 9 describe the processes undertaken for each of these indicators. Results indicate that for most of these indicators there are good data sources available in the Province to support their analysis either in their current form or with some minor bolstering or adjustment. One indicator for which data was particularly lacking was that examining species diversity.

Chapter 1

Introduction and background

Decades of research and data have confirmed that climate change is occurring, is caused largely by human activities, and poses significant risks for (and in many cases is already affecting) a broad range of human and natural systems (IPCC 2007c, USGCRP 2009, NRC 2010b). In addition to a rise in average global temperatures, discernable changes have been observed in day, night and seasonal temperatures, in the frequency, duration and intensities of heat waves, droughts and floods, wind and storm patterns, frost, snow and ice cover, and in global sea levels (IPCC 2007b). It is also clear that even with sustained reductions in global emissions the future climate is predicted to be quite different than that of today. The cumulative impacts of past human activities mean that the current trajectory of climate change is fixed for several decades (IPCC 2007a, Montenegro et al. 2007, Weaver et al. 2007, Solomon et al. 2009, NRC 2010b). Impacts on the natural environment are already occurring and will be substantial in the future. It is also likely that these changes will continue for centuries to come (Flannigan et al. 2002, Parmesan and Yohe 2003, Millar et al. 2007, Gayton 2008, Lemmen and Warren 2008, Williamson et al. 2009, Latta et al. 2010).

1.1 IMPACTS OF CLIMATE CHANGE ON THE FOREST AND RANGELAND ENVIRONMENT OF BRITISH COLUMBIA

All reported temperature trends show that BC has warmed in recent decades (Zhang et al. 2000, BC Ministry of Water 2002, Whitfield et al. 2002). Moreover, records suggest that the rate of temperature change in some parts of BC during the twentieth century exceeded the global average. When global climate model projections are applied to data for BC, forecasts show that increases in winter and summer temperatures are likely to continue with some regional disparities. Warming is likely to be greater in northern BC than in southern BC and greater in winter than in summer. The winter minimum temperature in northern BC is likely to experience the greatest change with models suggesting 4 – 9°C increases in minimum temperatures by the 2080s (Spittlehouse 2008). However, climate change goes beyond just increases in temperature. It also affects other climatic factors such as precipitation rate, timing and form. Historical analysis of precipitation records suggests that BC has generally become wetter at a rate of more than 22% per century with some observations of +50% per century occurring in winter in the interior (Rodenhuis et al. 2009). Predictions by season suggest that conditions will be wetter over much of the province but drier during summer in the south and on the coast. In addition, changes are expected in the form precipitation takes, with more precipitation falling as rain and less falling as snow during the cold season (Spittlehouse 2008). Increased occurrences of extreme weather events have been documented worldwide and climate models project a continuing rise in their frequency (IPCC 2007c). As such, extreme weather and weather-related events such as droughts and storms are likely to become more commonplace in BC with subsequent increases in the frequency and intensity of precipitation events, windstorms, forest fires and landslides.

Even if the most optimistic predictions are taken, these and other forecasted changes in climatic conditions are likely to affect the ecological processes in BC’s forests and rangelands significantly. Some changes have already been observed. The most notable and catastrophic to date has been an increase in the climatically favourable conditions for the mountain pine beetle, which has now led to an estimated 16.3 million hectares (some 27 per cent) of the Province’s forests being affected to some degree. Other less conspicuous but possibly no less threatening changes are being recorded and predicted such as alterations in: species and ecosystem distribution (Hebda 1997, Hamann and Wang 2006a, Nitschke and Innes 2008b), fire regimes (Flannigan et al. 2002, Soja et al. 2007, Nitschke and Innes 2008a), species phenology (Bunnell et al. 2008) and overall forest productivity (Boisvenue and Running 2006, Williamson et al. 2009).

1.2 ADAPTING TO CLIMATE CHANGE

The question of what to do about climate change and its impacts is being debated in multiple fora including those at the local, national, and international level. The available options are divided into two broad courses of action: mitigation to reduce emissions of greenhouse gases or to remove them from the atmosphere, and adaptation to reduce adverse impacts and increase beneficial impacts of exposure to climate change. Both of these courses of action are needed to manage and lessen the risks from climate change and both are being pursued. Adaptation refers “to an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2007a) (p. 750). Adaptation involves making adjustments in our decisions, activities and thinking because of observed or expected changes in climate, with the goals of moderating harm to the environment and society, or taking advantage of new opportunities (IPCC 2001, NRC 2010a). Adapting to climate change reduces vulnerability by ameliorating risks and capitalizing on benefits through maintaining ecological resilience (Nelson et al., 2007). Adaptation cannot prevent economic and other losses from climate change but it can reduce and delay them (Adger et al. 2009).

There are a multitude of different approaches to and information about climate change adaptation in forests and the environment generally, approaches operating at different temporal and spatial scales and levels of specificity (Innes et al. 2009, Aaheim et al. 2011, Klenk et al. 2011, Rodriguez-Calcerrada et al. 2011, Serengil et al. 2011). Tree crops are long lived compared to many rangeland species, meaning that the climatic conditions early in a rotation may differ from those in later in a rotation. Adaptation measures will likely require integration across all facets of production, from seedling production to processing.

Adaptation options have also been classified as being either proactive or reactive. Reactive adaptation measures occur after damage has or is occurring. They include approaches such as: salvage cutting, updated harvest scheduling, recalculating allowable cuts, and developing socio-economic support programs to help those communities which have been negatively affected by changes. Proactive or planned adaptation approaches by contrast involves undertaking anticipatory interventions at different levels and across sectors examples include diversification for forest and non-forest products (carbon and bioenergy), the development of improved vulnerability and impact assessments, the exploration of new opportunities (using new species or provenances, new areas for planting and relocating or altering the stock levels in certain regions), increased preparedness for disaster, and the modification of silvicultural regimes to assist with risk management. Proactive approaches to adaptation are recognised as more likely to avoid or reduce damage than reactive options which occur after damage has or is occurring (Easterling et al. 2004, Ohlson et al. 2005, Lemprière et al. 2008).

There is also the risk of maladaptation, where inappropriate adaptation (either naturally occurring or implemented as a part of the management regime) exacerbates problems into the future (Adger and Barnett 2009). This is a particular risk with longer-lived species – such as trees where adaptation strategies developed now may not necessarily be optimal by the end of a rotation if climate change trends or tree responses to climate are different to those we anticipate from current knowledge. Risk of maladaptation can be reduced by conducting ongoing monitoring which ensures that adaptation options are providing the favourable outcomes intended.

1.3 FOREST MONITORING

Monitoring of the natural environment is one of the most important activities to support the management of natural systems for climate change adaption purposes (Lovejoy and Hannah 2005, Fussel and Klein 2006, Brooke 2008, Lawler 2009, Singh et al. 2010, Spies et al. 2010). Given the large uncertainties associated with climate change, regular and systematic monitoring and reporting is the primary means for understanding what changes are actually taking place and for gathering data that can be used to anticipate and proactively respond to them.

Monitoring is a widely used and ambiguous term when applied in environmental management context - it is used at a variety of geographical scales in reference to a vast array of activities (Bunnell 2009). The most widely accepted typology of monitoring is that of Noss and Cooperrider (1994) who outline three broad categories of monitoring which serve different and complementary functions in the overall forest management process. These include:

- Implementation monitoring: undertaken in order to know whether certain recommended management guidelines and practices are being adhered to.
- Effectiveness monitoring: to learn about the status and trends of a measured management outcome.
- Validation monitoring: to validate the extent to which particular management interventions are having the desired effect (Noss 1994).

In discussing the monitoring of forest biodiversity, Garder (2010) adds to these an additional monitoring approach: surveillance monitoring. While Gardner couches his description of surveillance monitoring in the context of forest biodiversity he describes this type of monitoring as the assessment or evaluation of the general trends over time at a particular site, commenting specifically that this type of monitoring is "particularly useful in acting as a warning device of unpredictable changes in biodiversity, for understanding background levels for variability in control sites and for evaluating non-spatial human impacts (e.g. climate change)" (Gardner 2010) p. 46).

Surveillance monitoring is the type of forest monitoring my research focuses on as it is particularly well suited to better understanding the effects of climate change on the forest environment. The approach to monitoring I use in my study also fits with the description of monitoring described by Spellerburg (2005) who more generally describes monitoring as "the systematic collection of data in a standardized manner at regular intervals over time" (Spellerberg 2005)p. 2). In addition it also fits with Holmgren and Markland (2007) who describe forest monitoring systems as processes that support strategic decision making by systematic and repeated measurement and observation of forest resources and their management in order to supply the periodic delivery of valid, representative and relevant information on status and trends (Holmgren and Marklund 2007).

The monitoring being discussed here differs from the monitoring associated with adaptive management. While monitoring for adaptive management is important, this refers to collecting data about the impacts of management responses. Monitoring the impacts of climate change refers to the monitoring of the natural system (described above as surveillance monitoring), preferably while being able to factor out the effects of local management actions.

Lindenmayer and Likens (2010) also assign monitoring programs into three broad categories based on the drivers behind data collection and the scale at which the monitoring program operates. These are namely: question-driven monitoring, mandated monitoring and curiosity driven or passive monitoring. They comment that mandated monitoring programs are considered to produce course-level summaries of temporal changes in resource condition (e.g. Status reports) but provide limited understanding of the site-specific mechanisms that have given rise to those changes. By contrast, question-driven, long term monitoring programs work at the level of sites, landscapes or regions. They note that question-driven programs can provide better insights about the mechanisms or ecological processes giving rise to these emergent patterns.

1.4 USING EXISTING FOREST MONITORING TO ANTICIPATE AND RESPOND TO CLIMATE CHANGE

During the last several decades, forest managers have largely relied on SFM paradigms to set goals and inform forest management decisions. SFM refers to the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regenerative capacity and vitality (Anon 2003, FAO 2005). Monitoring is a key component of SFM and consequently, monitoring frameworks based on SFM paradigms have proliferated and have now become the mainstay of forest management data collection and reporting in many countries (Costanza et al. 1997, Hickey et al. 2005, Howell et al. 2008). While there are some differences provincially and nationally, the concept of SFM is firmly entrenched in both British Columbian and Canadian forest management objectives (Innes 2003, Bridge et al. 2005, CCFM 2006, MFR 2006, Hickey and Innes 2008).

When considering this paradigm’s goal, many forest managers assume that by restoring and maintaining historical conditions they are maximizing the chance of maintaining an ecosystem’s sustainability into the future. However, as we enter this new era of rapid climate change and global and regional climates are pushed beyond the bounds of the last several centuries (IPCC 2007b), the applicability of forest management focusing on maintaining or restoring past conditions, some of which are uncertain, is starting to be questioned. Some, for example, comment that this practice may require increasingly greater inputs of energy from managers and could produce forests that are ill-adapted to current conditions making them even more susceptible to undesirable changes (Millar et al. 2007). Others, hesitant to 'throw the baby out with the bath water', are finding ways to modify and/or link sustainable forest management goals to climate change adaption goals and needs (Spittlehouse and Stewart 2003, UNFF 2007, CCFM 2008, Ogden 2008). At the Canadian national level, SFM is defined by the Canadian Council of Forest Ministers (CCFM) Criteria and Indicators framework (CCFM 2005). This framework does not explicitly account for climate change considerations; however, recently the CCFM noted that "consideration of climate change and future climatic variability is needed in all aspects of SFM" (CCFM 2008) (p.9). Ogden and Innes (2007) found that over two thirds of the forest practitioners that they surveyed considered that the goals of climate change adaptation were synonymous with those of SFM suggesting that the criteria for the conservation and sustainable management of boreal forests are suitable objectives against which the performance of adaptation options can be assessed (Ogden and Innes 2007). Despite the recognised information needs and the connections that have been drawn between climate change adaptation and SFM more detailed work is required to better incorporate climate change considerations into the actual monitoring of SFM on the ground.

In BC, both the Canadian and British Columbian Governments have been working for the best part of three decades to develop data sources and inventory programs for monitoring and reporting on SFM (CCFM 2006, MFR 2006, NFI 2010, VRI 2010). While these programs have not been designed with climate change in mind they do contain valuable existing baseline information and data collection and supply processes that could effectively be adapted and augmented to better realize, anticipate and support climate change adaptation in BC's forests.

Using current data collections and inventories to monitor climate change builds on data already collected and is a logical step in informing decisions regarding climate change adaptation. The rationale for this is largely twofold. Firstly, climate change adaption monitoring (like all natural resource monitoring) will be infinitely more useful if it can be associated with existing baseline data that allows trends to be established and conclusions to be drawn regarding the speed and nature of the changes that are occurring (NRC 2000, Gardner 2010, Wilby et al. 2010). Secondly, due to the relatively high cost of monitoring, adopting this 'use what we've got' approach will be more pragmatic, cost-effective and on the whole more implementable - factors which have been recognised as key to the success of monitoring programs (Caughlan and Oakley 2001, Lindenmayer and Likens 2010).

Chapter 2

Determining a key set of biophysical indicators for monitoring in light of climate change

2.1 INTRODUCTION

The use of indicators to communicate information about the state and dynamics of the environment has, over the past two decades, become a globally accepted norm in monitoring, describing, and reporting on forests and their management (Prabhu et al. 2001, Raison et al. 2001, Howell et al. 2008, Wijewardana 2008). Hammond (1995) defines an environmental indicator as: " ….something that provides a clue to a matter of larger significance or makes perceptible a trend or phenomenon that is not immediately detectable" (p. 1). Designed to quantify and communicate complex phenomena in a simple manner, indicators represent a communication bridge between scientists and policy/decision makers (NRC 2000, Niemeijer 2002). By their nature, indicators are designed to isolate key aspects from an otherwise overwhelming amount of information and help decision makers to see the larger patterns of what is happening and help them determine appropriate actions. To develop and implement sound environmental policies, data are needed that capture the essence of the dynamics of environmental systems and changes in their function. These kinds of data then need to be incorporated into indicators (Hamblin 2001).

The choice of indicators for monitoring is fundamental to defining the approach to both monitoring and management. However, it is a major challenge to determine "which of the numerous measures of ecological systems characterize the entire system yet are simple enough to be effectively and efficiently monitored and modeled" (Dale and Beyeler, 2001, p. 4). Lindenmayer and Likens (2010) also refer to the danger of being "snowed by a blizzard of ecological details" (p. 20) and specifically caution against the creation of a huge 'laundry list' of ecological features to monitor that uses up valuable time and resources and makes a monitoring program too expensive to be sustained financially beyond the short-term (Lindenmayer and Likens 2010). Developing scientifically sound, useful and effective provincially applicable indicators for an area as physically, climatically and biologically diverse as BC is challenging. This difficulty is compounded immeasurably by the fact that forests are being altered in ways that are not well understood or even realized, such as the unknown effects of climate change on forest ecosystems and their productivity. Despite this complexity and uncertainty, simple and effective provincial-scale indicators for monitoring the effects of climate change are needed because much of the forest decision-making in BC is implemented at the provincial level. Thus, forest managers working at that level need relevant and timely information in order to incorporate climate change into decision making and in order to take defensible proactive actions for managing and mitigating its impacts to the best extent possible.

2.2 METHOD

In order to select a series of preliminary indicators for further investigation and eventual monitoring, an iterative, bottom-up process involving both expert participation (this chapter) and end-users (Chapter 3) was employed. While these two groups were not necessarily mutually exclusive the first group contained a select group of individuals with an in-depth knowledge of appropriate methods for monitoring and measuring species and ecological processes and/or in-depth knowledge of forest and climate change related issues in BC. The end users incorporated a wider group of environmental managers operating in the Province who simply had an interest or stake in forest management.

The expert participation process (detailed below) was developed by examining a combination of indicator selection processes and methodologies that have been put forward in the academic literature and organisational reports (e.g. NRC 2000, Bossel 2001, Dale and Beyeler 2001, Oliver 2002, Bridge et al. 2005, Bubb et al. 2005, UNCSD

2007, Gomontean et al. 2008, Niemeijer and de Groot 2008). In developing a process of indicator selection I was also mindful of some of the key concerns and challenges that have been associated with the development and use of indicators and of monitoring programs as a whole; for example, the need for indicators to be highly selective, pragmatic, easily measured and above all cost-effective (Caughlan and Oakley 2001, Failing and Gregory 2003, Legg and Nagy 2006, Lindenmayer and Likens 2010).

2.2.1 - A conceptual understanding of the total system and identification of 'straw indicators'

An important component of the process employed in the selection and development of the indicators was the provision of a set of straw-indicators to initiate or 'jump-start' the process of selecting indicators relevant for monitoring the forest environment in the context of climate change adaptation. Straw-indicators (or documents) are employed fairly commonly to develop indicators (or other technical documents) and are simple first attempts generated by one or two people to initiate and generate discussion and to provoke the generation of new and better indicators (CCFM 2002, Oliver 2002, Bridge et al. 2005, Bubb et al. 2005). For this project the straw-indicators were developed as a result of literature review, one-on-one interviews with key experts (n = 20) and a detailed analysis of other similar climate change assessment and forest management frameworks being used locally, nationally and internationally. In order to initiate the development of the straw indicators, a literature review of the key information examining climate change vulnerability and adaptation and the observed and modelled impacts occurring or likely to occur in BC's forest environment was conducted.

The results and preliminary findings of a forest and range climate change vulnerability assessment was also of great importance to the choice of indicators (Utzig and Holt 2009). Also of importance was one-on-one interviews conducted with each of the BC Government vulnerability assessment team leaders (n = 5) who had prepared reports examining the impacts of climate change on their key subject areas (soils, hydrology, ecology, wildlife and genetic resources). Other experts and key personnel managing the data collection and inventory processes considered of relevance to the framework both within and outside of government (n = 15) were also interviewed. These experts were selected for interview because they were identified as having an in-depth knowledge of the effects of climate change on a particular biophysical attribute or for being the custodian of a key data source identified. The interviews were conducted over the telephone using a qualitative interviewing approach. This type of approach is flexible, iterative, and continuous rather than prepared in advance and locked in stone (Rubin and Rubin 1995). Notes on the responses to questions were taken and these were incorporated in to a workshop background report, in particular within the rationale for the 22 straw indicators as well as the data sources available for monitoring certain topic areas.

In forming the straw indicators detailed assessment of other similar monitoring frameworks used to monitor the impacts of climate change was conducted. This review examined both past and present programs implemented at the local, national and international levels.

The output resulting from this literature review and liaison work was a background report. As well as giving a detailed summary of the topic area, the report also contained a set of 22 straw-indicators.

2.2.2 - Climate Change Monitoring Indicator Development Workshop

An indicator development workshop held in Victoria, BC on 15 January 2009 was a pivotal stage in the selection and development of the indicators. The goal of the workshop was to seek input from experts with in-depth knowledge of appropriate methods for monitoring the biophysical aspects of forests in light of climate change in BC. Invitations were extended to over 90 experts mainly from within the BC Government Ministries of Forest and Range, and Environment but also from within academic organizations and non-governmental organizations. The workshop was attended by 58 people who came from all over the province.

Delegates were sent a detailed information package, including the straw indicators, one week prior to the workshop. As well as giving a summary of the relevant literature, the information was designed to initiate and frame discussions at the workshop and prepare delegates for two key workshop activities. In the first activity, delegates were requested to consider the question: What do you think makes an indicator most relevant for inclusion in this monitoring framework? In completing the activity delegates worked in smaller groups (of approximately five people) to determine a series of characteristics that made a topic relevant for examination in BC in light of climate change. The findings of each smaller group were then discussed in plenary and key characteristics of relevance were arrived upon through group consensus. The results of this exercise are detailed in Figure 2.1.

GROUP 1

Accessibility, Buy-in, Longevity, Long-term Relevance, Not necessarily expert based just has to increase understanding of ecosystem functions and management, Predictive ability, Add new knowledge, Project meaning for the future, Nuance – current policy and management decisions – both now and into the future, Cost-effective – has to be – "big-picture cost-effectiveness", Good foundation and can be integrated into several places – soild baselines rather than response.

GROUP 2

Cost of monitoring, Use of existing data, Measurement repeatable over time – recognize that policies will change over time, important but not to the point of exclusion, Understandable, Flexible, Sensitivity to climate change, Being able to speak to/resonate with something important for human survival/society, long term relevance to society.

GROUP 3

Physical elements as well as biological processes, Lag times may make some less useful, Not too far removed from determinative processes – e.g., species with short generation times, Multi-scale – e.g., linking ground indicators to existing inventory data, Something that responds relatively quickly or monitored at a scale where some changes can be determined now, Link to predictive capacity, Scalable relates to local versus landscape, relates to a large range of issues versus local/specific indicators.

GROUP 4

Spatial and temporal scales – some should be scalable provincial to national to global, Should be measuring some basic attributes of ecosystems – not just what we think will be important – of use for models and analysis, Should have some analytical power, Leverage with other programs, Cost effectiveness.

GROUP 5

Cost, Repeatable but doesn't necessarily need field verification – remote access to data, Relevance to current policy, Relevance to ecosystem function, Understandable, Flexible, Spatial coverage.

KEY ATTRIBUTES IDENTIFIED AS IMPORTANT FOR INDICATORS TO BE INCLUDED IN THE CLIMATE CHANGE MONITORING FRAMEWORK

1. Cost effective
2. Use existing data sources and collections
3. Use existing trend data to the extent possible
4. Be based on available or easily obtainable, scientifically valid, empirical measurements that can be consistently repeated over time to observe trends
5. Be suitable to support and inform policy and land management decisions
6. Focus on factors that are sensitive or closely aligned to changes in climate
7. Be scalable spatially to be relevant at various levels of land management

Figure 2.1: Attributes identified during the workshop as being important for indicators to be included in a climate change monitoring framework in British Columbia

In the second workshop activity, delegates were split into two groups depending on their identified area of expertise. One group examined those indicators focusing on biodiversity and forest and rangeland disturbance factors such as fire and insects. The other group focused on examining indicators related to soils and hydrology. The two groups concurrently discussed each of the proposed straw indicators in the context of the characteristics of relevance and identified any further areas that were needed. The data sources that would be available to support each indicator's evaluation were proposed and discussed. Discussions of each sub-group were then reported back for discussion in a final plenary session. Discussions for all sessions at the workshop were extensively recorded and some of the key discussion points raised for each indicator are detailed in Tables 2.1 – 2.4.

After the workshop a detailed review and summary of the results of the indicator development workshop was conducted. A more comprehensive assessment was made of the data sources available to support the assessment of each indicator which resulted in a comprehensive list of data sources potentially suitable for supporting indicator evaluation. A draft title, rationale for monitoring in light of climate change and cost-benefit analysis of monitoring was prepared for each indicator based on their perceived importance and the effort required to gather data to support the indicator. The resulting indicator set was further reviewed, assessed and endorsed by a smaller committee (n=9) of forest experts who had been involved with the entire indicator selection process.

Table 2.1: Workshop discussion relating to biodiversity indicators

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME
Change in the distribution and composition of forest and rangeland ecosystems		
Discussions on this indicator were lengthy and dominated discussion for this sub-group. A number of key data sources were discussed and concerns with these datasets were identified. Of particular note were the issues regarding the ability to track changes using the existing data sources. Data gaps in the coverage identified included northern areas, alpine areas and grasslands.	Biogeoclimatic Ecosystem Classification system, Vegetation Resources Inventory, National Forest Inventory, Terrestrial Ecosystem Mapping	Indicator is regarded as highly important and should be retained in its existing form. In addition, the group considered that a new indicator should be developed looking at the effects of climate change on forest productivity
Area of forest and range by protected area categories		
Delegates did not perceive this indicator as important for monitoring in light of climate change. Definitional issues were raised with the type of protection to be identified.	Not applicable	Indicator was not regarded as important and was removed from the framework.
Levels of ecosystem fragmentation		
Delegates considered that this indicator should be monitored at the landscape level using course scale data and GIS based assessments. The indicator was only regarded as moderately important but was seen as a worthwhile analysis if the existing data was available.	Biogeoclimatic Ecosystem Classification system, Vegetation Resources Inventory, National Forest Inventory, Terrestrial Ecosystem Mapping	Indicator was regarded as moderately important and should be retained in its existing form if a cost-effective method for analysis could be derived from the existing data.
Trends in population and range information for [animal] species from a range of taxa and habitats		
Discussions on this indicator were lengthy. Delegates considered that the indicator should apply to species from a range of taxa (not just animals) but cautioned that there were no species in British Columbia that could be effectively monitored for the effects of climate change using existing data sources. It was noted that this indicator was much more resource intensive than many of the other indicators proposed because it was entirely reliant on hands-on field data and could not be assessed any way using remote sources. Some very course range maps are available for some species but these maps were not at the scale and accuracy needed to monitor changes brought about by climate change. In addition to the range and population information delegates considered that species phenology should also be included to the extent possible.	British Columbia Breeding Bird Atlas, British Columbia Conservation Data Centre, Canadian Community Monitoring Network, Environment Canada's Ecological Monitoring and Assessment Network, Forest and Range Evaluation Program, Invasive Alien Plant Program, Nature Conservancy of Canada, NatureCounts, NatureWatch,	Indicator regarded as important for monitoring in light of climate change however there are serious questions relating to the Province's capacity to do any monitoring of this indicator using existing data sources. Indicator was updated to include species' phenology.
Forest and range associated species at risk of losing their genetic diversity and forest management and conservation efforts for those populations and species		
Delegates commented that the ability to monitor genetics is rapidly improving. It was also noted however that genetic monitoring is largely focused on	Centre for Forest Conservation Genetics, Ministry of Forests,	Regarded as moderately important for monitoring the indicator was not seen as important for determining range and

those species of financial interest for the Province.	Land and Natural Resource Operations Research Branch - Forest Genetics Section, Ministry of Forests, Land and Natural Resource Operations Tree Improvement Branch - Headquarters Unit	population levels for species.

Table 2.2: Workshop discussion relating to forest disturbance indicators

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME
Scale and severity of insects and pathogens adversely affecting forest and rangeland health		
Discussions on this indicator were lengthy and the indicator was considered important for inclusion in the framework. The annual aerial surveys conducted by the Forest Practices Branch were considered to the best data source for this indicator. Concerns were raised however that this method is only able to pick up on insect and pathogen outbreak occurrences at a medium to large scale and that this would be problematic for acting on outbreaks (as by the time there have been detected they are too big to control).	Forest Practices Branch (Forest Health)	Indicator is regarded as important and should be retained in its existing form.
Scale and severity of wind throw damage affecting forests		
Some of the delegates were apprehensive about the need to track windthrow in light of climate change and did not perceive this indicator as key area for monitoring. Some data sources were identified however if they were not able to supply the information needed then the indicator should not be included within the framework.	Ministry of Forests, Land and Natural Resource Operations Forest Practices Branch, Ministry of Forests, Land and Natural Resource Operations Forest and Range Evaluation Program	Indicator was not regarded as key for monitoring. However it was retained pending future investigations to determine the capacity of monitoring using existing data sources.
Extent to which fire frequency, severity and seasonality has deviated from the historic range		
Delegates considered that this indicator should focus mainly on the fire season severity as opposed to other factors. Length of the fire season was also considered an appropriate indicator for monitoring in light of climate change. Historic range was not considered to be useful in the wording of the indicator title.	Wildfire Management Branch	Fire was regarded as important for monitoring. However, delegates considered that the indicator should focus on fire weather and its severity. The effects of this on season length were also recognised as being of importance. The indicator title was altered to reflect these comments.
Scale and severity of unseasonable or unexpected weather conditions		
Delegates considered this indicator to be important but that it should focus on the damage that is occurring from these events not just the events themselves. In particular the effects of drought and snow pack were discussed. A data sources for monitoring the effects of	Environment Canada Climate Network for British Columbia and Yukon	Indicator regarded as important for monitoring in light of climate change however there was a need to focus on the damage resulting to forests and rangelands as a result of these events as

drought was again the aerial surveys conducted by the Forest Protection Branch while snow pack data is gathered by the Environment Canada Climate Network for British Columbia and Yukon	Forest Protection Branch	opposed to just looking at the events themselves there were some questions raised about the capacity of the current data sources to do this especially for rangelands.

Table 2.3: Workshop discussion relating to water indicators

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME
Extent to which precipitation rates and timing within selected forest and rangeland catchments has deviated from the historic range		
This indicator was considered important if not 'critical' as it related to all sort of other aspects of the framework and the indicators put forward. British Columbia's monitoring however is dependent on external programs (Environment Canada) and currently there are some areas in the Province which are not included within the current monitoring network (high elevation and high latitude areas were identified in particular). Another data gap raised in relation to this indicator was transient snow zones where lots of variability may be occurring (shifts in the form precipitation takes). There is currently some ongoing collaborative work designed to address this gap. Database management was also seen as crucial to effectively monitoring this indicator and being able to maintain and provide access was regarded as critical with the number of organisations involved in a possible network of sites.	Environment Canada Water Survey Environment Canada River Forecast Centre BC Hydro's Regional Hydromet Data	The wording of the indicator title was considered inappropriate and was altered to remove "extent" and "deviated from the historic range". Monitoring of precipitation was extended to include the form which precipitation takes.
Extent to which snowpack in forest and rangeland catchments has deviated from historic amounts		
Delegates considered this indicator as important because changes in the timing of the development and loss of the snowpack are uncertain, but could have considerable impact on forest ecosystem processes and in turn biodiversity. At the workshop, delegates anticipated that the organization would be able to supply adequate data on snow depth to support a reasonable analysis and interpretation of the indicator.	Environment Canada Water Survey Environment Canada River Forecast Centre BC Hydro's Regional Hydromet Data	Wording changes were made to the indicator title in line with the comments above.
Extent to which streamflow rates and timing in selected forest and rangeland catchments has deviated from the historic range		
Delegates considered streamflow to be a very important attribute for monitoring and discussed it at length. Smaller streams were considered to be a persistent data gap which was particularly relevant for assessing the ecosystem processes affecting forest and rangelands. Most watersheds are monitored on a large scale (greater than $20km^2$) while impacts are most likely to be felt at a smaller scale. Delegates discussed the possibility of monitoring high water marks (of lakes that are dammed and/or regularly navigated). This was considered as an important interpretation of the results of monitoring this indicator. Monitoring ground water levels was also considered in discussion surrounding this indicator. However delegates considered it should not be included because it was not able to meet the initial criteria established in the earlier workshop exercise because of a paucity of data and the difficulty of collection.	MOE River Forecast Centre MOE Water Stewardship Division Sciences and Information Branch BC Hydro's Regional Hydromet Data	Wording changes were made to the indicator title in line with the comments above.

Water withdrawal was also considered for monitoring because there was considerable data available to measuring human impact on water supplies. This was also rejected by the wider group because it did not meet a number of the other selection criteria designed for choosing the indicators either.		
Extent to which temperatures in selected forest and rangeland streams and lakes have deviated from the historic range		
Stream temperature was seen by delegates as important for monitoring but it must be considered in the context of other factors. It was not considered particularly useful if only taken in isolation (without other preceding indicators such as stream flow). The need to ensure consistency in the calibration of monitoring equipment was discussed along with the need to design rigorous technical collection standards to apply across the suite of current organisations collecting this data.	MOE River Forecast Centre MOE Water Stewardship Division Sciences and Information Branch BC Hydro's Regional Hydromet Data Assessment Network	Wording changes were made to the indicator title in line with the comments above.
Changes in glacial mass balance		
Delegates considered that this indicator should be monitored at the landscape level using course scale data and GIS based assessments. The indicator was only regarded as moderately important but was seen as a worthwhile analysis if the existing data was available. An indicator monitoring water quality was seen as a more valuable addition to the framework then this indicator monitoring changes in glaciers.	Canadian Glacier Information Centre (CGIC) Canadian Cryospheric Information Network (CCIN) Western Canadian Cryospheric Network	Indicator was regarded as moderately important and should be retained in its existing form if a cost-effective method for analysis could be derived from the existing data. A new indicator was created looking at changes to water quality.

Table 2.4: Workshop discussion relating to soil/ geomorphic processes indicators

Scale and density of rapid mass movements and erosion events		
The indicator was only regarded as moderately important but was seen as a worthwhile analysis if the existing data was available. The Forest and Range Evaluation Program is in the process of developing the methodology to conduct a pilot study to examine the terrain stability at the landscape level. The approach offers considerable potential for supporting this indicator and is expected to begin within the next year. This indicator may have the potential to develop more fully in the future but is regarded a somewhat aspiration at this time.	Forest and Range Evaluation Program	Indicator was retained in the framework but is regarded as aspiration at this time.
Temperature of soil at selected forest and range sites		
Delegates did not perceive this indicator as important for monitoring in light of climate change. There are not soil inventories available to lend data to such an indicator.	Not applicable	Indicator was not regarded as important and was removed from the framework.

2.3 RESULTS/DISCUSSION

The process detailed above resulted in the development of a framework of sixteen indicators designed for monitoring and reporting on the biophysical effects of climate change in forests and rangelands. Table 2.5 details the indicators and Appendix A provides more detail on each indicator including the final title, rationale and the potential data sources identified.

Table 2.5: BC forest and range climate change monitoring and reporting framework indicators

1	Temperature
2	Precipitation frequency, timing and form
3	Frequency of extreme, unseasonable or unexpected weather conditions
4	Streamflow rates and timing
5	Water temperature
6	Snowpack
7	Water quality
8	Landslides and other mass movement events
9	Fire season length and severity
10	Extent of wind throw damage
11	Extent of attack by insects and pathogens
12	Composition and distribution of ecosystems
13	Ecosystem productivity
14	Ecosystem connectivity
15	Range and phenology of production relevant tree and grass species
16	Range and diversity of tree genotypes

While considerable effort has gone into selecting these indicators, they were by no means considered to be the final version of the indicator set. From the outset it was always anticipated that this indicator selection and development process would be iterative, with the framework expected to evolve as data availability and knowledge of climate change and its impacts on forests and rangelands in BC improves.

A preliminary list of monitoring programs and datasets of direct relevance to the project is also provided in Appendix A. Some thirty data sources were identified, with each having been designed to address their own information need, and none of which specifically include informing climate change adaptation. While these programs were not designed with climate change in mind, they do contain valuable existing baseline information and data collection and supply processes that could effectively be adapted, bolstered and/or augmented to better realize, anticipate and support climate change adaptation in BC's forests. Some of these data sources are further explored in Chapters 4 – 9 of this report.

Chapter 3

Climate change adaptation monitoring and reporting information needs of forest and range managers

3.1 INTRODUCTION

As discussed in the previous chapter monitoring and reporting information on the environment is a well-established activity in natural resource management (NRC 2000, Raison et al. 2001, Busch and Trexler 2002, Spellerberg 2005). Numerous scientifically-based environmental monitoring and reporting frameworks supply information to environmental managers and decision makers, although, over the years these initiatives have achieved varying levels of success (Lindenmayer and Likens 2010). While this success or otherwise can be attributed to a myriad of factors, one of the major stumbling blocks is a failure to engage the intended audience from the outset to make sure that the monitoring 'hits the mark' and is sufficiently selective to produce useful or usable information. Also related to this is ensuring that reporting is done in a way that is easily understood and digested by environmental managers and decision makers (NRC 2000, Jacobs et al. 2005, Lemos and Morehouse 2005, Holliday 2007, Liu et al. 2008).

With climate change presenting a daunting array of challenges for natural and human systems the need to bridge the gap and produce solid, useful and usable adaptation information is becoming increasingly urgent (Thiaw 2009, NRC 2010c, Spies et al. 2010). Many have noted that if early, defensible, proactive actions are taken and informed decisions can to be made then the chances of increasing adaptation to climate change and mitigating its effects are likely to be enhanced (Easterling et al. 2004, Ohlson et al. 2005, Johnson and Williamson 2007, Millar et al. 2007, Williamson et al. 2009). A widely recognised solution for moderating the lack of cohesion between those doing the monitoring and the intended audience largely involves developing from the outset a clear understanding of what information is likely to be most useful and usable in the eyes of the target audience at the start of the planning and management activities (Jacobs 2002, Joyce 2003, Lemos and Morehouse 2005) and determining a key set of questions of interest to them,

Given that the focus of the monitoring framework developed and discussed in Chapter 2 is to inform forest and range management and decision-making, it was vital that the final stage in the development of the indicators incorporate a ‘reality check’ to assess how well the indicator framework matched up with the information needs of the intended target audience. In June 2010 an internet survey was distributed to over five hundred forest and range managers operating in BC. The survey sought to better determine the key climate change monitoring and reporting information needs of forest and range managers and decision makers. The survey led to several important refinements to the indicator set and has been pivotal in influencing the approach designed to measuring each individual indicator.

3.2 METHODOLOGY

3.2.1 Survey design

introductory section giving a short background to climate change adaptation. In the second section I sought to investigate the climate change adaptation information needs of forest managers. Among the seven questions used in this section was a scale requesting respondents to rate the importance of a series of topic areas (correlating to the indicators identified in Chapter 2) using one of four ‘importance’ categories. Four categories were chosen because it was the maximum number of categories that could be used without respondents having to scroll across the horizontal landscape of the screen. Dillman (2007), who comments extensively on the need for surveys to be visually appealing and ‘respondent friendly’ to increase participant numbers, discourages respondents having to scroll extensively across the screen in the design of web surveys (Schaefer and Dillman 1998, Dillman 2007). Dillman also indicates that this may cause a bias by encouraging respondents to choose the more accessible response categories. A rating approach (as opposed to a ranking approach) was used for the same reason, namely that it was considered too complicated for respondents to rank (rather than rate) the 24 different topic areas (Dillman 2007). It was also thought that respondents might want to give equal importance to some of the topic areas. This section of the questionnaire also included questions asking respondents if there were other topic areas they considered important and what timeframes were of the greatest interest to them. They were also asked if there were any specific regions in the province that are of most importance for monitoring the effects of climate change.

In the third section of the survey, two questions were used to gather information on forest and range managers' perspectives on the status of current data and its analysis in light of climate change. This section also used two questions to develop an understanding of the best formats and media to reach decision makers. For one of these questions, respondents were asked to rate (again using a four-point scale) the frequency with which they used eleven various sources information in their decision making. Respondents were asked to choose the one of three levels of detail they needed to make decisions in their work area.

The final section of the survey was used to gather factual information about the respondent, including their location, current position, scale and focus of their work. For further reference, a copy of the survey is included in Appendix A.

3.2.2 Survey Instrumentation

As the survey only targeted environmental managers and decision makers in BC, I used a non-probability sampling approach where a key subset of the population was selected for study. The sample frame was a BC Government database of 550 people actively engaged in environmental management in the province; I employed a purposive sampling technique (Yin 1994, Babbie 2007). Data were collected through an online survey that was administered between May and July 2010. While the majority of these individual email addresses belonged to employees within the currently-named Ministry of Forests, Lands and Natural Resource Operations and the Ministry of Environment, other groups represented within my purposive sample included the Ministry of Transportation and

Infrastructure, the Ministry of Energy and Mines and the Ministry of Agriculture (note that several government re-organizations during the period 2009–2011 have resulted in a number of name changes), First Nations groups including the First Nations Forestry Council, and other non-profit organizations including the Nature Conservancy of Canada and professional organisations including those representing professional foresters and biologists.

I pre-tested the survey in May 2010 and received valuable feedback from five unaffiliated respondents. Comments and suggested amendments arising from the pre-test were incorporated where feasible. The survey was distributed under the name of the province's Chief Forester because it has been shown that people are more likely to respond to a survey if it is endorsed by a 'legitimate authority' (one whom the larger culture defines as legitimated to make such requests) (Dillman 2007). Following the delivery of the survey on 10 June 2010, a reminder was sent to all potential respondents exactly one week prior to the survey closing. Once a respondent had completed and submitted the survey they were not able to re-access the survey or submit additional responses.

3.2.3 Data Analysis

Depending on the data collected, both qualitative and quantitative techniques were used to analyze the data gathered in response to the questionnaire. Qualitative information collected was categorized and organized according to a series of topics developed through constant comparison or a process is referred to as 'coding' (Babbie 2007). An 'open coding' approach was adopted where responses received were broken down into discrete parts, closely examined and compared for similarities and differences (Strauss and Corbin 1998). Here, each response received was read thoroughly in order to ascertain and distil the key messages contained. These messages were categorized and sorted into groups depending on the response received.

For the two questions containing quantitative data with four-point response categories each response category was weighted (i.e. 1 = 'least important' and 4 = 'most important' or 1 = 'never used' and 4 = 'frequently used'), in order to determine a mean score for each topic area or information source. The weighted standard deviation of each category was also calculated as an indication of the degree to which respondents agreed on a particular point (Barnett et al. 2005).

3.2.4 Limitations of the survey method

All survey respondents remained anonymous in the hope that they would give more candid responses. This meant, however, that I was unable to easily re-survey those who did not respond in order to evaluate response/non-response bias. To overcome this, I employed a widely used non-respondent bias extrapolation method; I compared early vs. late respondents, as late respondents may be treated as proxies for non-respondents (Armstrong and Overton 1977). Thus, to assess the effect of non-response bias I compared the answer patterns of the first 24 respondents with those 24 responses that were received after the reminder email was sent in the final week of the survey. I used t-tests ($\alpha=0.05$) to compare the responses to quantitative questions. No significant differences were found between the early and the late respondents, which suggests that non-response bias was not an issue for this sample. Another limitation with the survey was my reliance on a self-reporting method of data collection, as some respondents misunderstood the question posed or the entire purpose of the survey. In an effort to alleviate this issue I had given my name, telephone and email and encouraged respondents to contact me directly if they had questions regarding the survey; however, no calls or emails with questions were received.

Some of the respondents misunderstood the terms of reference of the survey and the overall goal of the monitoring framework itself. This was most evident for example in the responses received for Question 2.3 that asked respondents if there were additional topic areas that were important for monitoring in forests in light of climate change. Here, three of the survey respondents gave topic areas that while relevant from a climate change perspective were beyond the terms of reference for monitoring in forests in light of climate change.

3.3 RESULTS

A response rate of approximately 18 per cent was achieved with a total of 96 individuals responding to the survey.

3.3.1 Respondents profile

In order to profile respondents the questionnaire sought data on each respondents' organization, location, the main focus of their current position, and the scale(s) at which they work.

Organisation

Unsurprisingly the majority (60%) of respondents indicated that they were employed by the Ministry of Forests, Lands and Natural Resource Operations, the lead government agency responsible for the management of approximately 94 per cent of BC's forest and range lands (Anon 1996, MFR 2009). A number of respondents indicated that they were from the BC Ministry of Environment (17%) the other key government agency with strong interest in the management of forest and rangelands. Also represented in the following proportions were: other BC Government ministries (6%), industry groups (6%), First Nations groups (5%), academia (4%) and civil society and community organizations (2%).

Location

One third of respondents were based in the capital city of British Columbia, Victoria (33%), while the remaining respondents were spread relatively evenly across other areas of the province. All forest districts within BC were represented by district level forest managers.

Scale of work

Many respondents specified that the main focus of their work was at the Provincial scale (45%). Others worked at the district (27%), regional (17%), federal (6%), municipal (6%) and international levels (2%).

3.3.2 Monitoring Information Needs

In this section of the questionnaire information was sought on the information needs of forest and range managers with regard to climate change.

The importance of various topic areas

Respondents were asked to rate the level of importance of 24 topic areas that had been preselected by forest and range experts as a result of earlier research focused on developing an indicator framework for monitoring biophysical attributes of the forest and rangeland environment in light of climate change (Chapter 2). Respondents rated each topic area from not very important (1) to extremely important (4). Table 1 presents the mean response values and weighted standard deviation of each of these topic areas. A higher mean corresponds to a higher overall importance score (i.e. voted more important) while a higher standard deviation (i.e. =/>1) suggests greater disagreement among respondents on the importance of a particular topic area.

<u>Topic areas perceived importance for monitoring in relation to climate change adaptation information needs[1]</u>

Topic Area	Mean	Standard Deviation
Ecosystem productivity	3.05	0.92
Ecosystem distribution	2.96	0.88
Ecosystem composition	2.93	0.83
Precipitation timing	2.93	0.93
Precipitation rate	2.85	0.89
Species' ranges	2.84	1.01
Snowpack extent and depth	2.79	0.95
Insect incursions	2.77	0.99
Precipitation form	2.76	0.97
Streamflow rate	2.65	0.92
Streamflow timing	2.65	0.91
Pathogen incursions	2.64	0.98
Fire season severity	2.62	1.02
Species phenology	2.58	1.00
Water quality	2.55	0.98
Ecosystem connectivity	2.54	0.98
Species population levels	2.53	1.00
Mass movement and erosion events	2.52	0.92
Genetic diversity	2.52	1.00

Water temperature	2.49	1.06
Unseasonable or unexpected weather	2.46	0.97
Fire season length	2.37	0.98
Wind throw damage	2.18	0.96
Extent of glaciers	2.15	1.03

[1] Rated on a scale from 1 to 4 where 1 = Not very important and 4 = Extremely important

Additional topics of interest

Respondents were also asked if they thought there were any additional topic areas that need to be monitored that were not already included in the preselected topic areas listed. This was an open-ended question that allowed each respondent to freely list any additional topic areas they thought were important for monitoring for climate change adaptation. The majority (58%) of respondents indicated that they considered no new additions necessary, while a further 26 per cent suggested additions that already aligned well with the existing indicators. Some of the additional indicators suggested were considered beyond the scope of this particular monitoring strategy which, as mentioned, is concerned with the effect of climate change on the biophysical aspects of forest and rangelands. These included: sea level rise, estuary extent, and transport exhaust regulation. Most of the others commented on the need for more upfront contextualisation of the existing topic areas through the inclusion of indicators examining temperature change and the frequency of extreme weather events such as droughts and severe cold snaps.

Key information needs

In order to better investigate the key climate change monitoring information needs we asked respondents to describe their specific information needs in relation to the topic areas they had suggested to be most important for monitoring. This was again an open-ended question with respondents encouraged to freely describe their needs. The detailed statements received were classified according to the main topics that respondents had raised. Figure 1 presents a breakdown of the reported information needs.

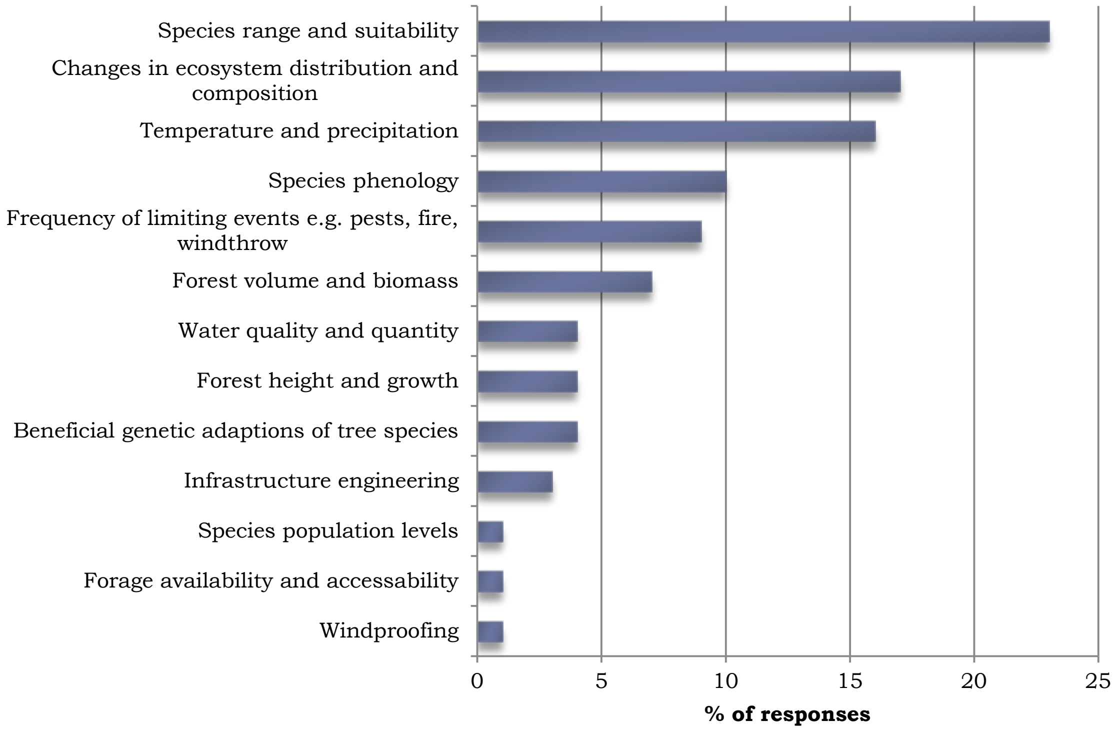

Figure 1 – Main climate change adaptation information needs of respondents

Many respondents (23%) listed species range and suitability as one of their specific information needs in relation to climate change adaptation. In most cases answers reflected a strong emphasis on the need to enhance and preserve forest and range productivity and the need for information that will allow managers to proactively respond to the reported and predicted changes in climate. For example as one respondent stated: "*A tree planted now must survive for 40-60 years if it is to have value. Ensuring the trees planted will grow is my greatest current need*".

Closely tied to species range and suitability was changes in ecosystem distribution and composition, which many respondents (17%) also listed as a key information need. In this case many expressed a need for more information to help develop and change operational practices to better incorporate the effects of climate change. For example, as one respondent commented: "*We need to know when is the right time to leave an area and when is the right time to reforest it? Can we stop having an obligation to reforest in a particular area if we know that it is climatically shifted to be suited to a grassland* *ecosystem?*". Many respondents also expressed interest in gaining more information about how climate change is affecting species phenology. This was, again, largely tied to a need for information regarding how to enhance the productivity of the forest and range environment including, for instance, when is the best time to replant and how the timing of grass/forb life stages are being altered so that stock turnout, movement and roundup could be suitably aligned. The frequency of both biotic and abiotic disturbance events was also of interest to many as was the need for overall information on changes in forest volume and subsequent forest biomass calculations.

Timeframes of interest

Respondents were asked to choose the timeframe that they were most interested in. This was specifically in relation to the information they had supplied in response to the above sections of the questionnaire and to give a brief rationale for their choice. Overall, respondents were greatly in favour of earlier timeframes, with the majority of respondents (82%) opting for timeframes within the next 50 years and some 54 per cent choosing timeframes within the next 20 years. Most opting for sooner timeframes commented that they need advice on what to do now and the sooner information could be provided to them the better. As one respondent commented: "*if we don't start getting our house in order to figure out current baseline trends, we will never be able to do it for the longer timeframes. As well by looking at a shorter timeframe we stand a better chance of determining critical change while there may be still a chance to react to it*". Only a minority (8%) of respondents opted for longer time periods between 50 and 100 years. In most cases, their rationale for choosing a longer timeframe was that they believed climate change monitoring needed to be done in the long term, rather than because they thought we should hold off on monitoring until then. Other respondents (10%) commented that they were interested in all timeframes or attributed different timeframes to various topics. For example, as one respondent commented "*things have been happening faster than anticipated, however when I think about trees it is a longer term but when I think about grasses, and insects it could be in a shorter term that the impacts are seen*".

Geographical areas of interest

Using an open-ended question, respondents were asked if they considered there to be any particular geographical regions in the province that are most important for monitoring in light of climate change. While a large proportion of the respondents (41%) did not think that there was a particular geographical area in which climate change monitoring should focus, a number thought there were areas that should be targeted for monitoring. Of those who listed particular areas to focus on, 41 per cent nominated the southern interior region of BC as the most important area to target, while much fewer thought that the coastal (10%) and northern interior (13%) regions warranted additional attention. The other 31 per cent commented on a variety of other geographical areas or forest types they considered were more important for monitoring, the most popular of these being alpine areas, regions identified as being most vulnerable to climate change and those forests containing a larger proportions of merchantable tree species.

3.3.3 Perceived capacity of the current data collection and analysis framework

This section of the questionnaire contained two-open ended questions. The first sought to assess the perceived adequacy of the current data collections and inventory processes for providing information to manage forests and rangelands in light of climate change. Here 22 per cent of the forest and range managers responding to the survey believed that there were sufficient data available to manage forests and rangelands in light of climate change, while most (63%) believed that the current data collections were inadequate for the purpose. Others (15%) responded that they were not sure or felt unqualified to answer. There were many data gaps identified but resoundingly the majority commented on the inadequacy of forest inventory data with many particularly concerned about the inability to determine the rate, direction, timing and magnitude of changes in ecosystem distribution, tree species ranges and forest growth and survival. The other key information gap identified was the capacity of the current climate monitoring network in the province.

The other question in this section asked whether respondents felt that the correct type of analysis was being done on the data already collected to produce information to manage forests in light of climate change. Here, respondents were somewhat more confident with 46 per cent believing that the existing data sources were being analysed well in light of climate change. Again, significant numbers of respondents (33%) were unsure or said “they did not know what if anything is being done”. The remaining 21 per cent responded that current data analysis was inadequate, many citing the need for increased ‘mining’ of existing data and the need for more cooperative and integrated interpretation of the data coming from all various monitoring and inventory programs.

3.3.4 Receiving information

Finally, in the last section of the survey two questions were used to ascertain how forest and range managers in BC currently received scientific information and incorporated into their decision making. In the first question, respondents were asked to rate the frequency they used eleven identified data sources. Table 2 shows the results of this analysis. Again, a higher mean corresponds to a higher frequency of use while a higher standard deviation (i.e. =/>1) suggests greater disagreement among respondents on the frequency to which the information source was used. There was little disagreement between respondents that the internet, technical articles and government reports and briefings are the sources that forest and range managers most often data sources used.

Frequency which various data sources are used by forest and range managers[1]

Topic Area	Mean	Standard Deviation
Internet	3.46	0.61
Technical articles	3.38	0.56
Government reports and briefings	3.36	0.57
Journal articles and other academic literature	3.14	0.75
Face-to-face extension	2.95	0.77
Cooperate Databases	2.90	1.02
Professional association(s)	2.75	0.82
Seminars	2.62	0.68
Webinars/e-lectures	2.55	0.81
Consultants	2.53	0.92
Newspapers/Magazines	2.53	0.80

[1] Rated on a scale from 1 to 4 where 1 = Never used and 4 = Frequently used

The second question asked respondents about the level of detail they generally use in order to incorporate scientific information into the decisions made in their work area. Most respondents (43%) said they would prefer to receive detailed descriptions of the scientific findings while many others (36%) wanted only a brief summary of the results presented to them (such as an at-a-glance briefing or an executive summary). Fewer (21%) commented that they generally needed access to the actual scientific data and results.

3.4 DISCUSSION

The high perceived overall importance for all of the topic areas identified generally validates the indicators chosen by the forest and range experts in BC at previous research phases. However, the results of the survey did lead to further refinements of the monitoring framework, including the reorganization of indicators under different criteria level headers and the development of a criterion examining the context of climate change in BC. In terms of the specific information needs, enhancing and maintaining forest and range productivity seemed to be the driver behind many of the respondents' key climate change information needs. This is no surprise given that many forest and range managers who responded to the survey represented the Ministry of Forests and Range whose stated purposes and functions under the *Ministry of Forest and Range Act 1996* are mainly centred around "encouraging maximum productivity of the forest and range resource" and "ensuring the long-term social and economic benefits" of forest and range are maintained (Anon 1996). This strong focus on productivity may also have been behind the large proportion of respondents who highlighted the southern interior of BC as a geographic region requiring greater monitoring attention as many of the province's forestry operations occur in this region.

Many forest and range managers confirmed that there were persistent and crucial gaps in the data available for managing forests and rangelands in BC in light of climate change. In fact the specific gaps that forest and range mangers identified coincide well with the areas they identified as being as being most critical for monitoring. This finding confirms the results of my preliminary investigation into the data available to support the indicators in the forest and range climate change monitoring framework and highlights the fact the some of the forest and range inventory programs and data collections will need to be augmented and/or bolstered in order to allow the province's forest and range managers to effectively anticipate and respond to climate change (Chapter 1). Further analysis of these gaps and how they can be best addressed is currently the subject of research that is continuing under this and other projects including notably, the Climate Related Monitoring Program which is currently working to address gaps in the meteorological monitoring network.

Data gaps aside, a surprising number of forest and range managers commented that they were unsure about the level of data available and/or did not know if there was any analysis currently being conducted to generate information to manage forests and rangelands in light of climate change. This may be a possible indication that the climate change information, initiatives and tools currently in operation in BC are not effectively reaching or being used by many forest and range managers and that further research on their knowledge and use of these products is needed.

Chapter 4

An approach for anticipating and responding to climate change by tracking changes in ecosystem distribution and composition

4.1 INTRODUCTION

As climatic envelopes change over the next century, alterations in the composition and spatial distribution of ecosystems are predicted to occur along with the development of novel assemblages of species resulting in the formation of new ecosystems (Rizzo and Wiken 1992, Hebda 1997, Hamann and Wang 2006b). The lives of animals, plants, and microorganisms that make up ecosystems are strongly attuned to changes in climate and hundreds of studies have already documented the direct and indirect effects that human-induced climate change has already had on ecosystems and the species within them (Parmesan and Yohe 2003, Soja et al. 2007, Bunnell et al. 2008, Gregory et al. 2009). While the global climate has always been subject to natural variation and species and ecosystems have adapted accordingly, the current rate of increase of carbon dioxide in the Earth's atmosphere is faster than at any time in the past, indicating that human-induced climate change in the current era is likely to be exceedingly rapid (Moberg et al. 2005, IPCC 2007c).

For the Northern Hemisphere, there is agreement amongst climate models that regions in the north will warm more and faster than areas nearer the equator (IPCC 2007c). This rapid rate of climate change will drive significant changes in the Earth's natural systems and challenge the ability of environmental managers and resource-based communities to adapt (Millar et al. 2007, Lemmen and Warren 2008, Lemprière et al. 2008, Williamson et al. 2009, Latta et al. 2010, NRC 2010a). One of the major concerns is that the climate changes predicted over the next century will be so fast that they will increasingly impinge on the ability of ecosystems to deliver the vital services required for human well-being (Parry et al. 2001, NRC 2008, Rosenzweig and Wilbanks 2010). Ecosystem services are the multitude of resources supplied by natural ecosystems. They are grouped into four broad categories: *provisioning*, such as the production of food, wood and freshwater; *regulating*, such as the control of climate, disease and flood; *supporting*, such as nutrient cycles and crop pollination; and *cultural*, such as spiritual and recreational benefits (MA 2006). Understanding how quickly ecosystems can adjust to climate change and how ecosystem services will be affected in the interim is one of the key challenges facing climate change researchers and natural resource managers today.

Tracking changes in the distribution and composition of ecosystems is considered to be a core indicator for monitoring the effects of climate change in BC. As well as providing a direct measure of ecosystem diversity and how it is changing, monitoring ecosystem distribution and composition could provide valuable data for answering important questions concerning the management of forests and rangelands as a whole. In the survey of forest and range managers operating in BC (see: Chapter 3), monitoring changes in ecosystem composition and distribution was regarded as extremely important for monitoring in light of climate change. Specifically, the forest and range managers that were surveyed wanted information on the timing and magnitude of changes in ecosystem distribution and composition in order to determine which ecosystems are changing the fastest and which are the most vulnerable to climate change. This information was considered important largely because it allowed for the adjustment of operational practices such as stocking standards and assessments of ecosystem productivity.

Classifying the distribution and composition of ecosystems is the process of delineating ecologically distinctive areas of the Earth's surface, where each area can be viewed as a discrete system resulting from the interplay of a variety of factors including geologic, landform, soil, vegetative, climatic, wildlife, water, and human factors (ESWG 1995). Ecosystems can, and have, been classified at almost any scale, from global classifications down to local assemblages of species. In BC, the Biogeoclimatic Ecosystem Classification (BEC) system has been used widely for the past thirty years. It is the most well known and highly regarded method of classifying ecosystems in the province with considerable background information, analyses and techniques established using the system. The BEC system is a hierarchical classification system that stratifies the landscape in map units according to a combination of ecological features, primarily climate and physiography (Pojar et al. 1987, Meidinger et al. 1991). Sixteen BEC zones, large geographic regions sharing a broadly similar climate, are recognized and can be further subdivided into subzones on the basis of differences in regional climates (Eng and Meidinger 1999). Variants are one of the finest climatic subdivisions within zones and represent the level that our proposed approach and analysis focuses on.

Over the last decade, theories and models have been used to assess and predict the potential effects of climate change on ecosystems in the region (Rizzo and Wiken 1992, Hebda 1997, Hamann and Wang 2006b, Nitschke and Innes 2008b). Hamann and Wang (2006) used the BEC zone climate envelopes, or the range of climatic conditions that characterize the zones, to model the possible future distributions of the BEC zone climates. Their modeling approach predicted that there will be shifts in BEC zones and species' ranges upwards in elevation and northward, with certain identified ecosystems appearing to be particularly vulnerable to such shifts. They forecast that the largest areal changes in climate envelopes will occur for the Interior Cedar Hemlock zone, which is expected to double in size, and in the Alpine Tundra and Spruce – Willow – Birch zones, which are projected to decrease by 97 and 99 per cent respectively (Hamann and Wang 2006b). Researchers point out, however, that the individual species that make up current ecosystems will be affected differently by climate change (Rizzo and Wiken 1992). Beyond climatic factors, ecological assemblages are dependent upon site factors such as soils, availability of water, slope, aspect, elevation and current vegetative make-up. As such, one cannot wholly assume that changes in climate will result in wholesale shifts of ecosystems to areas that are better suited (Rizzo and Wiken 1992, NRC 2008). The individual organisms and species will react to climate change in different ways, likely resulting in changes in ecosystem composition rather than the broad scale movement of whole ecosystems.

Despite these interesting and useful postulations, to date there have been few systematic attempts in the province to monitor the changes occurring in the composition and distribution of ecosystems in order to ascertain the extent to which climate-induced changes have actually materialized. Now, however, with broader recognition of the increasing impact of climate change on ecosystems and a desire to better account for and incorporate climate change considerations into environmental management we have reached a point where it is necessary to start to compare the predicted effects of climate change on ecosystems with the changes that are becoming evident in the environment. Here we present the proof of concept for an approach that could be used to direct the current forest monitoring and inventory programs available in BC to such an analysis. Our preliminary results show that while some bolstering of the existing monitoring framework is required the province does have the existing institutional capacity to start to examine how ecosystem distribution and composition is changing with climate change.

The National Forest Inventory (NFI) plots provide an excellent basis that could be used as the long term permanent sample sites for the collection of data for monitoring changes in ecosystem distribution and composition. The benefit of using the NFI system is that, to our knowledge, it is the only inventory program operating in BC that is consistent over both space and time. The NFI offers a sound, scientifically defensible distribution of plots across the province and an ongoing re-measurement strategy that collects and/or collates data for both the ground plots and the photos every ten years. When examined together and combined with other data sources available in BC, namely the Terrestrial Ecosystem Mapping (TEM) or Vegetation Resources Inventory (VRI) mapping, these ground and photo plots may offer the best possible approach for tracking changes in ecosystem distribution and composition over time.

The revised NFI system, launched in 2005, is a plot-based system that consists of permanent observation units located on a systematic national grid (Figure 4.1). The NFI is administered by the Government of Canada's Canadian Forest Service and was designed to provide credible information to inform domestic forest policies and positions, and to support science initiatives, and regional, national and international reporting commitments (NFI 2010). In BC, there are 268 NFI ground plots and 2414 NFI photo plots that are designed for re-measurement every decade (NFI 2009a, b). The photo plots occur in a nationwide 20km by 20km grid with each plot measuring 2x2 km. In BC, they are currently identified based on conventional, mid-scale aerial photography (Gillis et al. 2005).

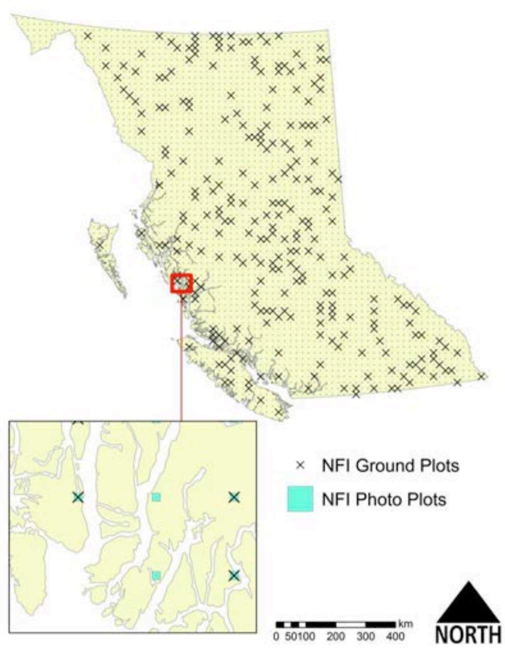

Figure 4.1 – Distribution of NFI photo and ground plots within BC

The ground plots occur within the centre of one in nine randomly selected photo plots. Gillis et al. (2005) comment that each ground plot includes a nested circular plot, line transect and soil pit. Data attributes collected that are of great relevance to this indicator include recordings of: large tree species composition, small tree species composition, a shrub species list and an ecological species list (NFI 2009a). As mentioned, both the ground and photo plots are on a decadal re-measurement cycle. The data that the NFI collect from the ground plots are the best possible option available in BC to determine how ecosystem composition is changing at the species level. Repeated measurement of the same ground plots over time will allow for a simple comparison between years to determine how the species composition has been changing within each plot. By contrast, the ecosystem distribution and a higher level ecosystem composition analysis can be completed by using the photo plots associated with the ground plots. Here however a large scale mapping technique is also needed to classify the ecosystems within the 2x2 km plot so that they may be examined in each re-measurement period to determine if and how the distribution of ecosystems occurring within the plots has changed. I identified two suitable mapping systems that are currently being used in BC for various purposes, namely TEM and VRI. Both TEM and VRI methodologies require direct air photo interpretation of ecosystem attributes in order to determine and map vegetation polygon characteristics. TEM and VRI are suitable for our approach to monitoring ecosystem distribution and composition because they are designed typically for use at larger scales where more detailed information is required. In order to be able to effectively supply information to decision makers we need to be able to recognise the subtle changes that are occurring over relatively small timeframes.

Administered by the Ecosystems Branch of the BC Ministry of Environment, TEM has been designed to provide management level information to a wide range of resource management applications including forest, range, wildlife and biodiversity management. Many of the ecosystem mapping projects under TEM are funded through the Forest Investment Account (MOE 2010). VRI, on the other hand, is managed by the Forest Analysis and Inventory Branch within the Ministry of Forests, Lands and Natural Resource Operations and relies on the private forest industry and forestry consultants to collect data. Both TEM and VRI are carried out in a similar fashion, which first involves estimating vegetation polygon characteristics from existing information, aerial photography, or other sources followed by ground sampling where relationships between aerial photograph features and ecosystem characteristics on the ground are established. The relationship between the initial polygon estimates and ground samples are used to adjust the photo-interpreted polygon estimate to produce final maps (TEM 1998, VRI 2010).

The proposed method would use either TEM or VRI to map the BEC variants occurring within the 2x2 km NFI photo plots that have a ground plot associated with them. Once a plot has been mapped using either of these large scale ecosystem mapping techniques a grid of 1x1 ha cells would be overlaid on each plot in order to make it easier to interpret and report on changes that are occurring. Each 1x1 ha cell would be treated as a homogeneous BEC variant based on whichever ecosystem makes up the majority of the cell.

Once all 1x1 ha cells within the plot have been labelled, the data may be aggregated to easily report on the ecosystem distribution and higher level ecosystem composition occurring at each plot and across the province. This information would be combined with species composition data from the NFI ground plots in order to get a better understanding of a specific ecosystem's make up. In order to allow for an analysis of changes in ecosystem composition and distribution, each plot would have to be remapped to the same standards at decadal intervals. Species composition data from the associated NFI ground plot would also be analysed over the same time period in order to determine and report on the changes that are taking place. Reported variation in ecosystem distribution and composition would need to be examined and interpreted in light of recorded climatic changes (gathered through another indicator in the framework) and in the context of changes predicted as a result of climate change modelling such as that described above.

4.2 TESTING THE APPROACH

In order to test the technical efficacy of the approach described for mapping ecosystem distribution and higher level composition, six NFI photo plots were isolated in the Southern Interior Mountains (SIM) Ecoprovince. Each of these plots had existing TEM and VRI mapping covering their entirety and an NFI ground plot occurring within them. The analysis was carried out using ESRI's ArcGIS 9.3 software.

The VRI data (veg_comp_lyr_R1_poly) was downloaded in August 2010 from GeoBC Geographic Data Discovery Service. TEM data for the SIM Ecoprovince were provided by staff from the Ministry of Environment Ecosystem Branch around the same time. In order to isolate all the ecosystem mapping data from the TEM dataset, all entries with the letters ‘EM’ in the ‘PROJ_TYPE’ field (e.g. TEM, NEMWHR, TEMNSS, etc.) where selected then exported to a new shapefile (TEI_Ecosys_Mapping_BCAlbers_CSRS.shp).

4.2.1 Creation of grids

Grids were created over the seven NFI plots using ArcGIS’s fishnet tool. This tool creates a line feature class that had to be converted to a polygon feature class using ArcMap’s Construct Features command. Each grid was 2x2 km, covering the entire NFI photo plot, and contained 400 1x1 ha cells.

4.2.2 Mapping of ecosystems occurring within the plots

Mapping the ecosystems occurring within each plot was initiated by creating a new field in the VRI and TEM datasets called BEC_full. This was populated with a concatenation of the BGC_ZONE, BGC_SUBZON and BC_VRT fields in the TEM dataset and the BEC_ZONE_CODE, BEC_SUBZONE, BEC_VARIANT fields in the VRI dataset. The creation of this new field allowed the polygons to be dissolved to the BEC variant level. The VRI and TEM datasets were clipped to the extent of the seven identified NFI plots and then dissolved based on the field BEC_full to create polygons outlining the BEC variants occurring within the six plots.

4.2.3 Joining the ecosystem maps with the grids

A Union was performed in order to create a shapefile with attributes from both the clipped/dissolved VRI dataset and the grid. This allowed us to determine the BEC variant make-up of the individual cells within the grids. The same was done with the TEM data. An area field (BEC_Area) was created in the Union shapefiles and the areas of each BEC variant with each grid cell was calculated using the field calculator.

A new field (PCTCelBEC) was created and populated with the BEC variant percent area of each cell (i.e. PCTCelBEC = BEC_Area/10000). A new field (NFICelNum) was then created and populated with a concatenation of the NFIPlotNum and Cell_Num fields in the Union shapefiles and the original grid polygon shapefile (Fishnet_poly.shp). This created a unique numerical identifier for each grid cell.

4.2.4 Classifying the grid cells

Each 1x1 ha grid cell was labelled according to the dominant BEC variant occurring within it. To determine which BEC variants made up a more than a 50% majority in each grid cell, all records from the union shapefiles that had a PctCelBEC value greater than 0.5 were selected and then exported as .dbf tables. The tables were then joined to the Fishnet_poly shapefiles using the common NFICelNum field. This step was performed in order to assign each cell with only one BEC_full value (in this case the >50% majority value contained within the dbf tables). I then checked the final datasets for null values in the BEC_full field as it was expected that in some cases the major BEC variant did not cover more than 50% of the cell. In these instances, the BEC variant which covered the largest area of the cell was determined and its value was entered. The grids were displayed by the BEC variant name and the number of hectares of each BEC variant per grid was calculated from the final datasets.

The results of this analysis are shown in Figures 4.2 – 4.7. Table 4.1 provides the area of BEC variant hectares found within each of the plots. Combined area statistics for all the plots are presented in Figure 4.8.

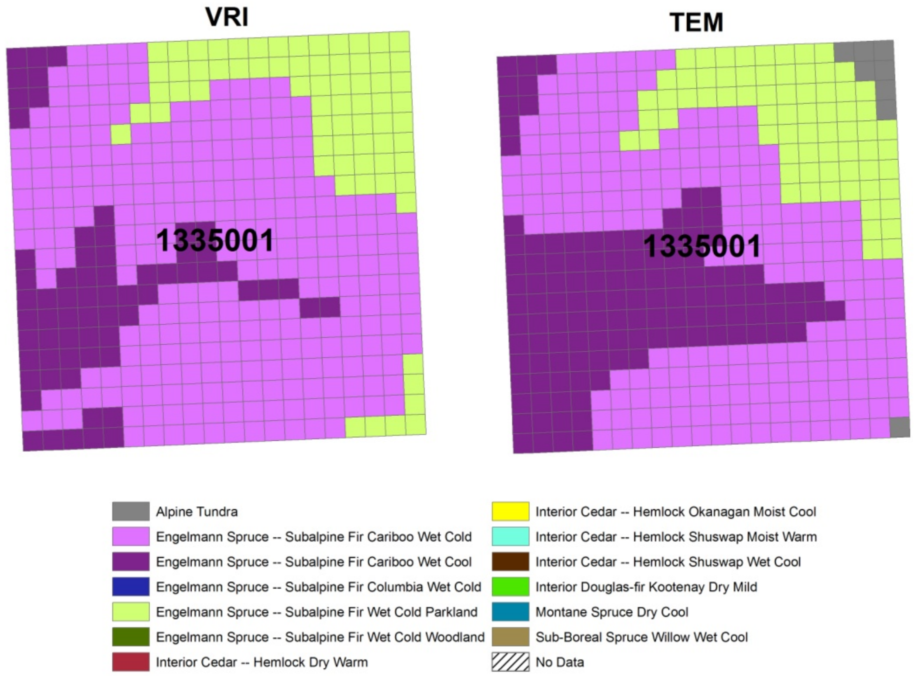

Figure 4.2 – NFI Plot 1335001 mapped using VRI and TEM to BEC variant level

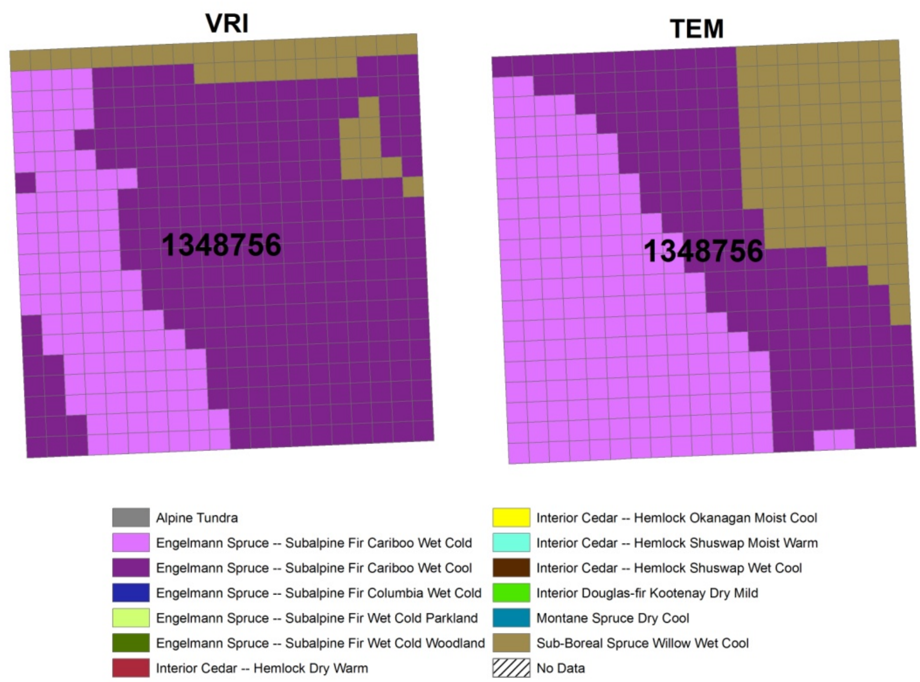

Figure 4.3 – NFI Plot 1348756 mapped using VRI and TEM to BEC variant level

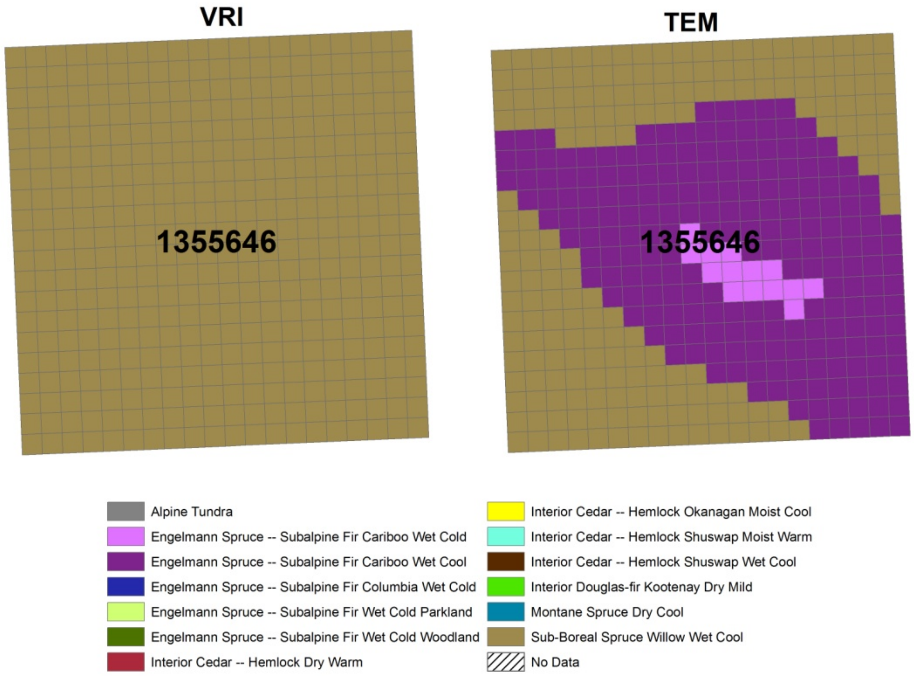

Figure 4.4 – NFI Plot 1355646 mapped using VRI and TEM to BEC variant level

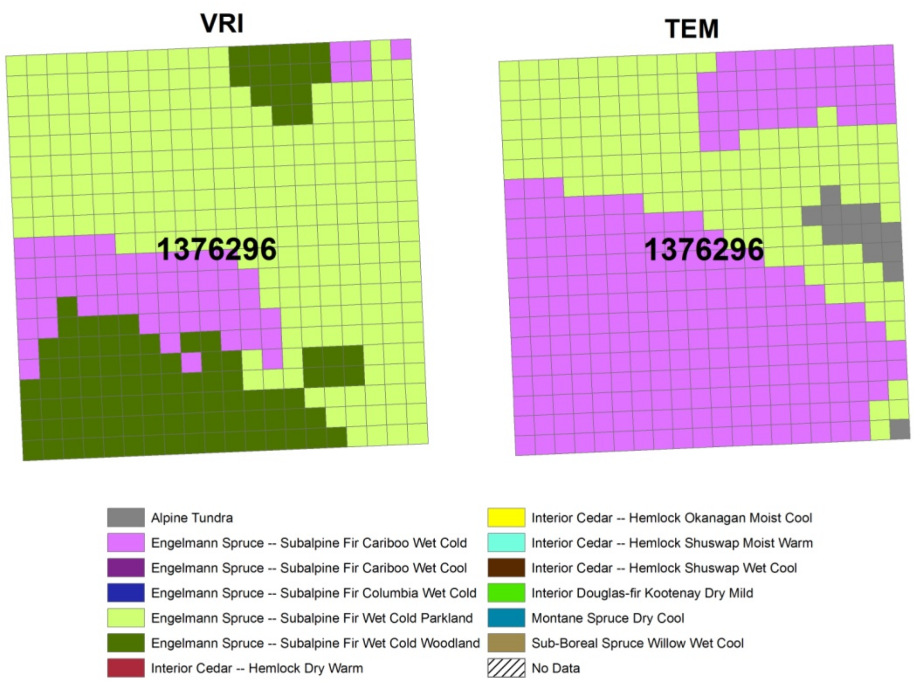

Figure 4.5 – NFI Plot 1376296 mapped using VRI and TEM to BEC variant level

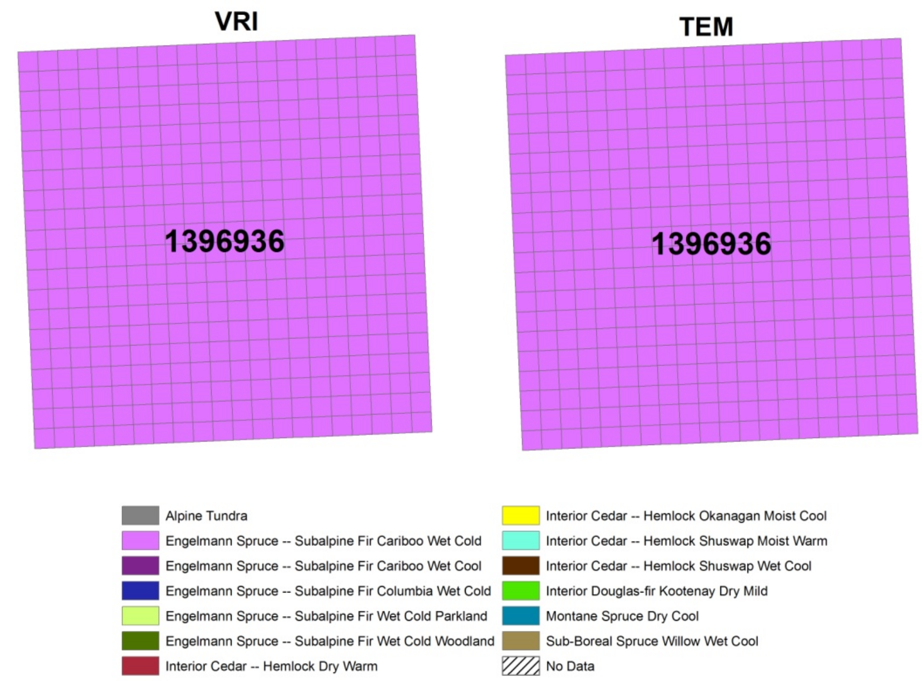

Figure 4.6 – NFI Plot 1396936 mapped using VRI and TEM to BEC variant level

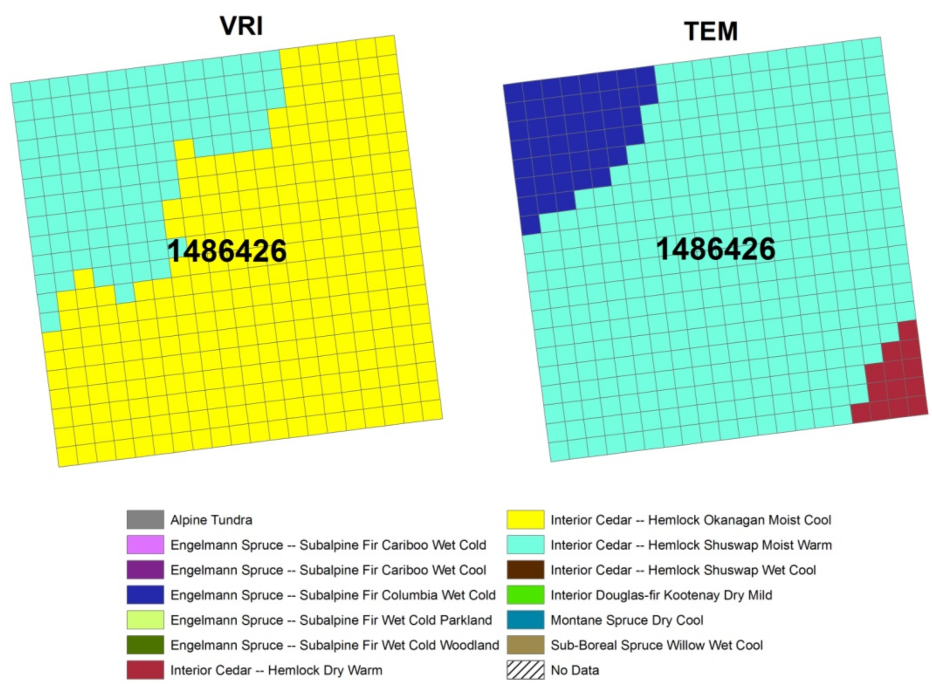

Figure 4.7 – NFI Plot 1486426 mapped using VRI and TEM to BEC variant level

Table 4.1: Area of BEC variants per plot

	Area (ha) TEM	Area (ha) VRI
PLOT 1335001		
Alpine Tundra	8	0
Engelmann Spruce -- Subalpine Fir Cariboo Wet Cold	200	264
Engelmann Spruce -- Subalpine Fir Cariboo Wet Cool	121	66
Engelmann Spruce -- Subalpine Fir Wet Cold Parkland	71	70
PLOT 1348756		
Engelmann Spruce -- Subalpine Fir Cariboo Wet Cold	173	104
Engelmann Spruce -- Subalpine Fir Cariboo Wet Cool	141	259
Sub-Boreal Spruce Willow Wet Cool	86	37
PLOT 1355646		
Engelmann Spruce -- Subalpine Fir Cariboo Wet Cold	14	104
Engelmann Spruce -- Subalpine Fir Cariboo Wet Cool	205	259
Sub-Boreal Spruce Willow Wet Cool	181	39
PLOT 1376296		
Alpine Tundra	13	0
Engelmann Spruce -- Subalpine Fir Cariboo Wet Cold	247	66
Engelmann Spruce -- Subalpine Fir Wet Cold Parkland	140	240
Engelmann Spruce -- Subalpine Fir Wet Cold Woodland	0	99
PLOT1396936		
Engelmann Spruce -- Subalpine Fir Cariboo Wet Cold	400	400
PLOT 1486426		
Engelmann Spruce -- Subalpine Fir Columbia Wet Cold	45	0
Interior Cedar -- Hemlock Dry Warm	13	0
Interior Cedar -- Hemlock Shuswap Moist Warm	342	114
Interior Cedar -- Hemlock Okanagan Moist Cool	0	286

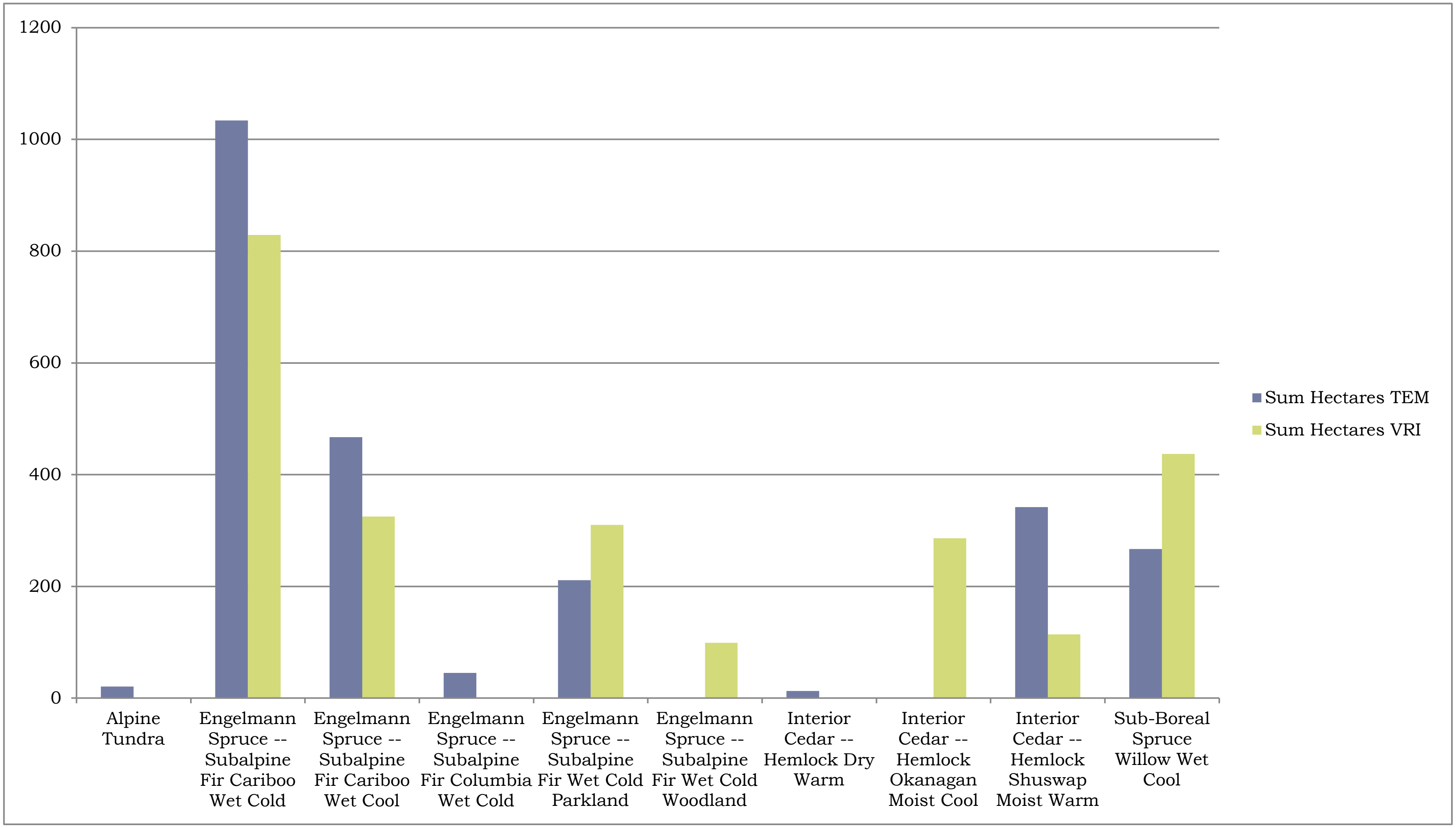

Figure 4.8: Sum of area of BEC variants within all six plots

4.3 DISCUSSION

The test shows that for some plots there are recognisable similarities between the two ecosystem mapping approaches and the results yielded (e.g., plots 1335001, 1348756, 1396936). For other plots, however, this is not the case (e.g., 1486426). Hence, some questions remain regarding the accuracy of BEC variant mapping using the existing data from TEM and VRI that may require further analysis and discussion between the relevant organizations in order to obtain the most accurate baseline possible. In order to build up trend information, mapping using either TEM or VRI would have to occur using a standardized approach at decadal intervals. While this represents an additional ongoing responsibility for either the Ecosystems Branch or the Forest Analysis and Inventory Branch, such systematically collected trend information on ecosystems is likely to be particularly useful for responding to not only climate change information needs but also for better addressing some of the indicators used in provincial, national and international reporting initiatives. These include those indicators examined through the BC State of the Forest reporting process, the Canadian Council of Forest Ministers Criteria and Indicators of Sustainable Forest Management and the Montreal Process Agreement for the Conservation and Sustainable Management of Temperate and Boreal Forests.

Another issue also remains. Due to the research mandate and purpose of the NFI, their ground plots are only established in forested or potentially forested conditions (i.e. classified as vegetated treed or potentially vegetated treed). This represents a limitation for our proposed approach as it means that a number of broad ecosystem groupings in BC are not represented within the NFI ground plots and therefore the composition of those ecosystems would not be monitored at the species level. In order to better illustrate this I mapped the extent of NFI ground plots by BEC zone. As shown in Figure 4.9 a number of the BEC zones are not covered by the NFI ground plots. Of particular note are the BEC zones: Boreal Altai Fescue Alpine, Coastal Mountain-heather Alpine, and Interior Mountain-heather Alpine. A proposal to expand ground plots into the non-forested landbase and place additional ground plots in forested locations was put forward by the Forest Analysis and Inventory Branch in 2008/09. However this was placed on hold due to current budgetary constraints. Until this matter is resolved it would be possible to select, at random, NFI photo plots occurring within these regions and examine changes occurring in ecosystem distribution and higher level compositional change using the procedure described above.

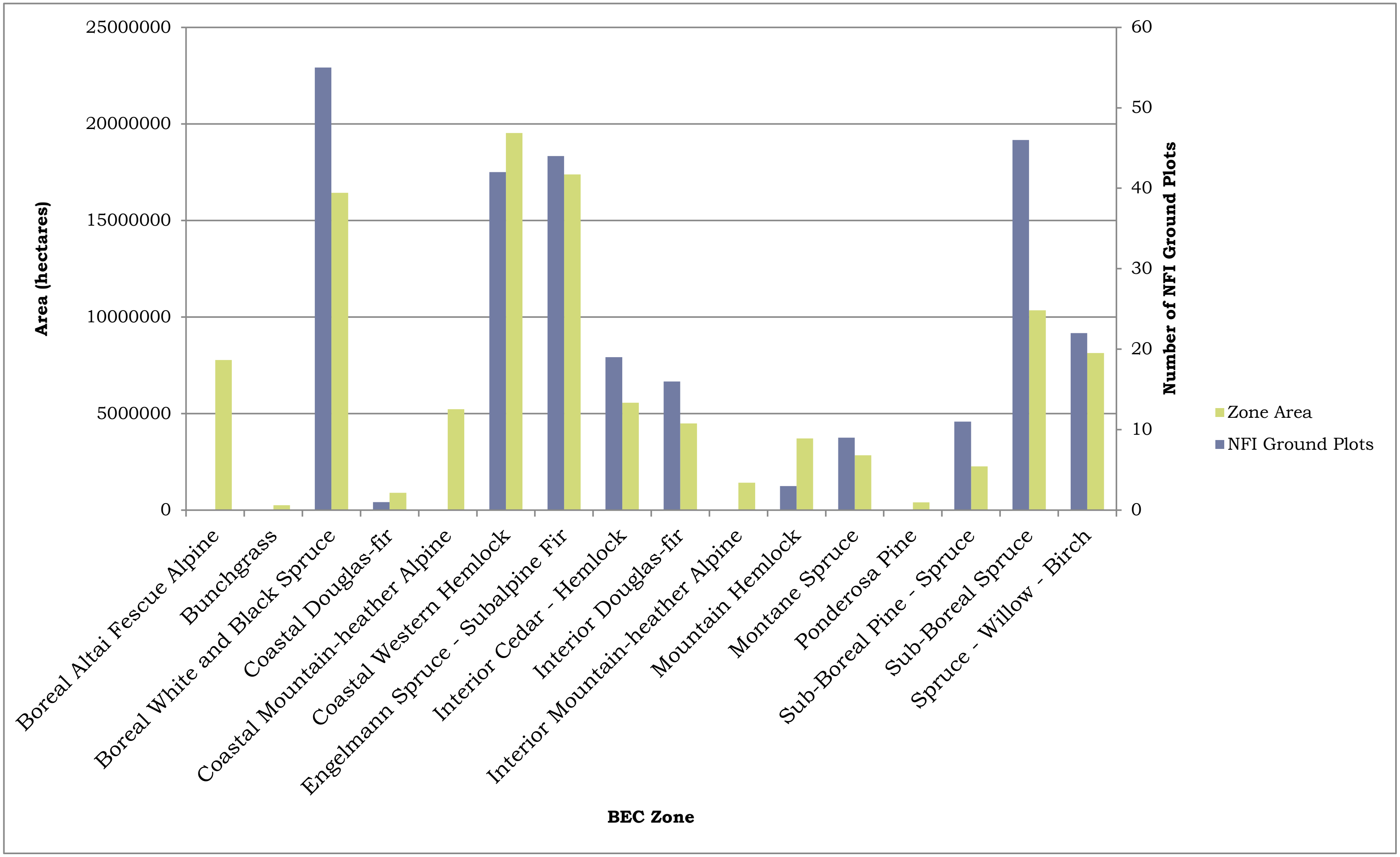

Figure 4.9: BEC zone areas and number NFI ground plots

Chapter 5

An approach for anticipating and responding to climate change by tracking changes in forest productivity

5.1 INTRODUCTION

Forest productivity commonly describes the ability of a forest to sustain itself into the future. It is the result of the combined effects of a number of physical, chemical and biological conditions and processes and generally refers to the rate at which a forest is able to convert energy and nutrients into growth (Perry et al. 1989, Boisvenue and Running 2006). Forest productivity is directly influenced by changes in temperature and precipitation regimes and thus as the global climate changes over the next century, forest productivity is expected to change as well (Birdsley et al. 1995). Anticipated alterations in temperature and precipitation resulting from climate change along with increased incidents of extreme weather events and disturbances caused by pests and diseases are likely to result in changes in ecosystem productivity.

The results of studies examining the impact of climate change on forest productivity vary greatly, depending on which factors are considered and the assumptions that are made (Boisvenue and Running 2006). For instance, studies that incorporate higher temperatures, enhanced CO_2 concentrations and increased precipitation tend to project increased forest productivity. However, if increased disturbances (fires, wind damage, insect outbreaks) and the ecosystem instability induced by species migrations are included in the study, negative impacts are usually suggested (Lemmen and Warren

2008, Latta et al. 2010). In any case there is no doubt that climate change will – and is indeed already affecting - forest productivity.

In our survey of forest managers working in BC, forest productivity was rated as the single most important topic about which forest managers needed information in order to be able to bring climate change considerations into forest management and operational practices in the province. This is no surprise, as the indirect impacts of climate change on forest productivity in BC have already been severe. As mentioned in Chapter 1, alterations to the climatically suitable range of the mountain pine beetle have now killed an estimated total of 675 million cubic metres of pine - half of the province's commercial pine - since the current infestation began in 1998 (MFR 2009). Estimates of forest productivity drive timber supply analyses and forest planning endeavours such as standards for species selection, seed transfer and stocking (Spittlehouse and Stewart 2003). Forest productivity estimates also affect many additional forest characteristics such as habitat for wildlife or fuels that increase wildfire risk (Latta et al. 2010).

Forest productivity can be monitored in a variety of ways but two of the most common methods are measures of overall forest volume and the use of site index. This chapter outlines our investigations into two key Ministry of Forests, Land and Natural Resource Operations datasets that are already in use in the province and which could form the basis of monitoring changes in forest productivity associated with climate change. The first of these datasets, the Vegetation Resources Monitoring Program (VRMP) has been developed to assess broad scale changes in forest volume over time. The second dataset, the Growth and Yield Permanent Sample Plots in BC, may be useful for tracking trends in the growth rates of trees species, particularly merchantable tree species. Further details of these data sets and my assessment of their capacity to be used to monitor climate change are outlined below.

5.2 ASSESSMENT OF THE DATA SOURCES

5.2.1 Vegetation Resources Monitoring Program

In 2003, BC completed the first provincial component of the NFI photo database and the corresponding ground sample component in 2006. The photo database was then updated for disturbance changes in 2006 and 2009. The resulting database was the BC VRMP. The VRMP is based on samples from the 2419 photo plots and 268 fixed area ground plots associated with the NFI (for more information on the NFI see the previous chapter). The Forest Analysis and Inventory Branch recently prepared a report on the VRMP which details the information able to be generated from the VRMP photo plot database including: total area, net volume, total biomass carbon for stem, branch, foliage, and roots, and total ecosystem carbon. VRMP also includes forest inventory classifiers of land cover, land type, vegetation type, leading species and age class, and spatial units of province, terrestrial eco zone, BEC zone, and the Ministry of Forests region.

The functionality of the VRMP database for use in forest resource monitoring in BC has already been tested by the Forest Analysis and Inventory Branch in order to generate estimates of forest resource changes due to natural and man-made disturbances and growth, for the period of 2000-2009 (Yuan 2010). Overall results of these tests showed that periodic changes in the provincial forest resource can be effectively monitored through scheduled re-measurements of the established plots and the incorporation of these data into the VRMP database. By reporting from the two VRMP photo databases, 2000 and 2009, the Forest Analysis and Inventory Branch have shown that the total change of net volume in BC during this timeframe is -320.7 million m^3 (RSE = -26.2%). This net loss of forest volume can largely attributed to harvesting, fires and Mountain Pine Beetle mortality. The report further comments that these totals are significantly greater than the corresponding increases due to forest growth.

Although further scientific research would be needed to link reported changes in forest productivity credibly to climate change (such as that linking Mountain Pine Beetle mortality with climate change) the VRMP has obvious relevance for the climate change monitoring framework. VRMP's strong capacity to be able to quickly and easily determine changes in the forest resource base over time would be a fundamental foundation to the analysis and interpretation of this indicator on a provincial basis. Further, as detailed above, in 2008/09 interest was expressed in using VRMP for biomass modelling. This was proposed to be done by expanding the ground plot program onto the non-forested landbase and by intensifying the number of plots in the forested landbase. As mentioned, at the time of writing this thesis this plan is still on hold. However it would be a valuable addition and would present an improved measure of forest productivity over time.

The Forest Analysis and Inventory Branch kindly allowed us to use the VRMP database in order to assess how "user friendly" and practical it was for reporting on changes in forest resource volume. I received the VRMP database information as a single compact disc on 22 October 2011. A short tutorial on using the database was provided by Dr. Xiaoping Yuan from the Forest Analysis and Inventory Branch and after this I was quickly and easily able to obtain the same figures as listed in the report above. Dr. Yuan did however caution that it was necessary to use only a large (eg. ecoprovince or above) area for analysis and the data could not accurately report at the forest district level or below.

5.2.2 Growth and Yield Permanent Sample Plots in BC

Growth and Yield Permanent Sample Plots in BC are long-term samples established in natural stands for the purpose of providing information on the rates of growth, mortality and changes in stand structure form stand establishment to maturity. There are over 5000 plots province-wide, ostensibly on a decadal re-measurement cycle. The Permanent Sample Plots may be used to determine the productivity of forest sites in BC through the calculation of site index. Site index as a measure of forest site productivity is a universal concept and is practiced in all forest regions globally with minor variations . In BC, site index is defined as the height of a site tree at breast height and at age 50. A site tree is the largest diameter tree on a 0.01-ha plot of the target species, provided that growth of the tree is free of suppression, damage, insect and disease attack, and silvicultural practices (MFR 2012b). The height growth of site trees reflects the potential productivity of the site: A high site index means that the trees are growing fast and the site is productive. Given that changes in climate are likely to influence the growth of trees, recording where drops (or increases) in site index have occurred may be relevant to monitoring this indicator and is likely to be a useful 'red flag' for showing where follow up correlation examinations may be useful.

Interest in the data from the Permanent Sample Plots led us to interview the current custodian of this dataset, Mr. Kevin Hardy from the Research Branch of the Ministry of Forests, Lands and Operations. Mr. Hardy commented that the data would be extremely useful for climate change analyses into variations in forest productivity although he did recognise that there would be significant issues related to background noise and determining if variations in site productivity were related to climate change.

Mr. Hardy also pointed out a number of persistent adverse issues with the dataset which led me to preclude it from use in our pilot tests. The greatest of these issues is that the exact age of trees is needed in order to derive a valid site index for the site but the ages listed in the current dataset have been proven inaccurate when verified against dendrochronological samples. There has been some past work collecting dendrochronological samples to verify the age of PSP trees, although this was restricted to coastal areas (beyond our study area). Another issue noted by Mr. Hardy is that a number of the plots may be in areas that have been damaged and thus they should be excluded from the dataset. These plots need to be ‘weeded’ out of the current dataset in order for it to be accurate enough to be useful in such analyses. Mr. Hardy also pointed out that it was inadvisable to use data from some sites (e.g., mesic sites) and species (e.g. Hemlock). These issues make it difficult to use the PSP data in its current format, however it is still regarded as a ‘low hanging fruit’ and with some limited development this data source is likely to be an extremely valuable source of climate change adaptation information. Recommended steps to such development include: isolating the merchantable tree species data that may best be examined, determining which plots have a long-term historical record in existence, examining which plots occur within close proximity to a weather station, and collecting dendrochronological samples for a selected sub-set of plots identified as most relevant.

5.3 DISCUSSION

Overall there are a number of very strong data sources available to support this indicator. Here we have been able to have a closer look at two of these data sources although there are other collections within the Ministry of Forests, Lands and Operations which would likely also be useful in supporting further analysis. The VRMP database is highly useful in that it offers an easy, ready-to-build-on approach that can be applied to give provincial level assessment in a short period of time. The PSP dataset, despite its current shortcomings, appears to have enormous potential for climate change and tree growth analyses. Given the high ranking of forest productivity information it is highlighted as a highly important area for future development

Chapter 6

Examining the impact of climate change on species level diversity

6.1 INTRODUCTION

Climate change is already affecting species across the globe. Recent review articles and meta-analyses have documented that increasing temperatures and changing patterns of precipitation are having detectable effects on species (Walther et al. 2002, Parmesan and Yohe 2003, Root et al. 2003). In BC, these effects are expected to provide both opportunity and pressure for the region's species. For some, opportunities may be found in the colonization of habitats or increased abundance of prey. For other BC species, pressure may come from factors such as reductions or alterations in ecosystems or habitats and invasive species moving into new ranges. In general, it is thought that climate change will positively affect some species at the northern edges of their ranges and negatively affect other species at their southern limits (Lovejoy and Hannah 2005, Hamann and Wang 2006a). If these species and populations are unable to adapt to the pressures associated with climate change they may be susceptible to decreases in populations, which will affect their survival and fecundity, and ultimately their abundance (Noss 2001, Wilson et al. 2005, Rosenzweig and Wilbanks 2010).

6.2 ASSESSMENT OF THE DATA SOURCES

In the initial phase of this research, we proposed to assess this indicator by looking at trends in population, range and phenology for species from a range of taxa and habitats. However during the indicator development phase (Phases 1 and 2), concerns were raised about the availability of data for such an analysis and further examination of the available data sources indicates that these concerns were well-founded. When this indicator was initially proposed, over ten different data sources were identified as having the possibility for supporting an analysis of changes in species ranges and phenologies. Many of the data sources belonged to the BC Government Ministry of Environment including the Conservation Data Centre, Ecocat, BC Species and Ecosystems Explorer and the Fisheries Data Warehouse. I investigated these and other government data sources and found a paucity of data available to support any analysis of the indicator at a provincial level, as originally proposed. Although there is a wealth of descriptive information at the ecosystem level held in these databases there is a lack of trend or detailed information from which meaningful assessments of the impacts of climate change on species level diversity could be developed. In these data sources I could not find any species whose ranges and phenologies were established and periodically studied to a level that I could use to ascertain changes over time. In recording species' ranges, the current trend seems to be to map a species' preferred (or likely) habitat rather than to monitor the species itself. This makes it impossible to determine factors such as range changes, especially when they may of the order of 6 km per decade, as suggested in the academic literature (Parmesan and Yohe 2003, Lovejoy and Hannah 2005). While some of the data sources do provide some locations where species have been recorded they do not represent a comprehensive distribution for the species/ecological community and without a good idea of the current known range of species any changes in range are unlikely to be picked up, as one would not know if the changes in range were actually the result of the species moving into a new climate or simply due to more accurate or increased recording of the species.

In addition to these government datasets I also investigated other data sets including the BC Breeding Bird Atlas, Nature Counts, Frog Watch, Worm Watch, Plant Watch and the Canadian Community Monitoring Network. For the most part these data sources contained only very limited data which would be of no use in assessing trends. The exception to this is birds for which there is a detailed set of data collected by the public and stored in the BC Breeding Bird Atlas (and similar derivatives including eBird and Nature Counts). The strength of bird data appears to be an international trend, with a variety of other climate change researchers commenting that bird monitoring data sets represent the most comprehensive time-series environmental data in existence (Lovejoy and Hannah 2005, Cox 2010, Newman et al. 2010). The BC Breeding Bird Atlas currently collects a vast amount of data on various bird species across the entire province and such data has already been proven useful for assessing the effects of climate change on bird species in BC. Bunnell et.al. (2008) have used BC bird data to show that there have been dramatic changes bird's ranges, arrival dates, departure dates, over-wintering population levels (Bunnell et al. 2008).

6.3 DISCUSSION

In any case for the purposes of this indicator and the target audience intended, the issue surrounding the data available to support the indicator as it stood through initial work described in Chapter 1 may be a moot point. The approach initially suggested for the indicator seems to miss-the-mark in terms of the data needs of the intended target audience. As detailed above through the initial work this indicator was designed to examine trends in population, range and phenology information for species from a range of taxa and habitats. In contrast, the results of the forest and range decision maker survey showed clearly while both species ranges and phenologies were of great interest to survey respondents their interest was entirely framed in the context of the need to enhance and preserve forest and range productivity. That is, survey respondents were interested in obtaining range and phenology information for tree, and grass and forb species that were considered relevant from a productivity perspective (see Chapter 2 for further information). Given this finding it may be appropriate to concentrate efforts on better monitoring of species relevant to productivity. Thus, it is suggested that efforts for examining this indicator be rolled into the assessments conducted through the previously examined indicators (ecosystem distribution and composition and forest productivity) and concentrate on bolstering the data sources associated with those indicators. In particular, the PSP dataset (described in Chapter 5) would be particularly relevant for examining tree species.

Chapter 7

Examining ecosystem connectivity in the context of climate change

7.1 INTRODUCTION

Decades of scientific research have identified correlations between ecosystem connectivity and the maintenance of biodiversity. Significant distances from one patch to the next interfere with pollination, seed dispersal, wildlife migration and breeding (Fahrig and Merriam 1985, Adler and Nuernberger 1994, Anderson and Danielson 1997, Lindenmayer et al. 2008, Brudvig et al. 2009). Climate change creates new challenges for biodiversity conservation and the need to preserve and manage for ecosystem connectivity has taken on a renewed importance (Lovejoy and Hannah 2005, Kramer et al. 2010). In a recent review of over a hundred academic articles recommending measures to adapt conservation to climate change, the need to increase connectivity was ranked as the most frequently recommended method of conserving biodiversity (Heller and Zavaleta 2009). The lives of animals, plants, and microorganisms that make up ecosystems are strongly attuned to changes in climate and many authors have documented the direct and indirect effects that human-induced climate change has already had on ecosystems and the species within them (Parmesan and Yohe 2003, Soja et al. 2007, Bunnell et al. 2008, Gregory et al. 2009). As climatic envelopes change over the next century, forecasts show that in order to adapt to human induced climate change some species may need to disperse into new habitats (Rizzo and Wiken 1992, Hebda 1997, Hamann and Wang 2006b). Successful colonization of new habitat will depend in part on the degree of landscape connectivity (Kindlmann and Burel 2008). As such, ensuring the maintenance of broad scale landscape connectivity will allow for such migration, an essential component for the preservation of species under the changing climate.

This indicator seeks to examine the connectivity between forest and range ecosystems in a climate change environment in order to predict and isolate those areas that are particularly vulnerable. In the scientific literature ecosystem connectivity is described as the degree to which a landscape facilitates or impedes movement of organisms among patches (Fahrig and Merriam 1985, Taylor et al. 1993) or more simply the ease with which these individuals can move about within the landscape\ (Kindlmann and Burel 2008). To facilitate climate change-induced migrations, many have suggested an increased focus on maintaining or improving landscape connectivity (Hansen et al. 2001b, Vos et al. 2008). This can be accomplished through the creation of corridors stretching in the direction of predicted migrations (i.e. usually to the poles or into higher altitudes) as well as through the restoration of the intervening matrix (Donald and Evans 2006). Corridors are continuous strips of habitat that have been traditionally thought of as structurally connecting two otherwise non-contiguous habitat patches. They enhance the landscape connectivity between ecosystems.

Recently with further analysis and research working to model and address the impact of climate change on biodiversity, the concept of spatial corridors has taken on new meaning and has now been extended to include the more novel concept of a ‘temporal corridor’ (Rose and Burton 2009). A temporal corridor is identified through the intersection of an ecological feature's current distribution with its distribution predicted as a result of bioclimate envelope modelling (Rose and Burton 2009). The concept of bioclimate envelope modelling and the recent work of researchers in BC was detailed in Chapter 3. Bioclimate envelope models have been widely used over the last decade to predict the potential distribution of species or whole ecosystems under climate change (Berry et al. 2003, Hamann and Wang 2006b, Virkkala et al. 2008, Rose and Burton 2009, Zheng et al. 2009). In essence these models determine a species or ecosystem’s current ‘climate envelope’ or ‘climate space’ either through techniques that correlate current species or ecosystem distributions with climate variables or through an understanding of species’ physiological responses to climate change (Pearson and Dawson 2003). Climate change predictions are then used to generate maps of current and future species distributions.

Bioclimate envelope models are simplistic in that they usually do not model demographic or any other ecological processes. Thus, bioclimatic models in their purest form consider only climatic variables and do not include in their processing other environmental factors that influence the distribution of species, such as the extent to which movements are actually possible given the current anthropogenic alterations in the landscape.

In order to monitor and better understand the interactions between ecosystem connectivity and climate change, a combination of data including the latest bioclimate envelope modelling developed by Dr Tongli Wang was used to analyse temporal corridors for various BEC zones within our study area. In order to add some further context to this information I used additional data, namely the BC roads layer and tenure layer.

7.2 APPROACH

The area of interest for the case study was the Thompson Okanagan Eco-region in the south east of BC (Figure 7.1).

Figure 7.1 – The area of interest, the Thompson Okanagan Eco-regions

7.1.1 Determining the BEC zones of interest in the area

To determine which of the BEC zones to use in the analysis, the BEC layer (abgc_bc_ver7) was downloaded on June 2010 in order to examine the zones falling within the region. Ten BEC zones were recorded in the area. However, some of these only occupied very marginal territory on the border of the region (Figures 7.2, 7.3).

These marginal areas were excluded from our analysis leaving only the six main BEC zones in the region.

7.1.2 Bioclimate envelope model

The latest bioclimatic envelope models prepared by Dr Tongli Wang from the University of British Columbia (designed for FFEI project grantees) was obtained for the study region for all BEC zones projected for the current (i.e. 1960 – 1990), 2020s, 2050s and 2080s time slices based on the Canadian Global Circulation Model (CGCM2-B2). Maps portraying locations projected to be suitable, as defined by the target's current envelope, in each time slice were overlaid using the "Overlay–Intersect" tool in ArcMap. The results of this analysis are discussed below for each individual ecosystem type.

Zone	Area (Ha) Present
Bunchgrass	149957
~~Coastal Western Hemlock~~	56
Engelmann Spruce - Subalpine Fir	325047
Interior Cedar - Hemlock	196529
Interior Douglas-fir	1525955
~~Interior Mountain-heather Alpine~~	539
Montane Spruce	848207
Ponderosa Pine	243715
~~Sub-Boreal Pine - Spruce~~	4709
~~Sub-Boreal Spruce~~	1936

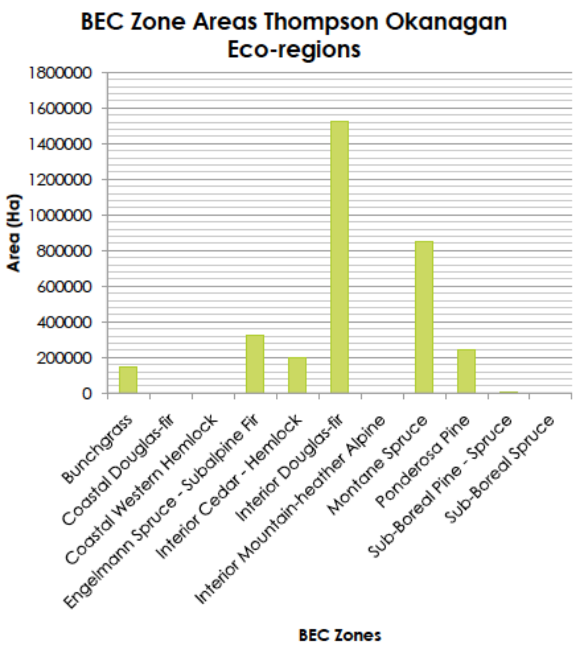

Figure 7.2 – BEC zones of interest in the Thompson Okanagan Eco-regions

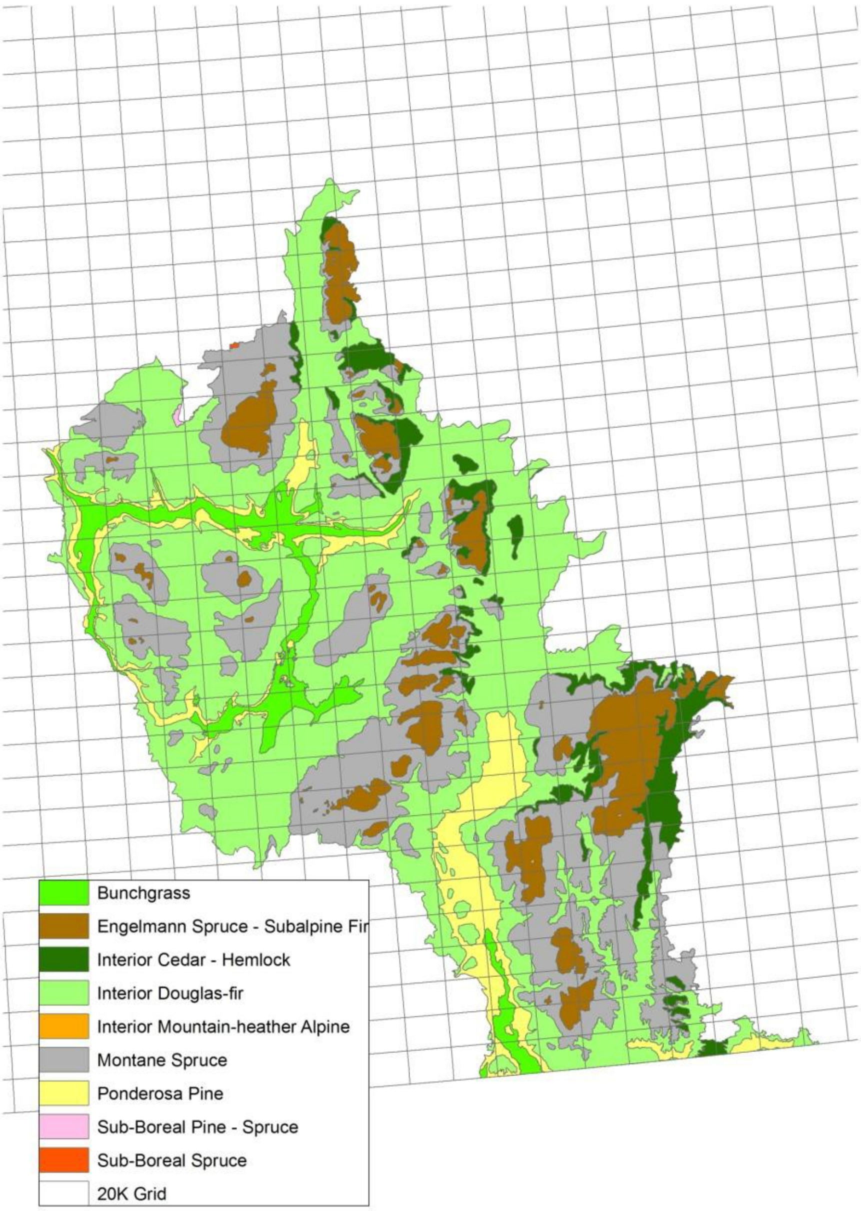

Figure 7.3 – BEC Zones within the Thompson Okanagan Eco-region

7.1.3 Roadedness

In order to better understand and visualise the effects of these predicted ecosystem changes with climate change in the context of current landscape connectivity I also created a "roadedness" layer. The presence (or absence) of roads is a meaningful overarching measure of ecosystem connectivity and the ecological integrity of terrestrial ecosystems (e.g. MFR 2006, MOE 2012). Roads affect natural ecosystems and wildlife by disturbing and destroying habitat, acting as barriers to wildlife movement, impeding gene flow among populations, and reducing the resilience of some species populations to disturbances (Noss 1994, Crist et al. 2005). Once a road is in place it may open up areas to other types of human disturbances and have cumulative impacts that persist as long as the road is in place (Noss 1994, MOE 2012).

In order to develop the roadedness layer, the provincial roads layer and the Arc GIS "Kernel Density" tool was used to develop a map that could be used to more easily assess the density of roads within the study region. In essence the roadedness layer was developed using this tool by fitting a smoothly curved surface over each line (i.e. road). The value is greatest on the line and diminishes away from it, reaching zero at a specified distance from the line (in this case 5 km was used). The resultant map, which may be thought of as very similar to a commonly used physical map showing topography, allows road density to be observed as colour features on a map of the region.

The roads layer, was obtained from the Land and Resource Data Warehouse in October 2010. The kernel density estimation was performed on the data set. The results of our analysis are shown in Figure 7.4 with the more roaded areas appearing as the darker areas on the map.

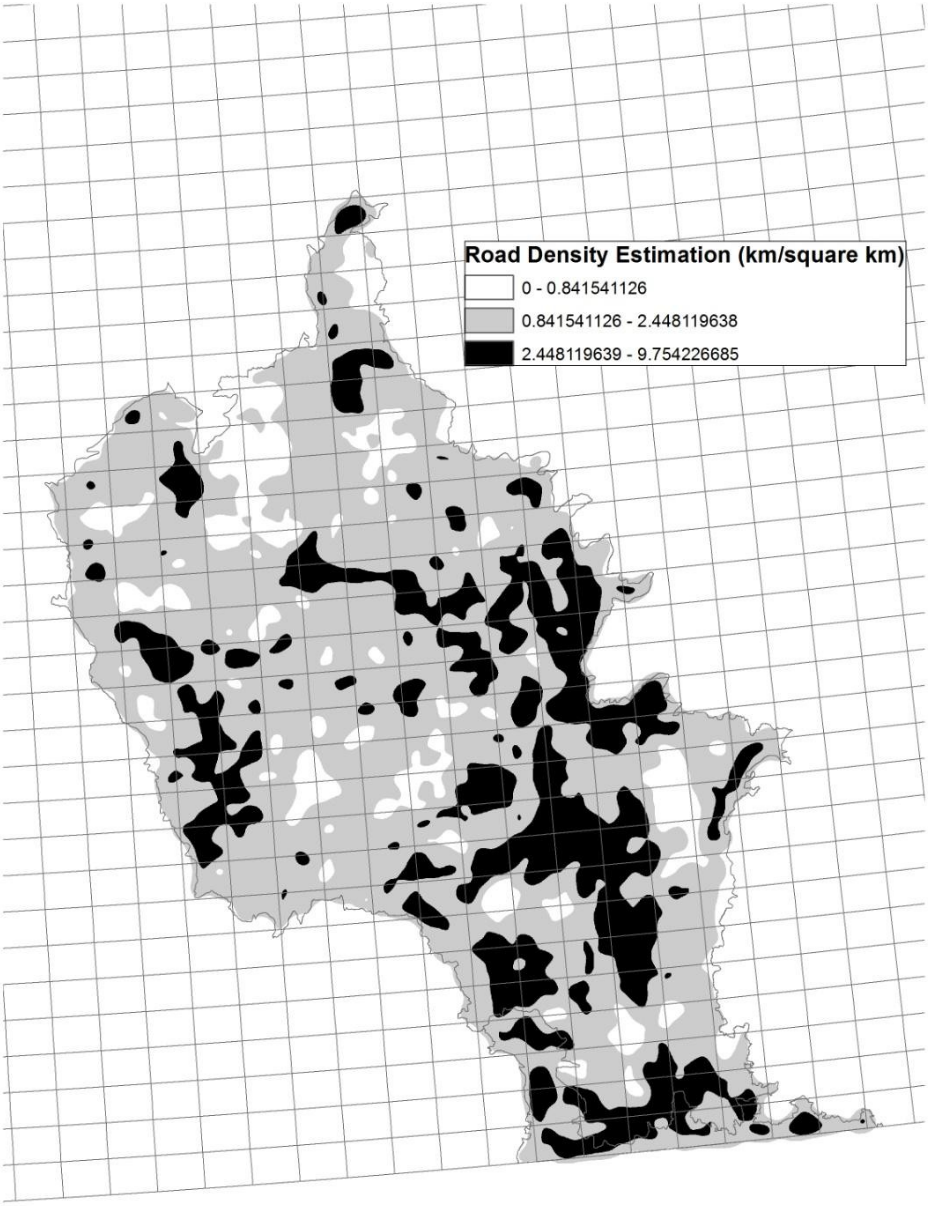

Figure 7.4 – ‘Roadedness’ within the Thompson Okanagan Eco-region

7.1.4 Tenure

In addition to roads I also looked at the tenure within the study area. Those areas under private ownership were considered to be more potentially vulnerable to possible future development. I could not locate a private land GIS layer for BC in any of the key data warehouses and one was therefore developed by excluding those areas held in publically-owned tenures or which were in some way the responsibility of the Crown. These are also displayed in Figure 7.5.

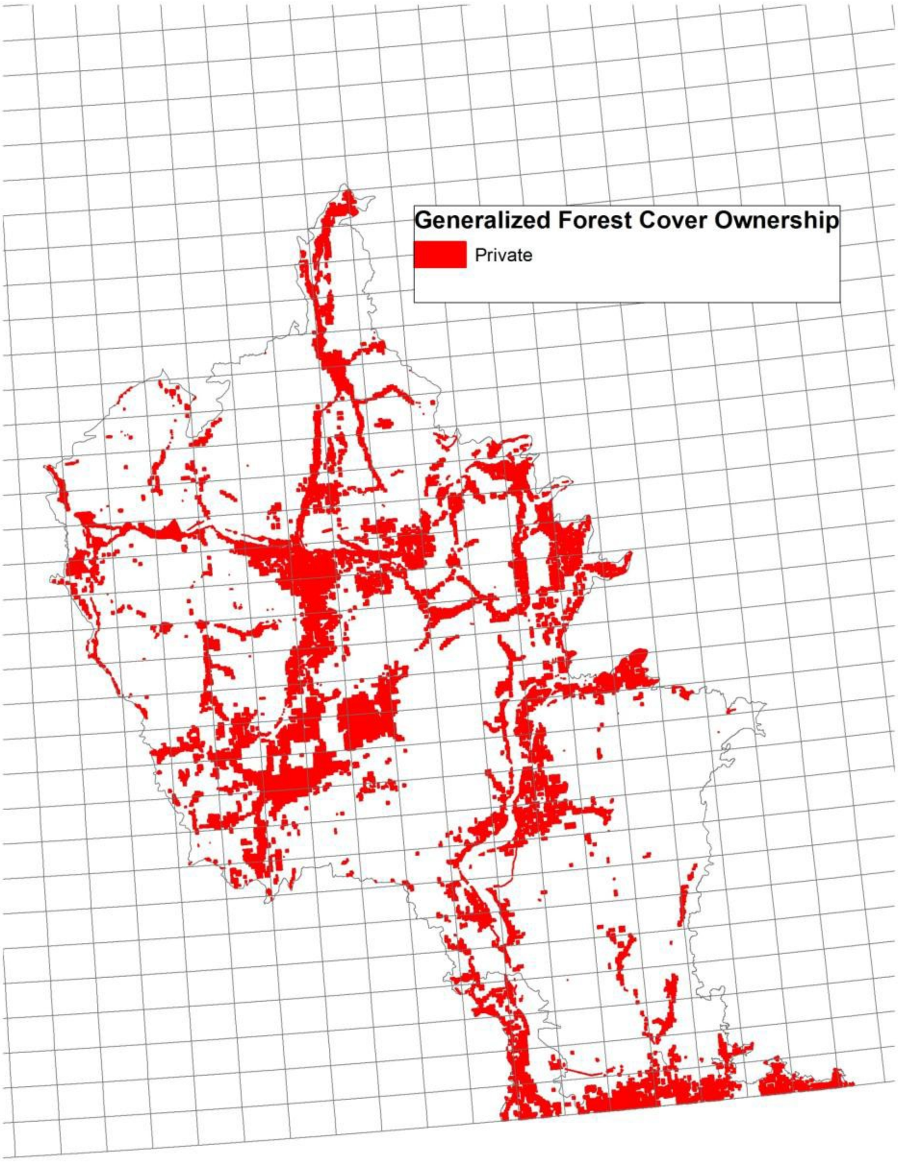

Figure 7.5 – Private land located within the Thompson Okanagan Eco-region

7.1.5 Identifying temporal corridors

The approach utilised by Rose and Burton (2009) was applied to determine the temporal corridors for the broad BEC zones found in the study area. Rose and Burton used four steps to identify temporal corridors. These included: (1) the development of bioclimatic envelopes for management targets; (2) the identification of locations projected to have future climates within each target's bioclimatic envelope for four timeslices (“current,” defined as 1961–1999; the 2020s; 2050s; and 2080s); (3) the overlay and intersection of these four timeslices using GIS; and (4) a final overlay of the range of persistent climate with a target's current distribution.

7.3 RESULTS

7.3.1 Bunchgrass

Using Wang’s BEC modelling data, the area of Bunchgrass in the Thompson Okanagan Ecoregion is projected to increase slightly, particularly in the north-eastern portion of its range in the region (Figure 7.6). The key area of these range increases corresponds with areas identified as having a moderately high level of roadedness, possibly meaning that the movement of species and genetic material into these areas may be affected. In terms of overlap between the three time slices there is a strong portion of the range in the mid- north eastern section that remains constant throughout the time periods examined (Figure 7.7). Of the predicted 2080 area of 2,192,353 km^2 26 per cent of the climatically suitable range for Bunchgrass is predicted to remain constant between the three time slices. This area, however, appears to be largely under private tenure indicating that it may have an increased vulnerability to future development or other land use change.

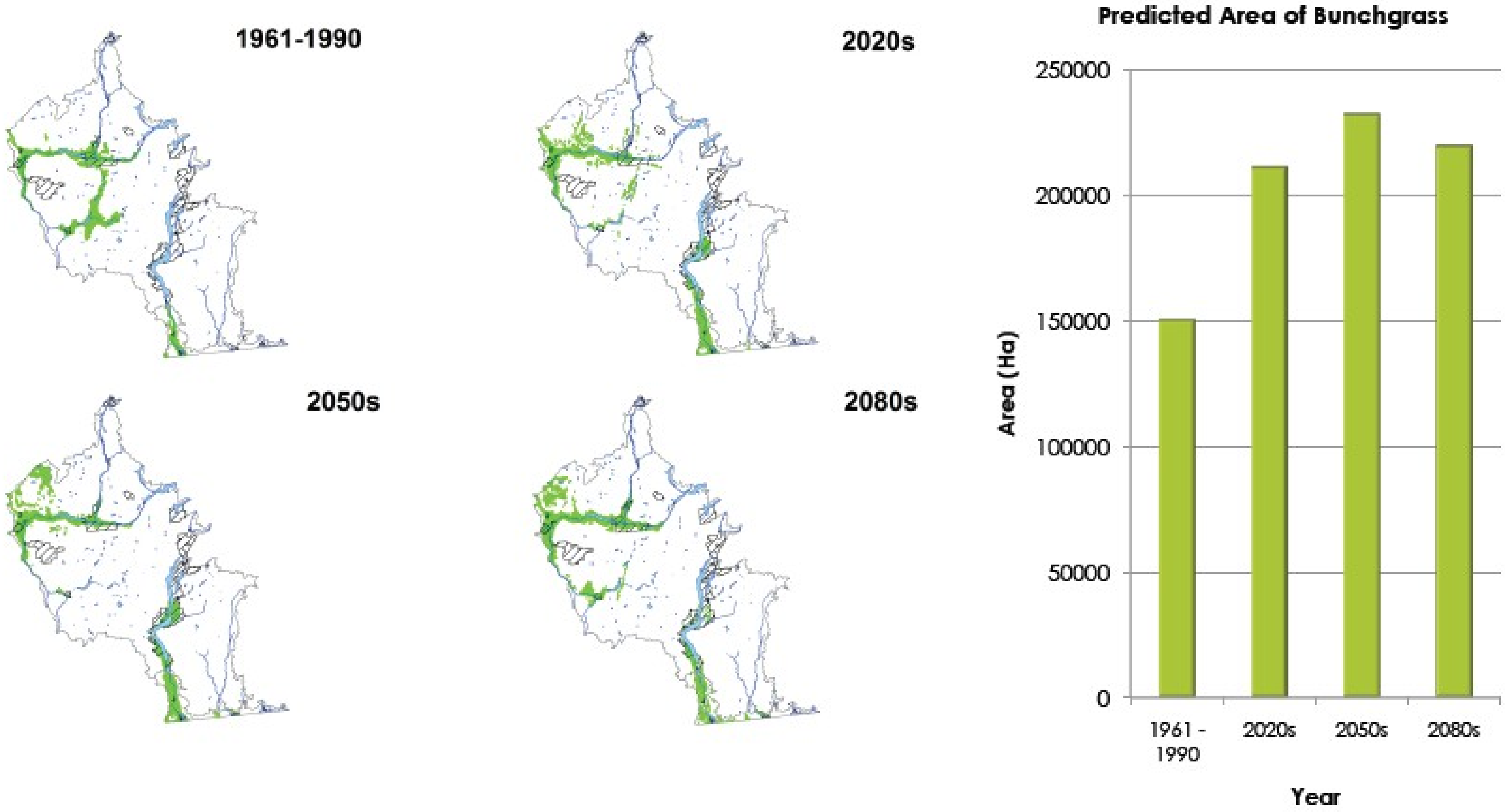

Figure 7.6 – Projected area increases for the Bunchgrass zone in the Thompson Okanagan Ecoregion (as provided by Wang)

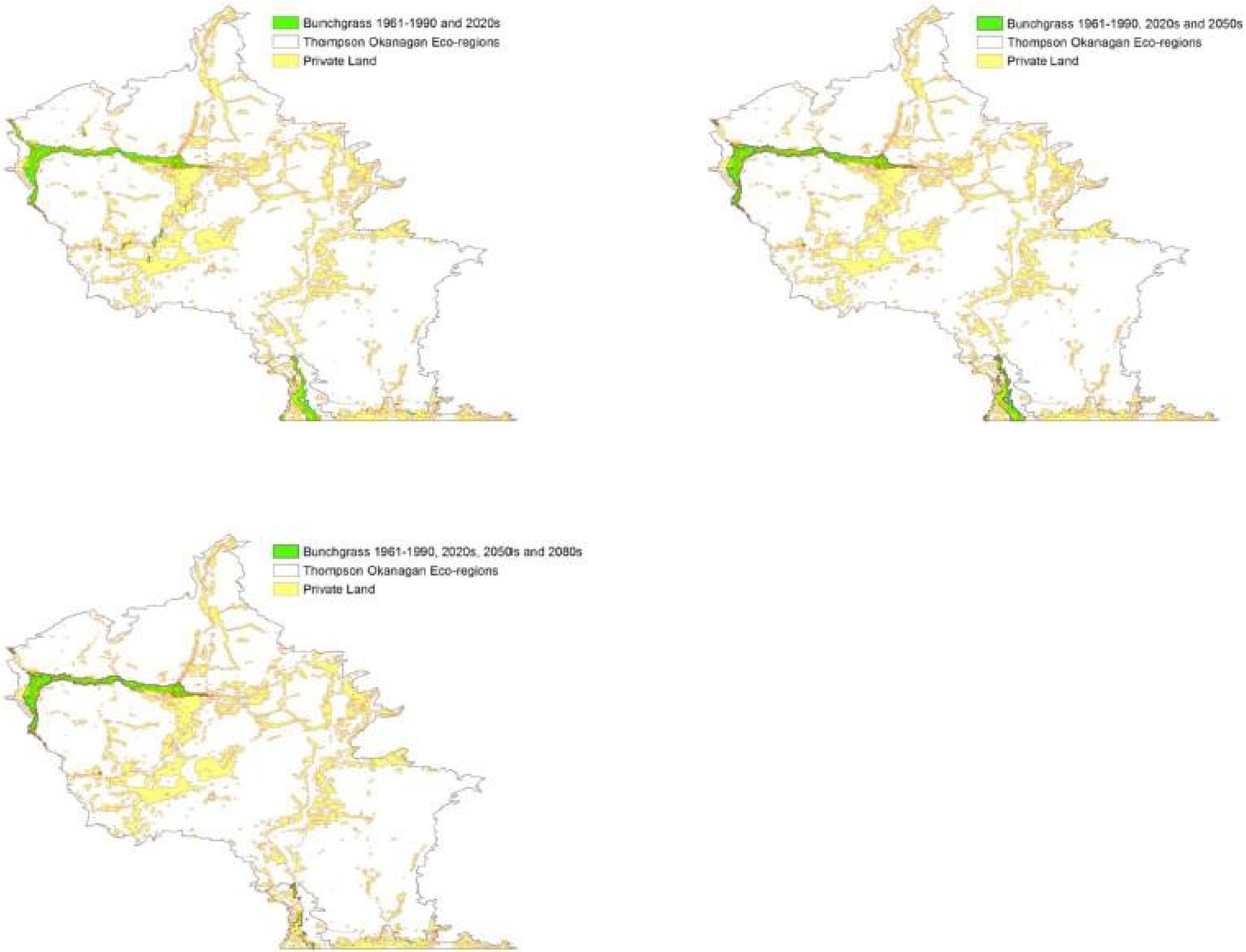

Figure 7.7 – Overlap between the predicted Bunchgrass area between the three time slices

7.3.2 Interior Cedar Hemlock

Using Wang's BEC modelling data the area of Interior Cedar Hemlock (ICH) in the Thompson Okanagan Ecoregion is projected to increase, particularly in the Southern portion of its range in the region (Figure 7.8). There are few roads in the region of these major increases. However, despite these predicted gains there appears to be few persistent temporal corridors to facilitate movement of genetic material into the new range which may indicate that the rise of this ecosystem type in the new climatic zone may not be feasible. Of the predicted 2080 area of 7,436,058 km^2, only 8 per cent of the climatically suitable range for ICH is predicted to remain constant between the three time slices, and that area is limited to the north eastern edge of the ecoregion (Figures 7.9).

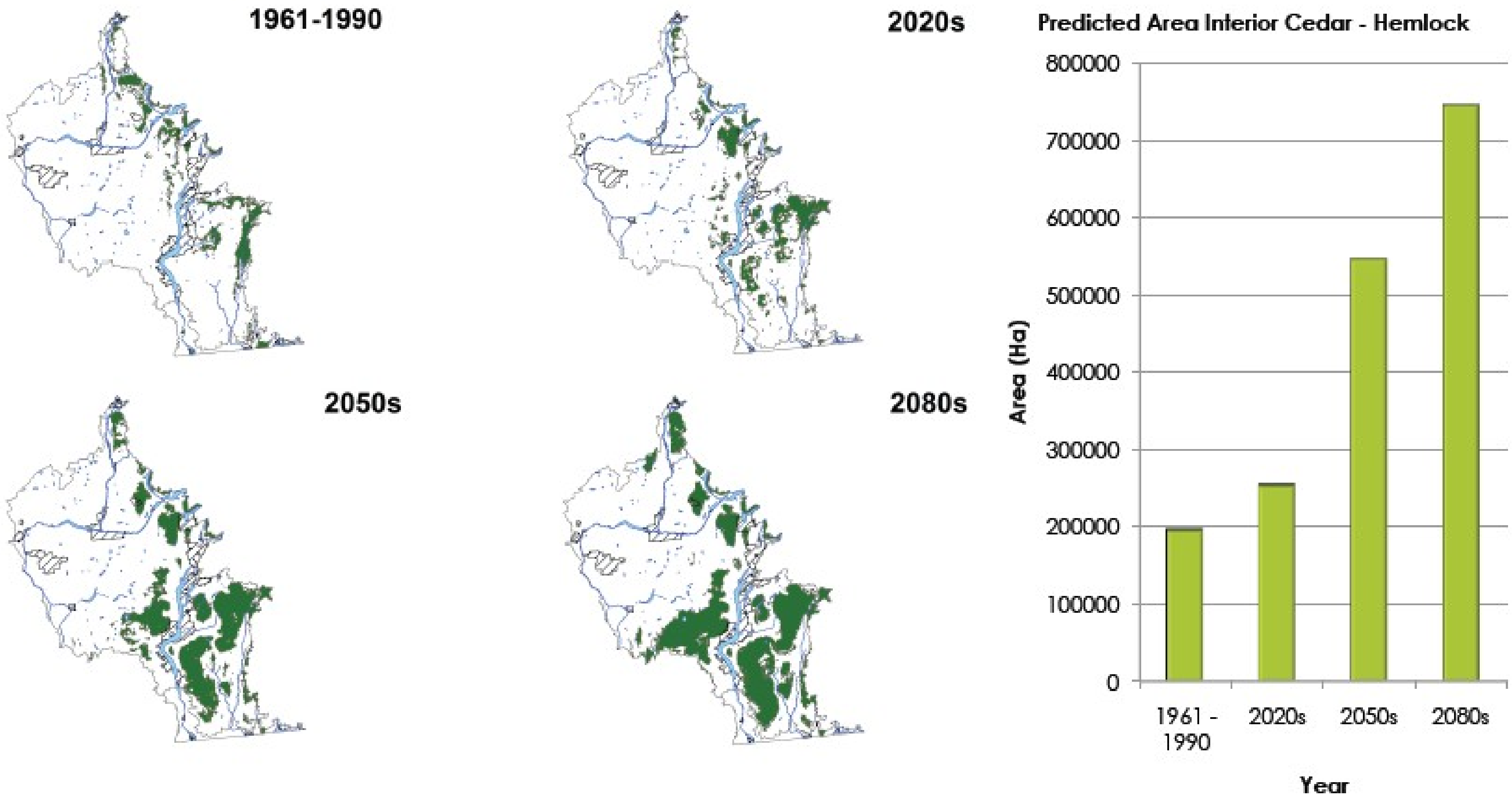

Figure 7.8 – Projected area increases for the Interior Cedar Hemlock zone in the Thompson Okanagan Ecoregion (as provided by Wang)

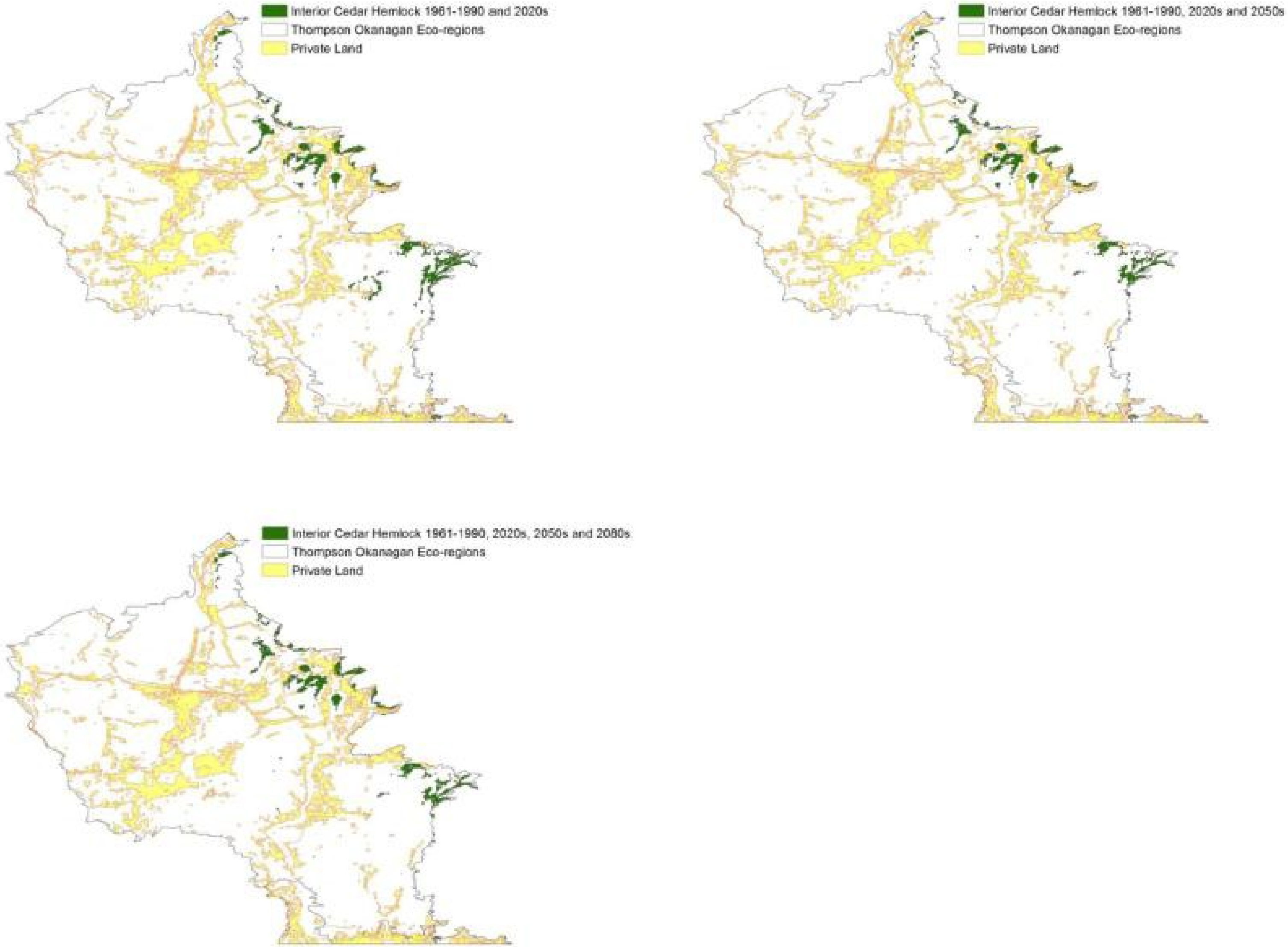

Figure 7.9 – Overlap between the predicted Interior Cedar Hemlock area between the three time slices

7.3.3 Interior Douglas-fir

Using Wang's BEC modelling data the area of Interior Douglas-fir in the Thompson Okanagan Ecoregion is projected to increase in the near future (2020) and then decreases back to slightly below its current range in the region by 2080 (Figure 7.10). Given the size of the range across all of the time periods, roads do not appear to be an issue for the overall connectivity of this ecosystem. Just over half of the 2080 range of 13,624,544 km^2 appears to be persistent across the three time slices (Figure 7.11)

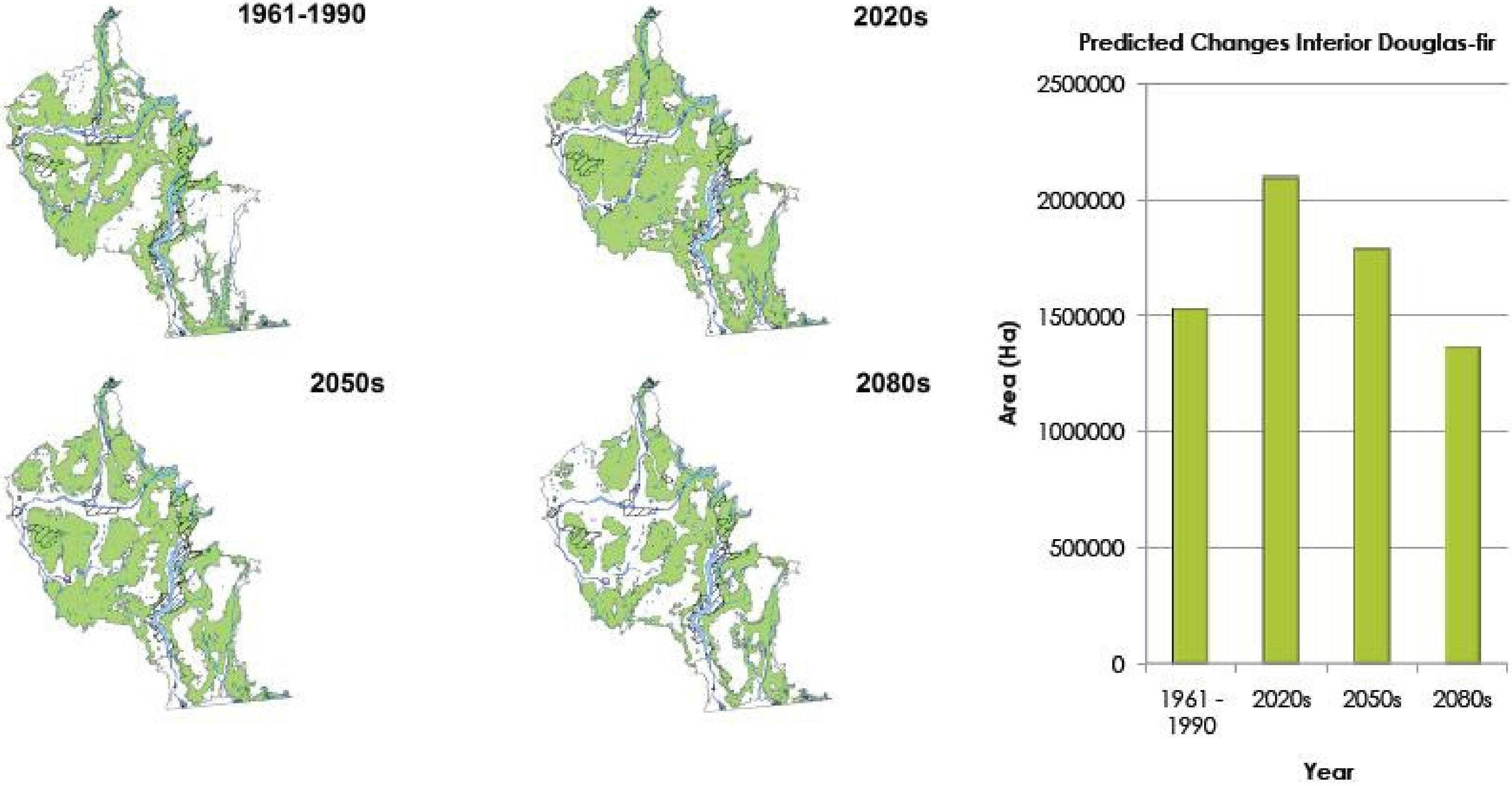

Figure 7.10 – Projected area increases for the Interior Douglas-fir zone in the Thompson Okanagan Ecoregion (as provided by Wang)

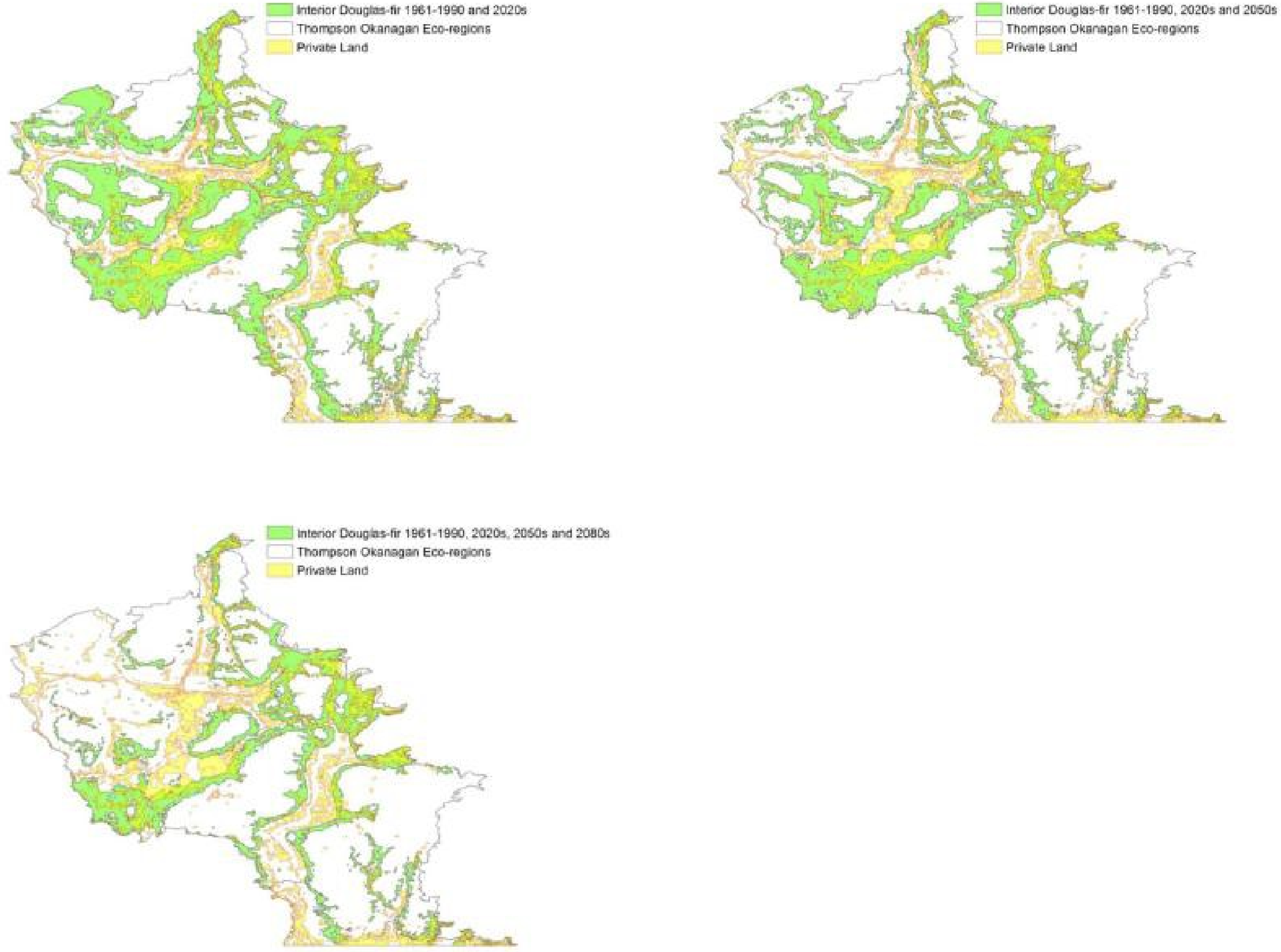

Figure 7.11 – Overlap between the predicted Interior Douglas-fir area between the three time slices

7.3.4 Ponderosa Pine

Using Wang's BEC modelling data the area of Ponderosa Pine (PP) in the Thompson Okanagan Ecoregion is projected to increase, particularly in the north-eastern portion of its range in the region (Figure 7.12). Some of the area in which these predicted increases occur appears to be heavily roaded, which may prove to be an issue for the ecosystem in the area. In addition, it appears there may be few persistent temporal corridors to facilitate movement of genetic material into the new range, which may indicate that expansion of this ecosystem type in the new climatic zone may not be feasible. Of the predicted 2080 area of, 9,050,664 km^2only 9 per cent of the climatically suitable range for PP is predicted to remain constant between the three time slices. Adding to concerns, this persistent area is in heavily roaded areas and mainly occurs on private land (Figure 7.13).

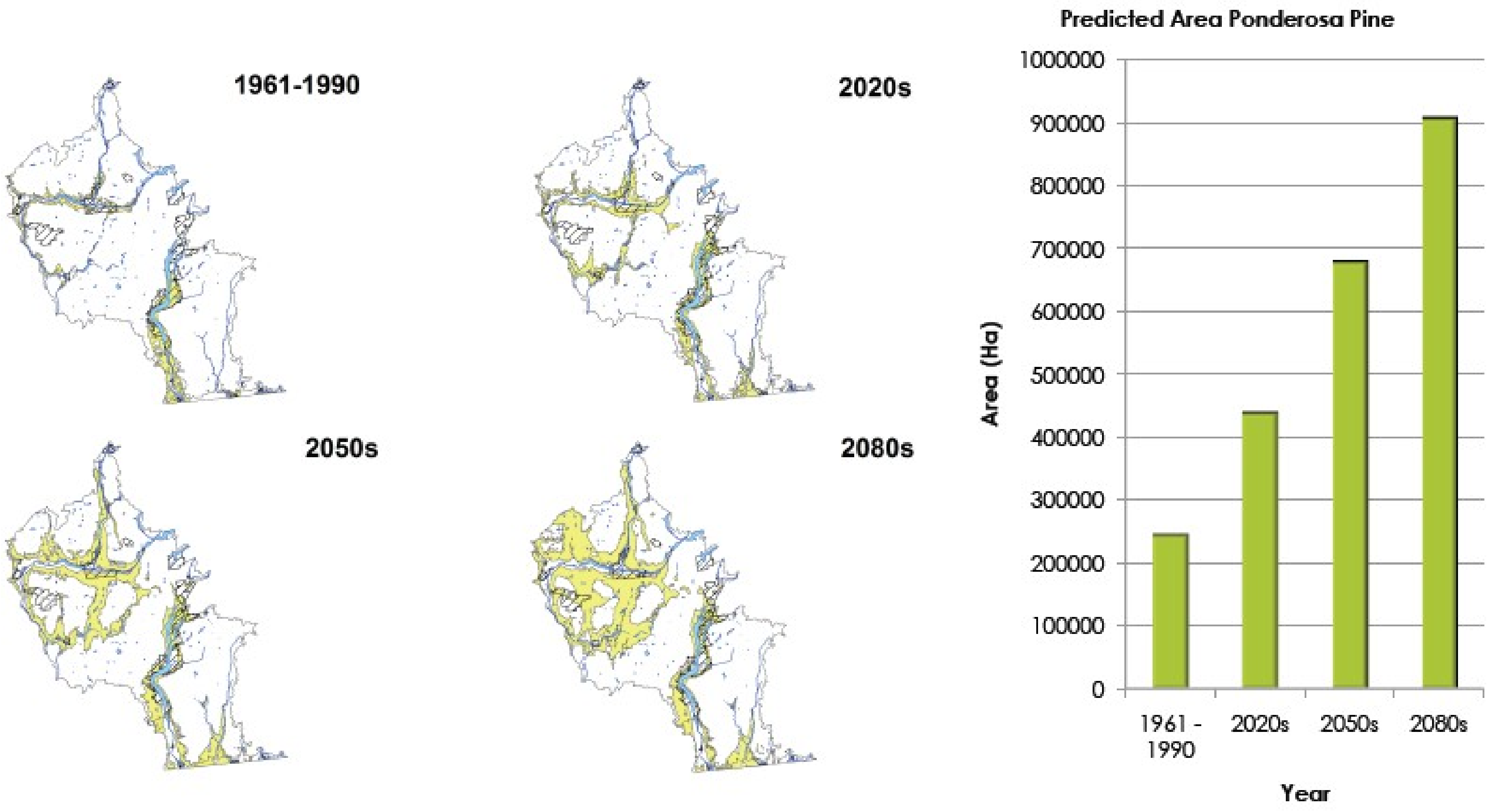

Figure 7.12 – Projected area increases for the Ponderosa Pine zone in the Thompson Okanagan Ecoregion (as provided by Wang)

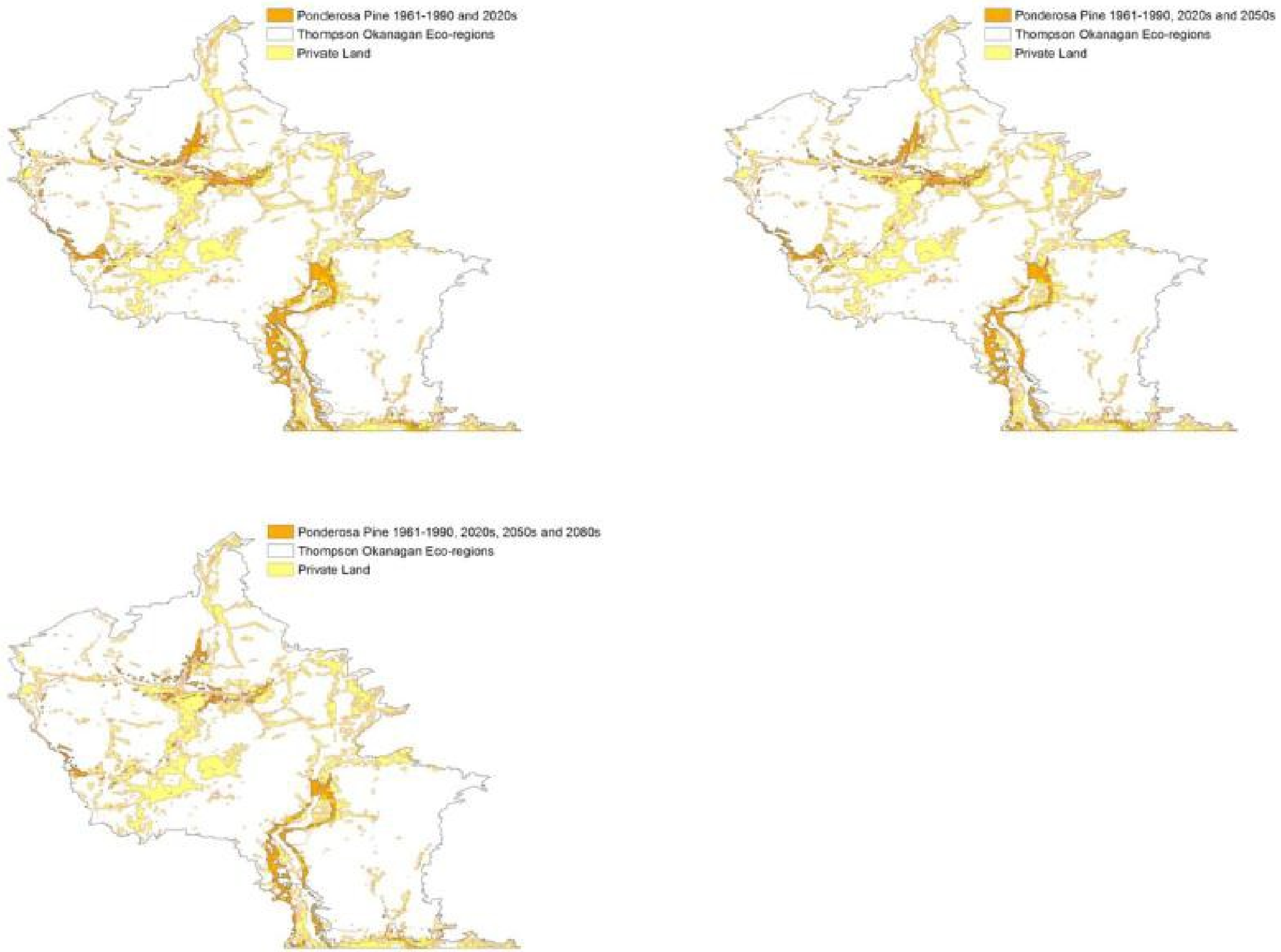

Figure 7.13 – Overlap between the predicted Ponderosa Pine area between the three time slices

7.3.5 Engelmann Spruce Subalpine Fir

Using Wang's BEC modelling data the area of Engelmann Spruce Subalpine Fir (ESSF) in the Thompson Okanagan Ecoregion is projected to decrease markedly to almost nothing by the 2080s (Figure 7.14). The reduction of climatically suitable range in the region is such that roads or temporal corridors are unlikely to be of any consequence for the ecosystem. Of the 25,782 km^2 of the ESSF range remaining in 2080 over 80 per cent is consistent across the three time zones although this is only because the range has contracted so extensively elsewhere in the region (Figure 7.15).

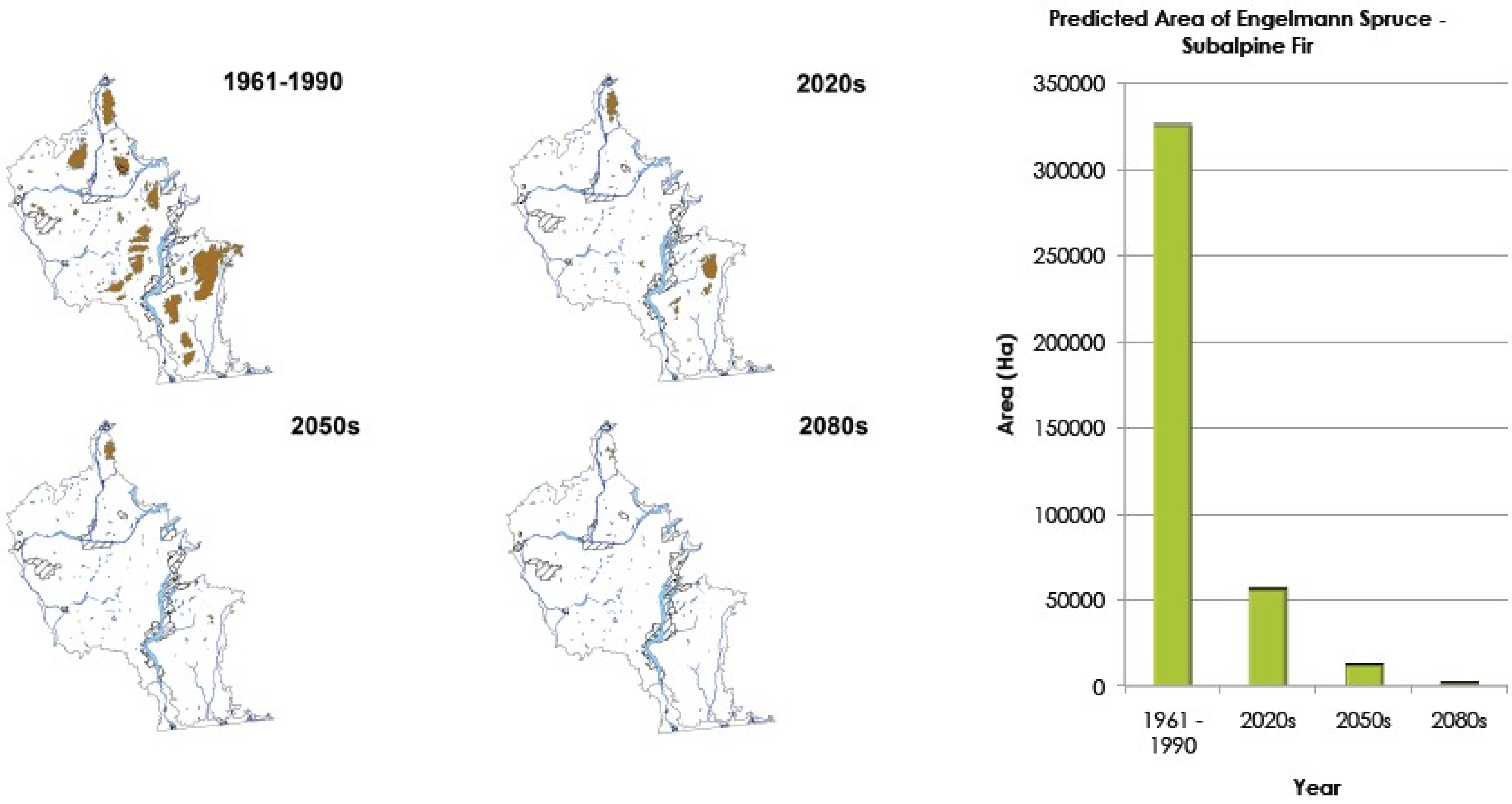

Figure 7.14 – Projected area increases for the Engelmann Spruce Subalpine Fir zone in the Thompson Okanagan Ecoregion (as provided by Wang)

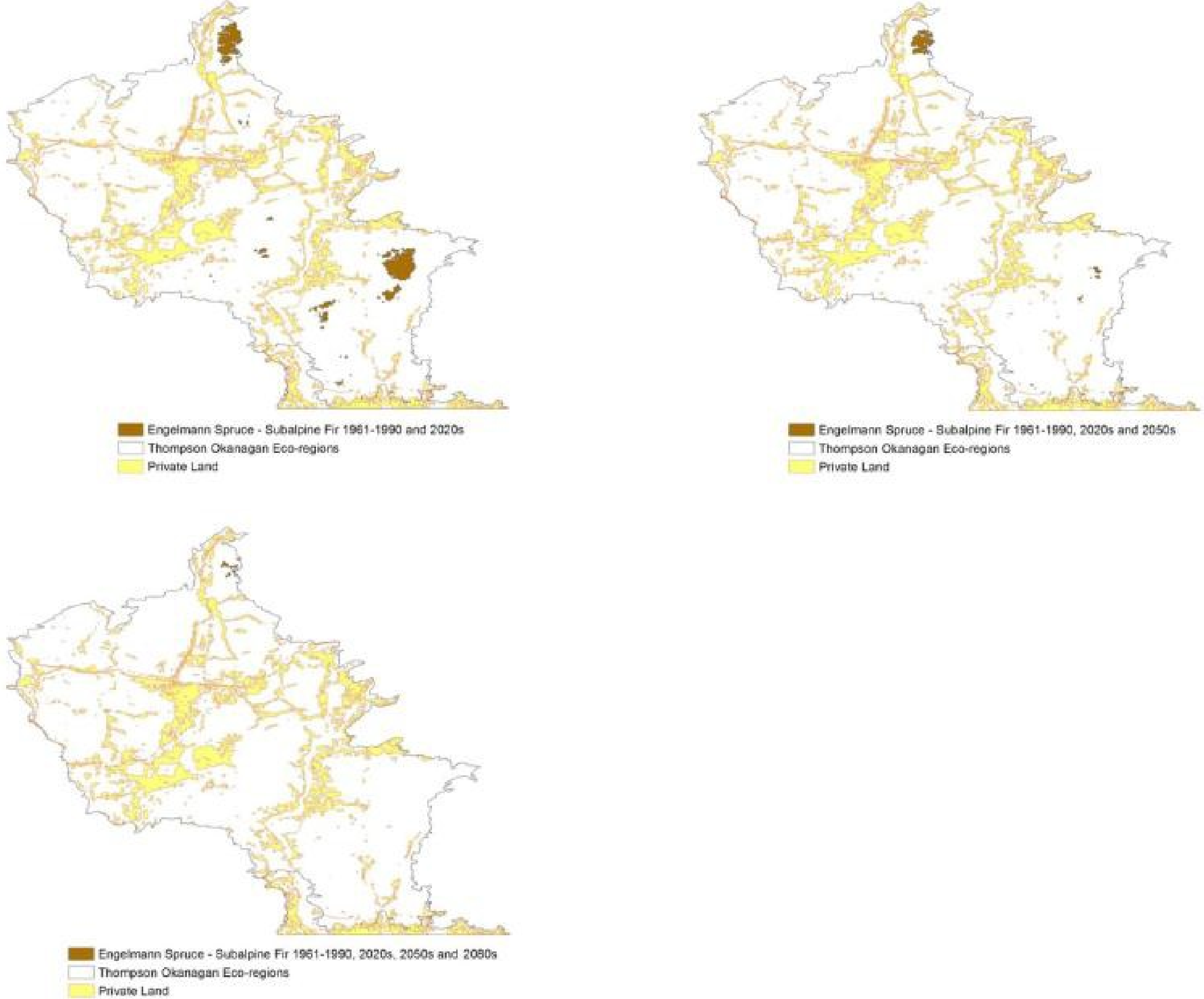

Figure 7.15 – Overlap between the predicted Engelmann Spruce Subalpine Fir zone area between the three time slices

7.3.6 Montane Spruce

Using Wang's BEC modelling data the area of Montane Spruce (MS) in the Thompson Okanagan Ecoregion is also projected to decrease markedly to almost nothing by the 2080s (Figure 7.16). Again, the reduction of climatically suitable range in the region is such that roads or temporal corridors are unlikely to be of any consequence for the ecosystem. None of the 1,624 km^2 of the MS range remaining in 2080 is consistent across the three time zones (Figure 7.17).

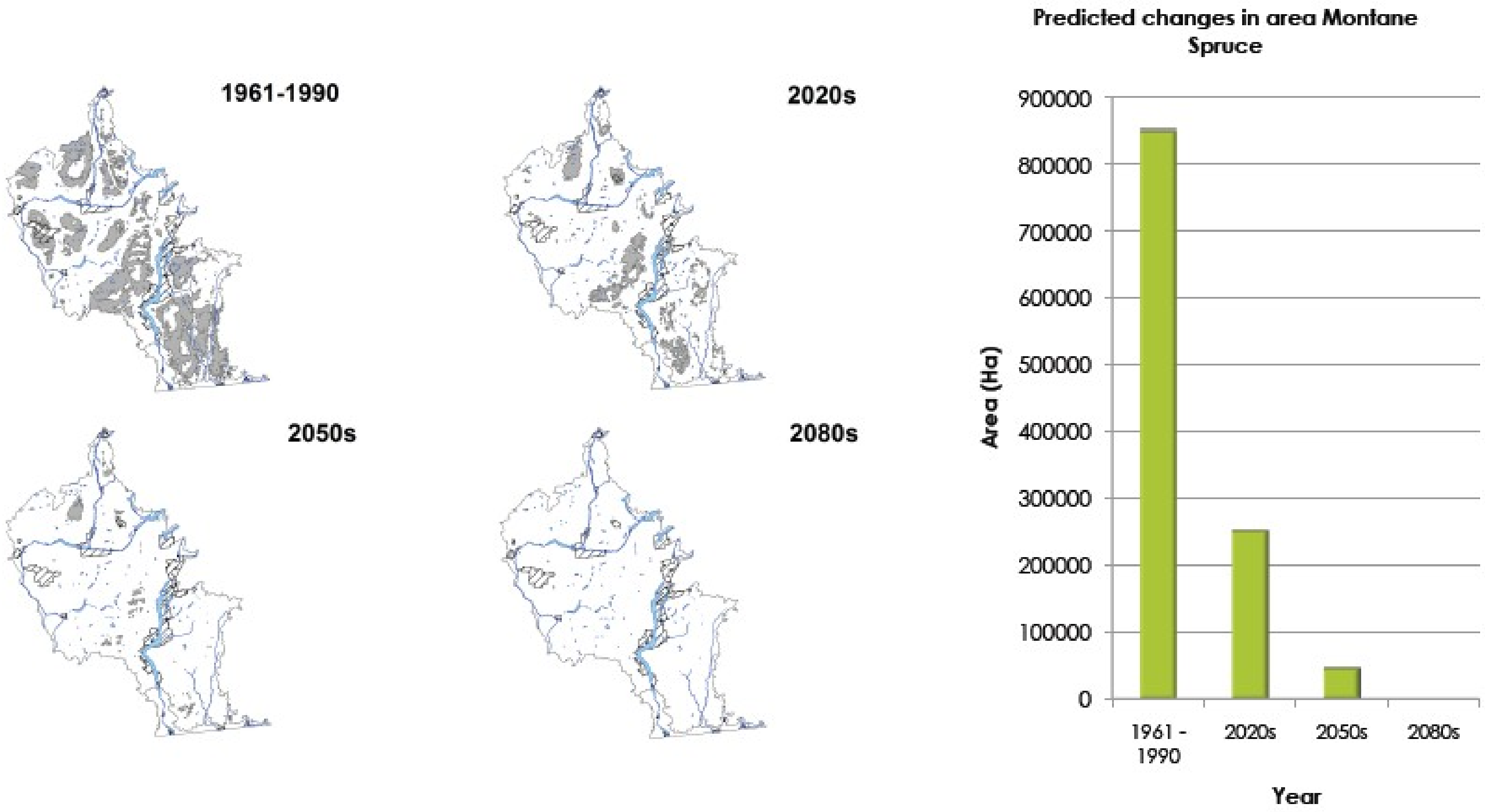

Figure 7.16 – Projected area increases for the Montane Spruce zone in the Thompson Okanagan Ecoregion (as provided by Wang)

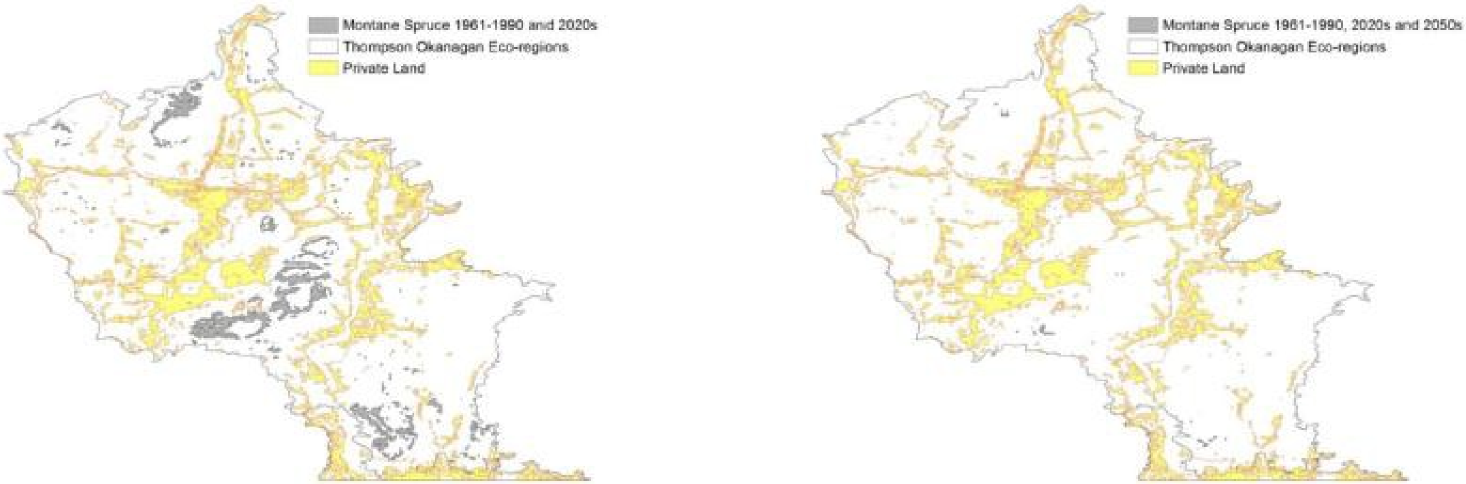

Figure 7.17 – Overlap between the predicted Montane Spruce zone area between the two time slices

7.4 DISCUSSION

The approach that I have tested in the Thompson Okanagan Ecoregion generally provides a simple and cost-effective way to identify BEC zones that may be particularly vulnerable in light of climate change at a provincial level. Rose and Burton's (2009) approach of temporal corridors that I have tested here builds nicely on Wang's bioclimatic modelling work and offers a very useful analysis for highlighting the likely extent of overlap between climatically suitable range of ecosystems and the likelihood that ecosystem's connectivity will be affected negatively by climate change. The use of additional basic spatial data sets like the roadedness and tenure layers I have developed here gives considerably more depth and interpretation to this analysis.

The approach I have tested could be improved by developing a better roadedness layer that incorporates data from the entire province and more justifiably categorises the extent of roadedness. For example, the areas that I have highlighted here as being 'most roaded' may not be considered as such in light of provincial level data. These data could also be improved through the use of area and percentage figures that I have not used in our pilot tests. Similarly, this analysis would also be improved by more effectively taking into account what is occurring at the provincial level. Contractions of various ecosystems examined here and the combined effects of temporal corridors, roads and tenure may not be significant at a provincial level. Increased depth of information and specialist expertise regarding the uniqueness (or otherwise) of the BEC zones and the species found within them would also be valuable additional information for interpreting the results of this indicator and the approach I have tested.

Chapter 8

Tracking changes in fire season length and severity

8.1 INTRODUCTION

There is relatively high uncertainty associated with most studies of climate change and forest fire, although most authors project an increase in the number of fires and the area burnt by fires across western Canada. This includes an increase in the number of fires ignited by lightning and an extension to the fire season length (Gillett et al. 2004, Hawkes et al. 2005, Flannigan et al. 2006, Podur and Wotton 2010, Metsaranta et al. 2011). In particular, southern and central parts of BC are expected to experience drier summers thereby potentially increasing the frequency, severity and intensity of fires. Some of the more northerly regions in the province are predicted to be wetter however and may experience subsequent decreases in fire disturbance (Spittlehouse 2008). Vegetation type will also influence changes in future fire frequency and intensity. As such, species migrations in response to changing climate may also affect future fire behaviour by changing the fuel types. Some other factors that influence fire seasons include wind, lightning frequency and fire management mechanisms.

In our survey of forest managers working in BC, information on fire season severity was rated as being moderately important in order to be able to bring climate change considerations into forest management and operational practices in the province. In comparison, fire season length was seen as being of a lower level of importance (Chapter 3). The data for monitoring this indicator comes entirely from the Wildfire Management Branch which operates approximately 260 hourly weather stations across the province. Temperature, relative humidity, precipitation, wind speed and wind direction are recorded by the fully automated stations. These data are transmitted to Protection Headquarters every hour from April through October but less frequently and from fewer stations during the winter months.

Through these weather data the Wildfire Management Branch calculates a severity rating based on information from the Canadian Forest Fire Weather Index (FWI) System. The Daily Severity Rating (DSR) is a numerical measure, based on the Fire Weather Index (FWI), specifically designed for averaging, either for any desired period of time (e.g., week, month, year) at a single fire weather station or spatially over a number of stations. The FWI itself, on the other hand, is not considered suitable for averaging, and should be used as its single daily value only. The DSR averaged over a whole fire season is termed the Seasonal Severity Rating (SSR) which can be used as an objective measure for comparing fire weather severity from one season to the next, or the fire climate of one region with another (GC 2012).

8.2 APPROACH

In order to examine the usefulness of the data collected and prepared by the Wildfire Management Branch for reporting on this indicator, I downloaded the fire management database information from the Ministry of Forests, Land and Natural Resource Operations FTP site on 22 October 2011. A short tutorial on using the database was provided by Dr. Eric Myer from the Wildfire Management Branch. The data were presented in their original format - an MS Excel table. Using pivot tables I was able to easily graph the historical severity rating for all stations in the province. For this case study analysis, however, I specifically examined the data available in the Kootenay Lake Forest District. While there were a number of stations in this district I only examined the data from four of the stations: Creston, Duncan, Goatfell and Howser as these stations had the longest historical records. I used the average DSR for each season for the years available. The DSR categories used by the Wildfire Management Branch are as follows: 1 = Very Low, 2 = Low, 3 = Moderate, 4 = High, 5 = Extreme. These numbers are used in Figures 8.1 – 8.4 describing each of the stations below.

8.3 RESULTS

8.3.1 Creston

The Creston Fire Weather Station has very good fire weather data that stretch from 1983 through to 2009, with records missing for the years 1985 - 1989 in addition to a few other daily records. Trends for the station across the time period show generally increasing fire weather severity rankings across all fire season months (July – September) (Figure 8.1). The fire season length also appears to be increasing in the area, with the Creston station experiencing a trend towards a moderate (3) fire weather danger class ranking in July and September over the last few years where previously very low (1) and low (2) fire danger classes were recorded.

8.3.2 Duncan

The Duncan Fire Weather Station also has good fire weather data that stretch from 1981 through to 2009, with years between 1983 – 1988 missing in addition to a few other daily records. Although less pronounced than at the Creston station this station also shows a weak trend towards increasing fire weather severity rankings across all fire season months (July – September) (Figure 8.2).

8.3.3 Goatfell

The Goatfell Fire Weather Station has excellent fire weather data that stretch from 1986 through to 2009, with only a few daily records missing. Trends for the station across this time period show slightly increasing fire weather severity rankings across all fire season months (July – September) (Figure 8.3). The fire season length also appears to be increasing in the area with the Goatfell station experiencing trends edging towards a moderate (3) fire weather danger class ranking in July and September over the last few years where previously a low (2) fire danger class was recorded.

8.3.4 Howser

The Howser Fire Weather Station also has very good fire weather data that stretch from 1981 through to 2009, with only 1985 missing and a few other daily records. Figure 8.4 shows trends for the station across this time period and reveals slightly increasing fire weather severity rankings across all fire season months (July – September). The fire season length also appears to be increasing in the area with the

Howser station experiencing trends edging towards a moderate (3) fire weather danger class ranking in July and September over the last few years where previously a low (2) fire danger class was recorded.

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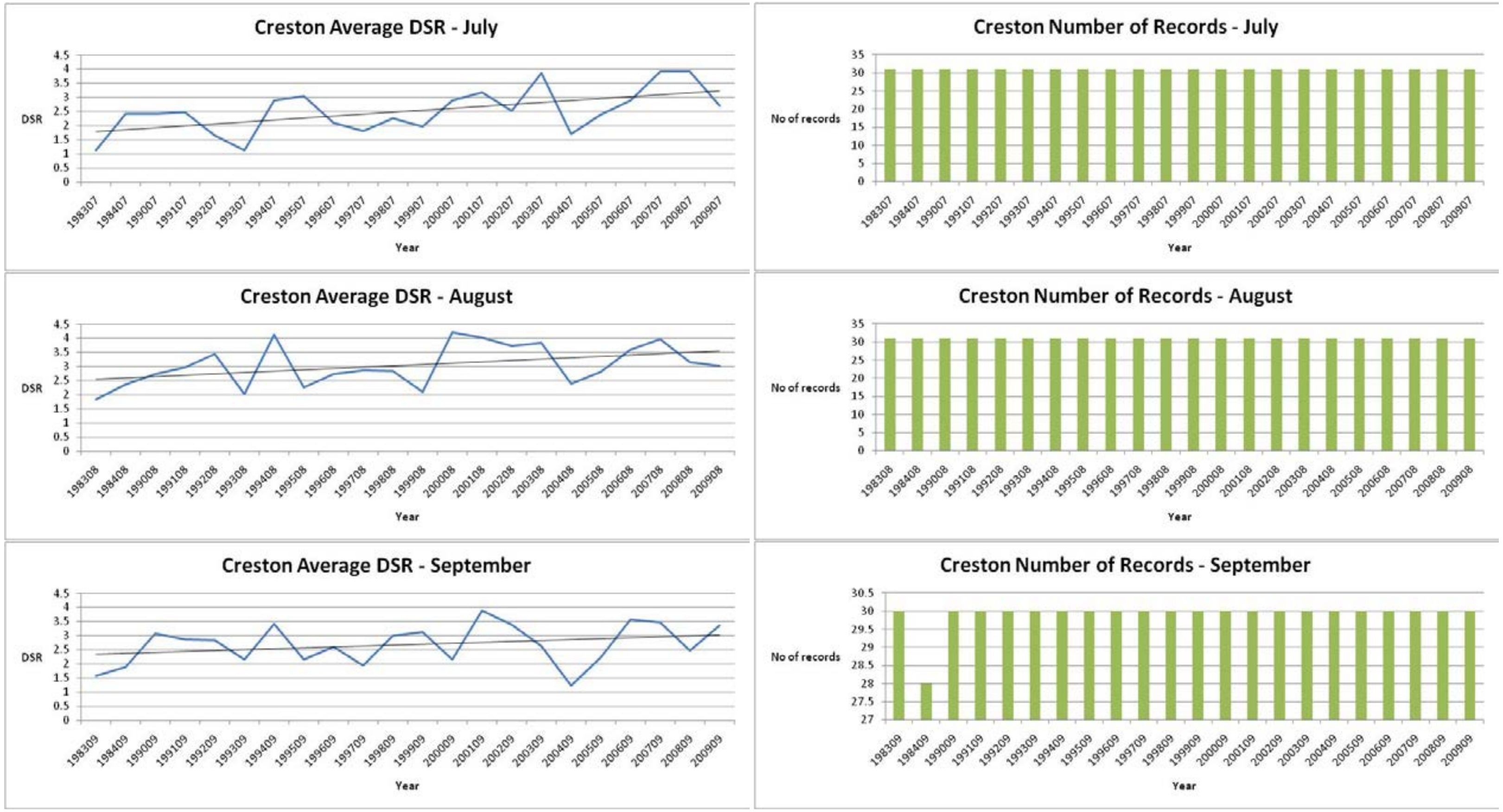

Figure 8.1 – Creston seasonal severity rankings for fire season months and record counts 1983, 1984, 1990 – 2009

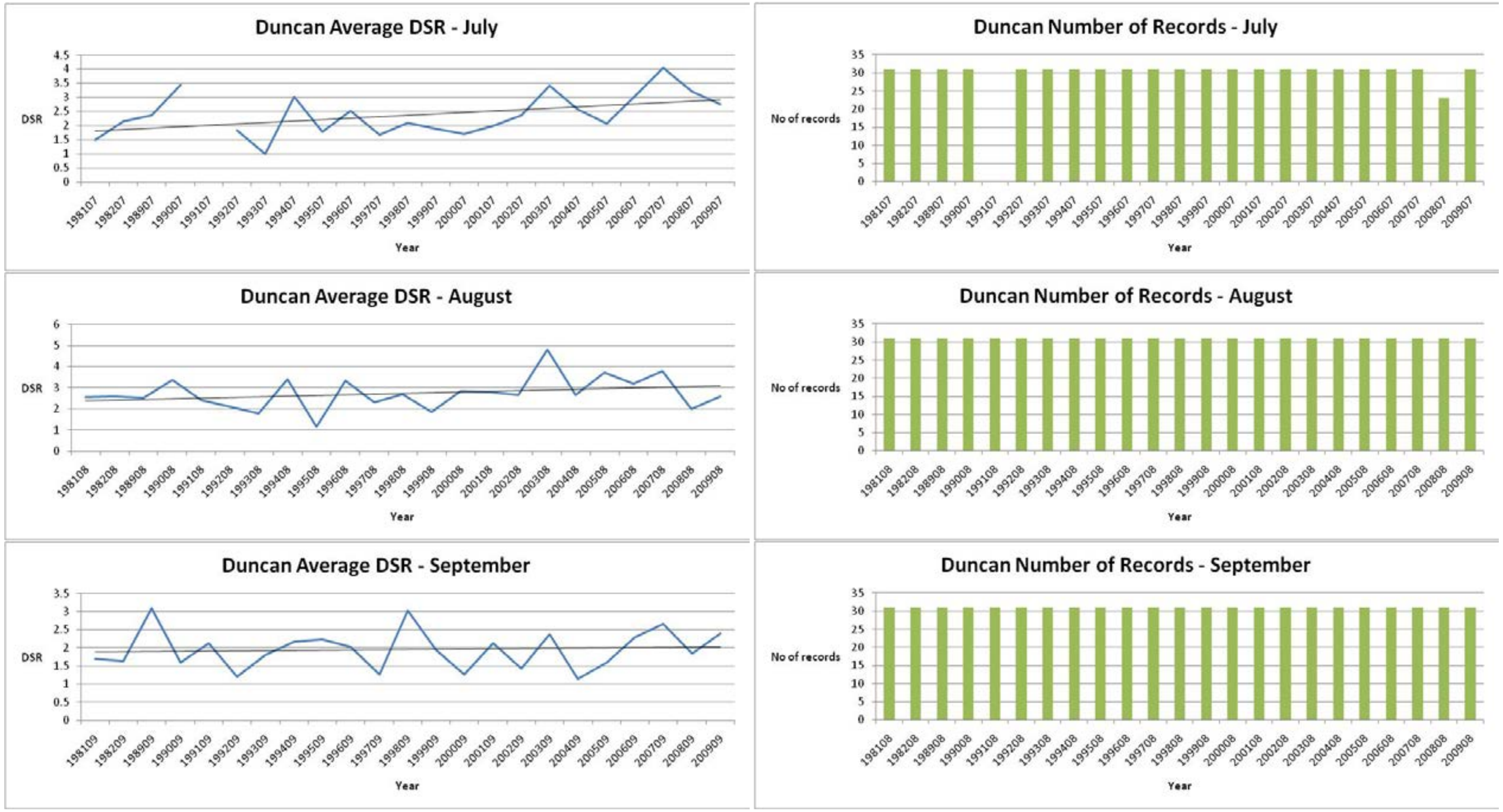

Figure 8.2 – Duncan seasonal severity rankings for fire season months and record counts 1981, 1982, 1989 – 2009

Figure 8.3 – Goatfell seasonal severity rankings for fire season months and record counts 1986 – 2009

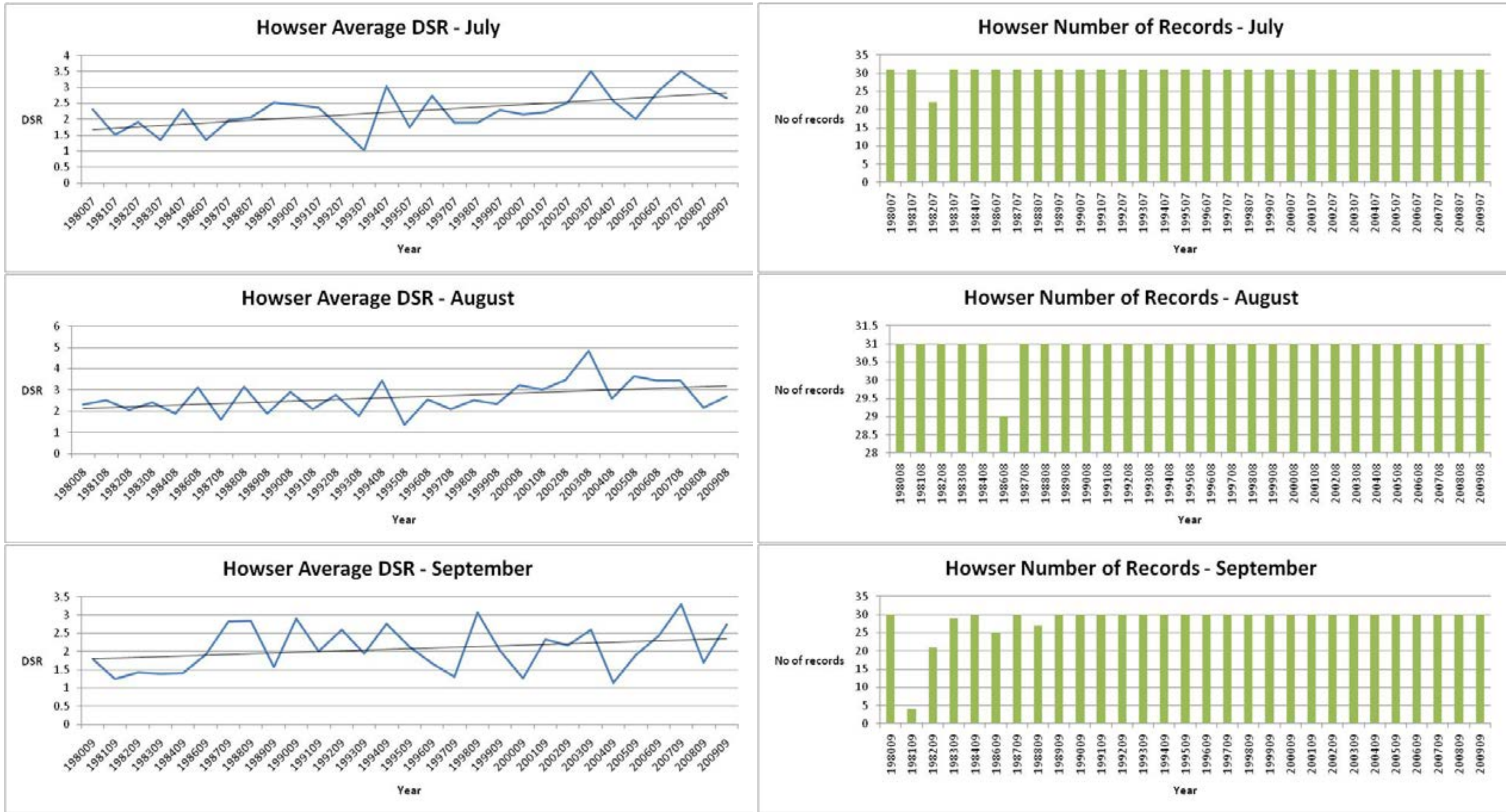

Figure 8.4 – Howser seasonal severity rankings for fire season months and record counts 1980, 1981, 1982, 1983, 1984, 1986 – 2009

8.4 DISCUSSION

The data from the Wildfire Management Branch are excellent and should be able to be used in their current format to examine changes in fire season length and severity with little amendment needed. Generally it appears that there are long-term data available from a number of sites well distributed across the province. In order to better determine the fire season length it would be useful to supplement the analyses I have described above with the dates of the first and last recorded fire of the season. I did request these data from the Wildfire Management Branch but they were not able to supply such data at the time.

Chapter 9

Examining insects and diseases affecting forest health in the context of climate change

9.1 INTRODUCTION

A large number and variety of sources predict that increases in the severity and frequency of disturbances caused by insects and pathogens will be one of the first observable signs of climate change (Coakley et al. 1999, Dale et al. 2001, Logan and Powell 2005, Innes et al. 2009, Hansen et al. 2001a). Insects have been identified as important for monitoring in light of climate change primarily because their short generation times, rapid abundant reproduction, and potentially high mobility make them able to adapt quickly to changing climatic conditions. Pathogens such as foliar disease have been identified as important for monitoring as the occurrence and impact of many are likely to increase where warmer and wetter environments are predicted (Spittlehouse 2005). There are a number of examples from BC of insects and pathogens that are already affecting forest health as a result of the climatic changes that have taken place for example, Mountain Pine Beetle and Dothistroma Needle Blight (Woods et al. 2005, Taylor et al. 2007, Welsh et al. 2009). It is likely that the impacts of these agents will increase as the climate continues to change. There is also a high likelihood that insects or diseases that are not currently considered pests will emerge rapidly to pose a serious threat to forest health.

The intention was for this indicator to report on the scale and severity of insect and pathogen incursions adversely affecting forest and rangeland health. In our survey of forest managers working in BC, information on the effect of insect incursions was rated as being moderately important in order to be able to bring climate change considerations into forest management and operational practices in the province. In comparison, pathogen incursions were seen as being of a lower level of importance.

9.2 APPROACH

This indicator would be monitored using the province-wide aerial surveys conducted by the Ministry of Forests, Land and Natural Resource Operations Forest Practices and Investment Branch. This Branch has surveyed the majority of the forested land in the province using aerial survey since 1999 resulting in the production of an annual report summarizing forest health conditions and digitized maps and tables describing pest conditions by region and district. The data available for monitoring this indicator are excellent and are easily accessible over the internet in both MS Excel and spatial formats. Outbreaks are recorded under the classes: trace, moderate, severe and very severe. In terms of insects the area affected by bark beetles is recorded (for approximately 9 different species) and defoliators (for 21 approximately different species). Twelve different diseases are recorded.

The Ministry of Forests, Land and Natural Resource Operations Forest Practices and Investment Branch produces an annual summary of aerial overview surveys for Southern BC (MFR 2012a). Although no summaries are produced for other areas these data are gathered provincially so a similar summary report could be generated. The summary report for 2010 gives a detailed analysis for the Southern BC region including summarising that mountain pine beetle continued to be the most damaging pest in the region with 558,118 hectares of forest in the region damaged by the pest. It is further reported that other pests causing large scale damage in the Southern Interior were the western spruce budworm (499,105 hectares), western balsam bark beetle (183,167 hectares), Douglas-fir beetle (10,857 hectares), spruce beetle (29,922 hectares), Douglas-fir tussock moth (16,302 hectares), two-year cycle spruce budworm (70,694 hectares), aspen serpentine leaf miner (67,282 hectares), and forest tent caterpillar (37,844 hectares). In addition to reporting detailed statistics on the area affected by various pests and diseases the success or otherwise of various treatments applied are also reported.

9.3 DISCUSSION

As with the fire data the baseline data available for monitoring the effects of pests and diseases is very good. The issue with monitoring this indicator will be drawing cross linkages between the data recorded for monitoring pests and diseases and the impacts of climate change. A strong scientific research program is needed at the provincial level to undertake the research necessary to draw these linkages. Such research is exemplified by the work of a number of researchers in the Pacific North West in recent years for example: Woods et al. 2005 and Taylor et al 2005.

Chapter 10

Conclusion

Monitoring forests and the biophysical processes acting on them has always been fundamental to evidence based forest management and decision making. Understanding how forests are changing and naturally adapting to climate change is vital for informing future sustainable forest management activities from the environmental perspective as well as the flow-on social and economic effects. With increasing pressures on the public resources available to monitor forests, it is more important than ever that the limited resources are effectively expended to address and target the key information needs. In addition, it is vital that long-term data sets are effectively utilised and 'wrung out' to expand our knowledge as much as they possibly can. This includes continually reassessing the key questions that decision makers have in regards to managing forests and assessing the capacity of the Province's long term datasets to answer those questions. One of the greatest challenges now facing forest managers (and humanity in general) is how to respond and proactively adapt to the effects of rapid, human accelerated climate change. This report assesses a selection of indicators that have been determined as pivotal for undertaking decisions in BC's forests in light of climate change. As detailed in Chapters 2 and 3, for forest managers operating in BC there are a number of aspects that fit this category, key among which are monitoring changes in forest productivity as well as changes in ecosystem distribution and composition.

A study of the data sources available to support analysis of a selection of the indicators identified (detailed in Chapters 4 through to 9) has shown that there are some very strong data collections held provincially that could be used to answer the new questions relating to climate change. These include datasets collected and analysed by both provincial and federal governments such as the NFI, VRMP, PSP and others. In some cases these can be unpacked as used effectively at a more localised scale (e.g. PSP), but others (e.g. VRMP) cannot. While this research has largely shown that many of these datasets do have the capacity to be used in their current format (or with only slight augmentation), there are some attributes identified for which there is a paucity of data. Key among these is the indicator examining species diversity (Chapter 5). Respondents to the survey (Chapter 3) very clearly indicated that they did want more data about the adaptability of tree and grass species to climate change. The Province appears to be particularly lacking in any long-term species level data that can be readily used to respond to this identified information need.

Issues also remain with clearly interpreting the extent to which recorded changes are likely to be the result of climate change or whether they are influenced by other factors. Here the solution points back to a recognised need to integrate and combine the different kinds of monitoring, such as those mentioned in Chapter 1.3, and for a solid ongoing program funding scientific research concerning the effects of climate change on BC's environment. Because of a recognised need to make climate change policy and decisions at a provincial level the focus of this framework has been largely on the large provincial scale monitoring and datasets held within the province that, for the most part, are collected on an ongoing basis. A need and role also exists for localised, "question driven" monitoring and research programs to better interpret the results obtained from the overarching, broad-sweeping data collections investigated in this report. A good example of such a program is that conducted by the Ministry of Forests, Lands and Natural Resource Operations Research Branch which operates three facilities undertaking active forest research programs. There are also countless other forest research programs operating within the government, academic and private spheres which could be used to better interpret and supplement the 'base-line' information which would be derived from a framework such as this.

In addition to making use of forest monitoring and research in interpreting the findings of the framework, another key source of interpretation information should be the models that are being generated detailing the effect of climate change on the forest environment. As detailed in Chapters 4 and 7, theories and models have been used to assess and predict the potential effects of climate change on ecosystems in the region (Rizzo and Wiken 1992, Hebda 1997, Hamann and Wang 2006b, Nitschke and Innes 2008b). Hamann and Wang (2006). Modelling the possible future distributions of the BEC zone climates is a prime example. There is also strong modelling work in the area of pests and diseases (Woods et al. 2005, Taylor et al. 2007) and stream temperature (Nelitz et al. 2008). Strong linkages between the data collected under this framework and this type of modelling work may serve to verify the extent to which predicted changes are eventuating and to calibrate models to more accurately predict future changes.

If further work was to eventuate from this monitoring program there is a need to effectively incorporate information generated from the framework into forest management practices. A program such as the Forest and Range Evaluation Program would be absolutely critical for undertaking the implementation necessary to work with forest managers to effectively implement the findings that resulted from the framework. As with the Forest and Range Evaluation model, the effectiveness of forest management practices and their capacity to achieve the desired forest management objectives (in this case climate change adaptation) would need ongoing evaluation.

The summary of work detailed in this report is the result of a strong collaborative effort across various government agencies operating and collecting data on forests in BC including a number of separate branches within the Ministry of Environment and the Ministry of Forests, Land and Natural Resource Operations, and from within the Canadian Government. The results of the project (including those detailed within this report) have already been widely disseminated through a variety of extension avenues including at presentations such as the Climate Change and Forests Seminar Series and to the BC Government Natural Resource Monitoring Community of Practice. A summary report from Phase 1 and 2 activities is also on the Forest and Range Evaluation Program Website (Eddington et al. 2009). These extension activities have lead to interest and inquiries from a number of community organisations who have requested data and other advice. These have included: First Nations Groups wishing to initiate climate change monitoring programs on their lands (e.g. Xeni Gwet’in) and other on-ground land managers.

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Appendix A

Indicators selected and data sources identified through Phase 1 and 2 research

INDICATORS RELATED TO BIODIVERSITY

Ecosystem distribution and composition

Rationale for monitoring in light of climate change

As climatic envelopes within BC change, alterations in the composition, diversity and spatial distribution of ecosystems are predicted along with the development of novel assemblages of species resulting in the formation of new ecosystems. Models suggest that there will be shifts in ecosystem and species' ranges upwards in elevation and northward with certain identified ecosystems appearing to be particularly vulnerable to such shifts. However, during the workshop experts stressed and noted that such models are based on ecosystem-level changes: research is increasingly suggesting that the individual species that make up current ecosystems may be affected differently by climate change, resulting in changes in ecosystem composition rather than changes in ecosystem distribution. As well as providing a direct measure of ecosystem diversity and the extent to which it is being maintained, monitoring of this indicator provides context for interpretation of many of the other indicators put forward.

Possible approach to monitoring

This indicator would seek to examine changes in the distribution and composition of forest and rangeland ecosystems over time. Due to the strong field requirement, successful monitoring under this indicator will be largely reliant on building strong links with the proposed climate change programs identified in the key potential data sources listed below. The changing distribution and composition of forest and rangeland ecosystems should be tracked using changes to the Biogeoclimatic Ecosystem Classification (BEC) System zones over time. This system has been used for the past thirty years in BC and contains valuable baseline data for monitoring at the ecosystem level. Changes in the spatial distribution of BEC zones would need to be monitored along with changes in the composition and eventually the development of new ecosystems over time. Modelling scenarios should be widely used to inform and target monitoring under this indicator and aid in the analysis and interpretation of trend data and the formation of recommendations for management.

Potential data sources

Ministry of Forests, Land and Natural Resource Operations Research Branch, Biogeoclimatic Ecosystem Classification (BEC): Some modeling of ecosystem change under various climate scenarios using BEC and BEC data is currently underway both inside and outside the Ministry of Forests, Land and Natural Resource Operations. The Ministry of Forests, Land and Natural Resource Operations Research Branch is currently assessing areas and ecosystems most sensitive to climate change with the intent of installing permanent plots for observing changes over time to BEC zones.

Ministry of Forests, Land and Natural Resource Operations Forest Analysis and Inventory Branch (FAIB): FAIB is currently in the process of exploring options to adapt the National Forest Inventory and the Vegetation Resources Inventory to support climate change monitoring. Proposed changes include a doubling of the number of National Forest Inventory ground plots to enhance biomass and understory data.

Forest Ecosystem Research Network of Sites (FERNS): FERNS research is focused largely around the forest harvesting options and ecosystem function although the program may offer some useful data to help target this analysis under the indicator.

Cost/benefit of monitoring

Monitoring the composition and spatial distribution of existing, evolving and emerging ecosystems could be the single most important aspect of this monitoring program. While the cost of monitoring this indicator is considered to be high, costs could be lowered significantly by building synergies with proposed programs to be conducted by the key potential data sources identified.

Ecosystem productivity

Rationale for monitoring in light of climate change

Anticipated alterations in temperature and precipitation along with increased incidents of extreme weather events and disturbances caused by pests and diseases may result in changes in ecosystem productivity. Some regions and ecosystems may experience enhanced productivity while others may experience declines. Measuring these trends also relates to determining how climate change effects growth of species at the margins of their range. For example, some may be declining in growth and other species may see unexpected increases from the historic data. Carbon sequestration (sink versus source) is also of interest and also tied to changes in which components of the ecosystem respond in terms of growth (positively or negatively and rate of change). Monitoring these changes in light of climate change over the coming decades will improve our understanding of the resilience of ecosystems to ongoing environmental stressors and inform us of the nature of changes that are occurring.

Possible approach to monitoring

The National Forest Inventory (NFI) uses air photo sampling and ground sampling that could be used to support reporting against this indicator. NFI uses a system of air photo samples (2km by 2km) which are generally 1:20,000 but could also be at other resolutions in future (either 1:30,000 to reduce costs, or at low level higher resolution depending on cost and benefits). Information from ground samples will include estimates of growth by species (forest cover height and volume and changes over time) as well as collection of above ground biomass information on treed and non-tree species (eg range clippings, coarse woody debris). Estimates for tree heights and basal areas from the photo plots will be adjusted based on information from the ground plots. Some units also have ground plots which are not located on the grid but which could be statistically adjusted and included in the analyses: Change Monitoring Inventory (CMI), MPB funded full eco VRI phase 2. Data supplied from these measurements can also be used to adjust growth and yield models in the future.

Satellite remote sensing also offers a number of increasingly practical options for monitoring ecosystem productivity (for example, using the Normalized Difference

Vegetation Index (NDVI) obtained using Advanced Very High Resolution Radiometer (AVHRR) equipment on the NOAA satellites).

Potential data sources

Forest Analysis and Inventory Branch (FAIB): FAIB is currently in the process of exploring options to adapt the National Forest Inventory and the Vegetation Resources Inventory to support climate change monitoring. Proposed changes include a doubling of the number of National Forest Inventory ground plots to enhance biomass and understory data.

Cost/benefit of monitoring

Monitoring the ecosystem productivity is considered to be highly important in light of climate change. While the cost of monitoring this indicator may potentially be high, costs could be lowered significantly by building synergies with primary data suppliers and adopting remote sensing techniques where appropriate.

Species diversity

Rationale for monitoring in light of climate change

Climate change is anticipated to provide both opportunity and pressure for BC's species. Opportunity may come in the form of increased potential habitats due to new climate regimes for some species that have restricted ranges. Pressure may come from factors such as reductions or alterations in ecosystems or habitats and invasive species moving into new ranges. Many different impacts and scenarios are possible, some of which may not yet be understood or realized. Impacts of climate change are also likely to be confounded by other anthropogenic processes such as land-use change and loss of habitat.

Suggested approach to monitoring

This indicator would examine trends in population, range and phenology information for species from a range of taxa and habitats. There is no single species or even group of species that will be an ideal indicator for determining the impacts of climate change on forests and rangelands. Consequently, workshop delegates proposed including information for the widest possible range of species in climate change monitoring and analysis. Using such an approach to monitoring species in this framework would allow the flexibility to include new research and analyses as they become available. It would also allow us to more readily target this potentially costly area of climate change monitoring to focus on species found within ecosystems or relying on habitats reported in time to be vulnerable. However, it requires a considerable level of expertise that may not be readily available.

Potential data sources

British Columbia Breeding Bird Atlas: Seven year project (launched in 2007) set up to measure distribution and relative abundance of birds in BC. The on-line breeding bird atlas database can be manipulated by the user to show trends in bird populations, ranges, and abundance, all of which could be used to monitor changes in bird distribution and abundance in BC. Although a cause-and-effect relationship cannot be established with these data alone, the information can be tied with other data sources to further scientific understanding of the vulnerabilities of birds to climate changes.

British Columbia Conservation Data Centre systematically collates and disseminates information on plants, animals, fish and ecosystems (ecological communities) at risk in BC. This information is compiled and maintained in a computerized database which provides a centralized source of information on the status, locations and level of protection of these organisms and ecosystems. This information is being used by MOE to prioritize species and ecosystems of conservation concern through the Provincial Conservation Framework. Due to the Species at Risk Act, listed species with recovery plans will likely receive higher priority for funding and monitoring with regard to population trends.

Canadian Community Monitoring Network (CCMN): Indicators include worms and organic matter decomposition for soil health, benthic diversity for water quality, lichens for air quality, tree crown condition and seedling regeneration for vegetation, frog and salamander species richness for forests and wetlands, lake and river ice formation and thaw and the flowering of plants for climate variability. As more resources are directed towards monitoring, CCMN plans to expand to parks and protected areas.

Environment Canada's Ecological Monitoring and Assessment Network (EMAN) is responsible for reporting on the status and trends of ecosystems across Canada. It has partnered with the International Long-term Ecological Research Network (ILTER) and facilitates collaboration of ecological monitoring efforts across governments, communities, academic establishments, non-governmental organizations, student groups, volunteer groups and anyone else involved in ecological monitoring. In 2001, EMAN partnered with Nature Canada to engage in the Canadian Community Monitoring Network (CCMN).

Forest and Range Evaluation Program (FREP) has a number of research and monitoring programs of relevance to this indicator. The most pertinent activities are those currently being conducted by the Wildlife Resource Value Team which addresses the conservation of wildlife habitat.

MOE Fisheries Inventory Data Queries (FIDQ) provides access to the Fisheries Data Warehouse which contains information on fish species and their habitats that is of importance to assessment of this indicator.

NatureCounts: This website and database managed by Bird Studies Canada collates natural inventory and monitoring data for birds, amphibians, reptiles and bats. Examples of bird programs feeding into the database include the Marsh Monitoring Program (MMP), BC-Yukon Nocturnal Owl Survey, and the Canadian Migration Monitoring Network.

Nature Watch: Citizen-science monitoring coordinated by EMAN and Nature Canada. Programs include FrogWatch, WormWatch, IceWatch and PlantWatch. Programs in the development stage include lichens, tree health and benthic macro-invertebrates.

National Forest Inventory BC (NFI-BC): The NFI-BC involves two separate sets of permanent plots: one a set of photo plots and the other a set of ground plots. It is anticipated that NFI-BC would be able to provide data on species from both of these plot types.

Provincial Conservation Framework developed by the MOE in collaboration with other scientists, conservation organizations, industry and government provides a set of science-based tools and actions for conserving species and ecosystems in BC.

Species Inventory (SPI) is a provincial dataset comprised of wildlife inventory data collected during surveys undertaken to determine the presence or absence; relative abundance or absolute abundance of any wildlife species. In this dataset, wildlife species include all vertebrates except fish (i.e. mammals, birds, amphibians, and reptiles), some invertebrates (arthropods) and macrofungi found in BC. Some of the data contained in the dataset is sensitive and requires special permission to access.

Cost/benefit of monitoring

Monitoring trends in population, range and phenology information for forest and rangeland species is considered very important for the monitoring framework. The approach suggested offers a low cost way to monitor this indicator as it is based entirely on analyzing and interpreting data that is already collected rather than conducting additional field based research programs. Despite the number of data sources listed it is highly likely that there will be considerable difficulty reporting detailed trend information for the vast majority of species (including even those that are considered iconic to BC). At the expert workshop, it was emphasized by both Ministry of Forests, Land and Natural Resource Operations and MOE research staff that the monitoring of individual species would be seriously compromised by the inadequacy of current data sets in BC.

Genetic diversity

Rationale for monitoring in light of climate change

Species are prone to increased risk of extinction when a significant proportion of their genetic diversity is lost. Such loss usually results from factors such as habitat reduction and fragmentation, reduced population levels, pests and disease infestations, and restrictions and/or shifts in former range (all threats which will potentially increase with anticipated climatic changes). Populations and individual species that have been affected by these factors can lose some of their genetic diversity, which may in turn result in decreased resilience and ability to adapt to future environmental changes.

Suggested approach to monitoring

This indicator examines trends in the distribution, composition, and structure of forest and range genotypes (the internally coded inheritable information carried by all living organisms). Monitoring under this indicator could start with the development of a list of forest and rangeland species and populations considered to be at risk from isolation and loss of genetic variation. To the extent practicable, this information would need to be supported using baseline data on genetic diversity (stand and landscape level), including genetic composition (spatio-temporal distribution); and quantitative information from direct measures of changes (e.g., rate/direction of loss) in genetic variation. Analysis may also include monitoring the application of formal measures to mitigate declines in genetic variation such as in situ and ex situ conservation programs and assisted migration (moving species/genetic provenances outside their range).

Potential data sources

Centre for Forest Conservation Genetics (CFCG): The CFCG has a mandate to (1) study population genetic structure of forest trees using existing or new data; (2) assess the current degree of gene conservation both in situ in existing reserves and ex situ in collections, and the need for additional protection (although this is moving to Ministry of Forests, Land and Natural Resource Operations in the future); and (3) evaluate the current degree of maintenance of genetic diversity in breeding and deployment populations of improved varieties to meet current and future environmental challenges.

Ministry of Forests, Land and Natural Resource Operations Research Branch, Forest Genetics Section undertakes both theoretical research (quantitative genetics, climate-based seed transfer systems) and the practical applications of forest tree genecology, tree breeding and genetic conservation activities.

Ministry of Forests, Land and Natural Resource Operations Tree Improvement Branch, Headquarters Unit undertakes policy development and analysis; risk, impact and vulnerability assessments; criteria and indicator sustainable forest management reporting (CCFM, State of the Forest); evaluation and monitoring; and decision support. This unit is also responsible for the support of genetic resource conservation and management (GRM) spatial and non-spatial data sets, map products and information management systems, including the Seed Planning and Registry system, SeedMap, and GRM linkages to other corporate information management systems (RESULTS, MapView). Responsibilities include the development and support of GRM baseline data for the evaluation and monitoring of genetic diversity indicators and measures including seed selection, use and deployment. Climate change performance measures are also being developed to support climate-based GRM policy and practices (seed transfer).

Cost/benefit of monitoring

While not considered to be as critical as Indicators 1 and 2, an assessment of genetic level diversity was deemed worthwhile for climate change analysis, especially if costs could be reduced by creating strong linkages with existing programs examining the state of genetic resources in BC. We note that technologies in this field are advancing rapidly and the type of monitoring considered even five years ago as cost-prohibitive is now feasible.

Ecosystem connectivity

Rationale for monitoring in light of climate change

This indicator examines the level of connectivity between forest and range ecosystems, both terrestrial and aquatic. Connectivity comprises the dispersion pattern of patches within the landscape. Significant distances from one patch to the next have been clearly shown to interfere with pollination, seed dispersal, wildlife migration and breeding. Forecasts show that in order to adapt to climate change some species may need to migrate (northward and to higher altitudes), hence, ensuring the connectivity of both terrestrial and aquatic environments that will allow for such migration may become increasingly important. We recommend that the fragmentation of freshwater ecosystems is also monitored under this indicator. Both natural and artificial barriers may inhibit fish passage and changes in streamflow and temperature associated with climate change may interact with such barriers to affect freshwater ecosystems. It may also become more important to monitor the effects of natural causes of changes in connectivity (e.g., fire and landslides) as the frequency of these events may increase as a result of climatic changes.

Suggested approach to monitoring

While a Province wide analysis of trends in ecosystem connectivity would be the goal for reporting under this indicator it may be prudent to develop and test methods for monitoring ecosystem connectivity on a regional, ecosystem or case study basis initially. Modelling scenarios and in time data collected under Indicators 1, 2 and 3 should be widely adopted to inform and target the areas or ecosystems for which this analysis is most appropriate (e.g., habitat for vulnerable species and ecosystems).

Potential data sources

Data sources listed for Indicators 1, 2 and 3 above would be used in the analysis and targeting of this indicator. In addition to these sources, data collected by the following organizations is also of potential relevance:

British Columbia Parks is responsible for the stewardship of crown-owned protected areas in BC including Provincial Parks, ecological reserves, and conservation lands. This information along with that from Parks Canada may be used to determine intact natural areas.

Forest and Range Evaluation Program (FREP): The FREP Biodiversity team is currently monitoring stand level biodiversity and is in the process of developing an approach for landscape level biodiversity monitoring to determine if the present policy of retaining wildlife tree patches and riparian reserves is achieving the desired levels and types of structures to maintain species diversity. The FREP Fish/Riparian team is examining the extent to which interconnectivity of aquatic ecosystems and fish habitats within drainage basins is being maintained.

Fisheries and Oceans Canada - Habitat and Enhancement Branch produces regular reports dealing with species regions (e.g., the lower mainland). They in turn rely on information derived from a range of sources, including their own staff, MOE, municipal staff and private organizations (such as Streamkeepers' associations, fish and game clubs, river management societies, etc.). Some local groups are particularly well organized and could be drawn on for detailed information: examples include the Alouette River Management Society and the Pitt River & Area Watershed Network.

Parks Canada, the agency responsible for the stewardship of national parks collects a range of data related to the ecological integrity of these areas which may prove useful for supporting analysis of this indicator.

Hectares BC is a collaborative project created under the Biodiversity BC partnership. The purpose is to improve access to summarized, integrated, geospatial data about BC for the interest and information of any interested party. Available data is from a number of sources and is easy to query.

Cost/benefit of monitoring

This indicator is currently seen as being of high importance to the monitoring framework. Costs of monitoring could be reduced by conducting spatial analysis on existing information and data compiled under Indicator 1, by targeting analysis through the use of climate change models and through the adoption of remotely sensed data.

INDICATORS RELATING TO FOREST DISTURBANCE

Insects and diseases

Rationale for monitoring in light of climate change

Insects have been identified as important for monitoring in light of climate change primarily because their short generation times, rapid abundant reproduction, and potentially high mobility make them able to adapt quickly to changing climatic conditions. Pathogens such as foliar disease have been identified as important for monitoring as the occurrence and impact of many are likely to increase where warmer and wetter environments are predicted. There are a number of examples from British Columbia of insects and pathogens that are already affecting forest health as a result of the climatic changes that have taken place (for example, Mountain Pine Beetle and Dothistroma Needle Blight). It is likely that the impacts of these agents will increase as the climate continues to change. There is also a high likelihood that insects or diseases that are not currently considered pests will emerge rapidly to pose a serious threat to forest health.

Suggested approach to monitoring

This indicator would report on the scale and severity of insects and pathogens adversely affecting forest and rangeland health. If utilising only currently collected data, this indicator would be monitored using Province-wide aerial surveys. However, this method is only able to identify insect and pathogen outbreak occurrences at a medium to large scale and in order to be truly useful to management, finer scale monitoring is needed to collect data that will enable early warning of insect and pest outbreaks and allow for early and aggressive intervention to delay and possibly mitigate impacts. Such finer scale monitoring would include: surveys, trapping and local analysis of occurrences (to determine extent of damage/condition/ changes in species complexes) and the use of reference sites to determine current conditions as a baseline.

Potential data sources

Ministry of Forests, Land and Natural Resource Operations Forest Practices Branch has surveyed the majority of the forested land in the Province using aerial survey since 1999 resulting in the production of an annual report summarizing forest health conditions and digitized maps and tables describing pest conditions by region and district.

Finer scale insect and pathogen monitoring is conducted in various areas throughout the Province although these studies are localized and the results are not routinely collated or standardized by the Ministry of Forests, Land and Natural Resource Operations.

Some historic data are available from the former Forest and Insects Disease Survey (FIDS) of the Canadian Forest Service, particularly in relation to its now discontinued ARNEWS plots. ARNEWS was primarily an eastern program so there were only 15 plots in BC. Twelve of these were located on Vancouver Island, the Lower Mainland or close to the US border, with the remaining three being at Terrace, Prince George and Quesnel. While some insect and disease monitoring is still undertaken by the CFS, it is very limited and unlikely to be of much use (in its current form) to the proposed program.

Cost/benefit of monitoring

Monitoring the scale and impact of pests and diseases adversely affecting forest and rangeland health is seen as being highly important for the monitoring framework. While the cost of finer scale monitoring is potentially high there may be opportunities for creating synergies with proposed increases in field based monitoring programs reported under indicator 1.

Wind throw

Rationale for monitoring in light of climate change

Increases in the intensity, frequency and severity of stormy weather predicted as a result of climate change is likely to result in increased scale and severity of wind throw damage to forests. Northern Vancouver Island, areas of the Central BC coast and parts of the Queen Charlotte Islands are likely to be most susceptible to these disturbances. Forests may also become increasingly susceptible to wind damage if stressed by other climate change related factors such as destabilizing soils (occurring from increased precipitation) and pest incursions.

Suggested approach to monitoring

This indicator reports on the scale and severity of wind throw damage affecting forests. It should be monitored using Province wide aerial surveys to record medium to large scale damage resulting from wind throw. This information should be supplemented where possible with information collected on a regional basis especially for those areas expected to experience increases in the intensity, frequency and severity of storms or suffering from other stressors thought to be climate related.

Potential data sources

Ministry of Forests, Land and Natural Resource Operations Forest Practices Branch has surveyed the majority of the forested land in the Province using aerial survey since 1999 resulting in the production of an annual report summarizing forest health conditions and digitized maps and tables by region and district.

Forest and Range Evaluation Program (FREP) has a cutblock level wind throw monitoring protocol and a review is underway of all FREP protocols to see how best to integrate wind throw monitoring on sites visited for other resource value monitoring.

Cost/benefit of monitoring

This indicator is currently seen as being of moderate importance to the monitoring framework. It is likely that current aerial surveys conducted will be able to provide adequate information to support a reasonable analysis and interpretation of the indicator.

Fire season

Rationale for monitoring in light of climate change

Climate change models project an increase in the number of fires and area burnt by fires across western Canada. This includes an increase in the number of fires ignited by lightning and an extension to the fire season length. Southern and central parts of BC are expected to experience drier summers thereby potentially increasing the frequency, severity and intensity of fires. Northern areas, which are predicted to be wetter, may experience a decrease in fire disturbance. Alterations in the fire regime will affect ecosystem transitions, the assemblages of species and their productive capacity.

Suggested approach to monitoring

The annual length of the fire season should be reported Province wide by region using the date of the first and last reported fire. The seasonal severity of the fire should also be captured using the seasonal severity ratings determined by the Ministry of Forests, Land and Natural Resource Operations Wildfire Management Branch.

Potential data sources

Ministry of Forests, Land and Natural Resource Operations Wildfire Management Branch reports annually and collects data on the number of fires, areas affected by fire and the cause (lightening or humans) of fires. This Branch also calculates a seasonal severity rating based on information from the Canadian Forest Fire Danger Rating System.

Cost/benefit of monitoring

This indicator is currently seen as being of moderate importance to the monitoring framework and it is anticipated that the data sources listed will be able to supply adequate data to support reasonable analysis and interpretation of the indicator keeping the costs of monitoring and analysis fairly low.

Mass movements

Rationale for monitoring in light of climate change

The frequency and extent of rapid mass movements are influenced by precipitation amount and intensity; snow accumulation, melt rate, and distribution; and roads and other land uses. Alterations in these factors as a result of climate changes may result in variations in the magnitude and frequency of mass movements adversely affecting forest health. Vegetation also influences the likelihood of mass movements through the soil-stabilizing effects of root systems and the effects of vegetation structure and composition on hydrology. Hence changes in vegetation type and condition such as that caused by exacerbated pest or wind damage may further increase the frequency of mass movements and erosion events.

Suggested approach to monitoring

This indicator examines the scale and density of mass movements and erosion events (landslides, rockfalls, debris torrents, debris avalanches, debris flows, etc.). Province-wide aerial surveys or remotely sensed data should be used to record mass movements and erosion events over a certain size. This information should be supplemented where possible with information collected on a regional basis in order to aid interpretation and gain some understanding of mass movement events occurring under forest canopy.

Potential data sources

We were unable to find evidence of systematic programs directed at monitoring mass movement frequency and extent. Some studies have previously been done by the MOE in areas on Vancouver Island and the Queen Charlotte Islands.

Some transportation corridors maintain records of disruption although these have not been traditionally used for monitoring. For example, geotechnical investigations have been undertaken for the Sea-to-Sky Highway. Similar records may be available for the Trans-Canada Highway and for the various rail tracks crossing BC.

Information on mass movement events that disrupt forest roads was a reporting requirement under the Forest Practices Code but is no longer required. Some Districts, and some licensees, continue to report such disturbances, but the information not collected systematically across the Province.

Forest and Range Evaluation Program (FREP) is in the process of developing the methodology to conduct a pilot study to examine the terrain stability at the landscape level. The approach offers considerable potential for supporting this indicator and is expected to begin within the next year.

Cost/benefit of monitoring

Mass movement was seen as reasonably important for monitoring in light of climate change although data to support monitoring of the indicator on anything but a small case study basis is not currently available, making its analysis potentially costly.

INDICATORS RELATED TO ECOSYSTEM DRIVERS

Precipitation

Rationale for monitoring in light of climate change

Precipitation rates, timing and form are anticipated to change as a result of climatic change. Predictions show a shift to warmer, wetter years, more frequent wet years, greater year-to-year variability, and more extreme precipitation events as well as a change in the form precipitation takes, with more precipitation falling as rain and less falling as snow during the cold season. Such changes will almost certainly have significant effects on forest and rangeland ecosystems. Monitoring these changes and their nature will be important for informing future forest and range management decisions.

Suggested approach to monitoring

This indicator should monitor precipitation rates, timing and forms within forest and rangeland catchments, reporting information Province wide (by region) using data from as many climate stations as practicable. To the extent possible monitoring of water related indicators should be coordinated within a complementary network (i.e. measurements for all should be taken from similar locations or catchments) in order to aid the interpretation of the results.

Potential data sources

Environment Canada Climate Network for British Columbia and Yukon operates a network of approximately 500 climate stations in BC and the Yukon and maintains an associated archive of historical weather information. At 350 of these stations daily measurements of temperature and precipitation are taken.

BC Hydro's Regional Hydromet Data networks collect near real-time hydrometeorological data at various automated data collection stations in or near their reservoir systems across the Province to support reservoir operations. Major types of hydrometeorological data collected include precipitation, air temperature, lake levels, stream levels/flows and snow water equivalents.

Provincial Climate Related Monitoring Network Initiative is a relatively new joint project to expand BC's hydrometric and other climate-related networks to improve the Province’s ability to monitor, predict and adapt to changing climatic conditions that pose new threats for human health, safety and property, such as risks of flooding, storm surges, wildfire and drought. In the first 2 years of the project the goal is to identify and evaluate the existing provincial Climate Related Networks (CRNs) operated by MoTI, Ministry of Forests, Land and Natural Resource Operations and MOE to ensure that core climate data are collected on a year round basis and to advise on needed upgrades.

MOE River Forecast Centre is the lead agency in the Province responsible for the collection, quality control, analysis and archiving of snow data. Manually sampled snow survey data are collected from almost 200 sites around the Province while remotely sensed snow and meteorological data from Automatic Snow Pillows, transmitted via satellite, are collected at over 50 sites around the Province.

Cost/benefit of monitoring

This indicator is regarded as highly important, if not critical, for monitoring in light of climate change. It also provides context for the interpretation of many of the other indicators identified. While a number of potentially valuable data sources have been listed for this indicator, the current network of monitoring sites has been publically recognised as having a strong bias towards lower and more populated latitudes and elevations. Forest and range experts have also indicated that these existing monitoring stations are unlikely to be in areas identified as being particularly sensitive to climate changes (including higher elevations and transient snow zones) and are unlikely to be able to capture information on the various forms of precipitation adequately. The Environment Canada Climate Network has also been reported as being in decline, the extent of this decline is not yet known.

Snowpack

Rationale for monitoring in light of climate change

Snow accumulation and its characteristics are the result of air temperature, precipitation, storm frequency, wind, and the amount of moisture in the atmosphere. Changes in these and other climate properties will therefore affect snowpack. Reduced snowpack is anticipated and the snowline in mountainous areas is forecasted to rise in elevation. Changes in the timing of the development and loss of the snowpack are rather uncertain but could have considerable effects on forest ecosystem processes, as has been shown for snowpack variations associated with the Pacific Decadal Oscillation.

Suggested approach to monitoring

Snowfall depth should be reported Province wide (by region) using data from as many climate stations as practicable. To the extent possible monitoring of water related indicators should be coordinated within a complementary network (i.e. measurements for all should be taken from similar locations or catchments) in order to aid the interpretation of the results.

Potential data sources

MOE River Forecast Centre is the lead agency in the Province responsible for the collection, quality control, analysis and archiving of snow data. Manually sampled snow survey data are collected from almost 200 sites around the Province while remotely sensed snow and meteorologic data from Automatic Snow Pillows, transmitted via satellite, are collected at over 50 sites around the Province.

Cost/benefit of monitoring

Extent of snowpack is currently seen as being of moderate importance to the monitoring framework. At the expert workshop, River Forecast Centre staff anticipated that the organization would be able to supply adequate data on snow depth to support a reasonable analysis and interpretation of the indicator.

Streamflow

Rationale for monitoring in light of climate change

Predicted lower flows in summer and later in the season may reduce the amount of water available to forest and range ecosystems. These lower flows are also associated with warmer water temperatures and declining water quality, both of which threaten the health of aquatic ecosystems (an issue which may be further exacerbated when water is drawn for human use). Increased storms and precipitation amounts predicted as a result of climate changes may result in higher-than-usual water volume and velocity for winter months in some regions, potentially leading to increased river turbulence, scouring, and reduced in-stream channel stability (although these effects will depend on the nature of the hydrological system such as whether it is rain or snowmelt dominated).

Suggested approach to monitoring

Streamflow should be reported Province wide (by region) using data from as many monitoring stations as practicable. To the extent possible monitoring of water related indicators should be coordinated within a complementary network (i.e. measurements for all should be taken from similar locations or catchments) in order to aid the interpretation of the results.

Potential data sources

Environment Canada Water Survey collects hydrometric data including water level and streamflow statistics for a variety of sites throughout the Province. This network is funded through a cost share program between the BC and Federal governments. The network was in decline for many years and by the late 1990s had been reduced by over 40 per cent. In the last decade, substantial funding was committed to rebuilding the network (especially for climate change analysis purposes) although the current fiscal environment has made this commitment again uncertain.

BC Hydro's Regional Hydromet Data networks collect near real-time hydrometeorological data at various automated data collection stations in or near their reservoir systems across the Province to support reservoir operations. Major types of hydrometeorological data collected include precipitation, air temperature, lake levels, stream levels/flows and snow water equivalents.

Cost/benefit of monitoring

This indicator is regarded as highly important for monitoring in light of climate change. Although further assessment is required, forest and range experts have indicated that the existing network of monitoring sites is inadequate and is likely to not only have a bias towards streams found in lower more populated latitudes and elevations but also towards larger rivers, leaving smaller streams, considered of critical importance to forest and range ecosystems, likely to be underrepresented in the network.

Water temperature

Rationale for monitoring in light of climate change

Increased water temperatures are predicted as a result of climate changes especially in northern areas. Warmer temperatures are expected to affect the fitness, survival, and reproductive success of certain fish and other aquatic species. Over the long term, higher temperatures may result in a shift in the distribution of cold-water species to higher latitudes and elevations. However, if other factors such as habitat discontinuities were to limit these range shifts, an overall reduction in the distribution of certain species would be the result. By contrast, river warming may have positive consequences for aquatic species that prefer (or can tolerate) warmer water temperatures. Native warm-water species may be able to expand their range into higher-altitude lakes and more northerly regions. Warmer temperatures may also allow invasive or exotic species to expand in range.

Suggested approach to monitoring

Water temperature should be reported Province wide (by region) using data from as many monitoring stations as practicable. To the extent possible monitoring of water related indicators should be coordinated within a complementary network (i.e. measurements for all should be taken from similar locations or catchments) in order to aid the interpretation of the results.

Potential data sources

MOE River Forecast Centre conducts some water temperature monitoring although there is currently no systematic, continuous collection program in place.

MOE Water Stewardship Division Sciences and Information Branch is currently conducting research into how water temperature monitoring can be improved (specifically for climate change analysis) although it is not yet known if this program will receive funding to continue in the next financial year.

BC Hydro's Regional Hydromet Data networks collect near real-time hydrometeorological data at various automated data collection stations in or near our reservoir systems across the Province to support reservoir operations. Major types of hydrometeorological data collected include precipitation, air temperature, lake levels, stream levels/flows and snow water equivalents however water temperature is only measured at some locations.

Cost/benefit of monitoring

This indicator is regarded as highly important for monitoring in light of climate change. We were unable to find evidence of any systematic programs that contain the necessary data required for supporting the indicator, thus, it is likely that the existing monitoring network would need to be bolstered to support a reasonable analysis of this indicator.

Water quality

Rationale for monitoring in light of climate change

Climate driven changes to hydrological systems are likely to cause changes in the physical, chemical and biological characteristics of water in forest and rangeland streams and lakes. Such changes are likely to have significant impacts on freshwater and estuarine ecosystems and aquatic species found within forests and rangelands and may also have some impact on the quality of water available for human use.

Suggested approach to monitoring

MOE Water Stewardship Division Science and Information Branch is currently conducting a detailed literature review that may be used to further inform the development of an approach to monitoring water quality in light of climate change. Although further work is required, based on preliminary assessment it appears that monitoring levels of dissolved organic content (DOC) may have potential.

Potential data sources

Forest and Range Evaluation Program (FREP) has data on fine sediment generation potential for 540 sites across the Province. In 2008, evaluations were undertaken in watersheds with recognized fish values and/or community watersheds. This assessment also included an additional rating that considered the size of the stream.

MOE Environmental Protection Division reports on water quality in the Province although this reporting is biased to a view of water quality in developed areas, rather than for undeveloped watersheds where hydrological systems are in a more natural state.

MOE Water Stewardship Division Science and Information Branch: As mentioned above, this branch is currently conducting research into the effects of climate change on water quality. It is likely that this work will result in an assessment of the adequacy of the existing monitoring network leading to some further recommendations regarding water quality monitoring in light of climate change.

Cost/benefit of monitoring

This indicator is regarded as moderately important for monitoring in light of climate change. While further research (including that currently being conducted by MOE) is needed to assess the extent to which the indicator can be supported by existing data sources, forest and range experts have indicated that there are enough data being collected to support at least a partial examination of the indicator.

Glaciers

Rationale for monitoring in light of climate change

Glacier retreat may cause changes in the flow patterns and possibly the temperature of some forest and rangeland streams and rivers. These changes, along with other climate-driven changes to hydrological systems, are likely to have significant impacts on freshwater and estuarine ecosystems and aquatic species. In the short term, melting glaciers will likely discharge more water into some BC streams and rivers potentially increasing stream turbidity and damaging fish habitat and riparian areas. In the longer term, glacier retreat will likely mean reduced water volume in glacier-fed streams and rivers, especially during the summer months potentially, exacerbating changes in stream flow and temperature.

Suggested approach to monitoring

The spatial distribution of glaciers should be monitored using either aerial surveys or remotely sensed data to record changes over time. Information should be interpreted in the context of data coming from the water related indicators described above.

Potential data sources

Canadian Glacier Information Centre (CGIC) currently controls data and literature about Canadian glaciers. The principal collection element is the Canadian Glacier Inventory, a printed and electronic catalogue of Canada's glaciers, complemented by an air photo collection.

Canadian Cryospheric Information Network (CCIN) has been developed as a collaborative partnership between the Federal Government (Canadian Space Agency, Meteorological Service of Canada, Natural Resources Canada), University of

Waterloo and the private sector (Noetix Research Inc.) to provide the data and information management infrastructure for the Canadian cryospheric community.

Western Canadian Cryospheric Network is a consortium of six Canadian universities, two American universities and government and private scientists who are examining the links between climatic change and glacier fluctuations in western Canada.

Cost/benefit of monitoring

This indicator is regarded as moderately important for monitoring in light of climate change. Data sources are likely to be able to support a reasonable analysis of the indicator. Costs of monitoring this indicator may be reduced through the adoption of remotely sensed data.

Unseasonable or unexpected weather conditions

Rationale for monitoring in light of climate change

During periods of climate adjustment there is a strong likelihood of unseasonable or unexpected weather. This may include late or early frosts, extreme snowfalls, ice storms, hail, droughts and other weather-related events. Many of these can have major impacts on forests and rangelands.

Suggested approach to monitoring

Reporting under this indicator should include an examination of the frequency and intensity of unseasonable or unexpected weather events over long time periods to see how the current decade compares with those of the past.

Potential data sources

Environment Canada Climate Network for British Columbia and Yukon operates a network of approximately 500 climate stations in BC and the Yukon and maintains an associated archive of historical weather information.

Environment Canada's Meteorological Service of Canada (MSC) monitors and collects data on severe weather conditions, such as hurricanes, tornadoes, severe thunderstorms, storm surges, strong winds, high heat or humidity, heavy rain or snow, blizzards, freezing rain and extreme cold.

Ministry of Forests, Land and Natural Resource Operations Wildfire Management Branch reports annually on specific events although is not set up to report on ‘diffuse’ events such as droughts.

Pacific Climate Impacts Consortium (PCIC) produces climate information to inform adaptation in both operational activities and long term planning in order to reduce vulnerability to climate variability, climate change, and extreme weather events. They produce a wide spectrum of key data about past, current and future climate and weather events that may be used to inform this indicator.

Cost/benefit of monitoring

This indicator is currently seen as being of moderate importance to the monitoring framework and it is anticipated that the data sources listed will be able to supply adequate data to support reasonable analysis and interpretation of the indicator. The costs of monitoring and analysis should thus be fairly low.