### INFORMING AND SUPPORTING CLIMATE CHANGE ADAPTATION IN BRITISH COLUMBIA'S FORESTS THROUGH MONITORING

by

Margaret Maree Eddington

### A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

### THE REQUIREMENTS FOR THE DEGREE OF

### DOCTOR OF PHILOSOPHY

in

The Faculty of Graduate Studies and Postdoctoral Studies

(Forestry)

### THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

January 2014

©Margaret Maree Eddington 2014

### Abstract

Given the large uncertainties associated with climate change, regular and systematic measurement of various aspects of the natural environment is the primary means for understanding what changes are actually taking place. This research is focused on the development of a strategy for monitoring the biophysical attributes of British Columbia's forest and rangelands in order to supply the information needed to bring climate change adaptation considerations into decision-making in the Province.

A framework of indicators for monitoring the impacts of climate change was developed through iterative, bottom-up processes involving both expert and end-user participation. The former involved interviews with key experts and an indicator development workshop attended by 58 delegates from across the Province. The latter involved a web-based survey designed to better identify the indicator framework's target audience as well as their key information needs and management questions with regard to climate change adaptation. The resultant framework identifies seventeen indicators of varying importance for monitoring in light of climate change.

I developed approaches to measuring some of the indicators and analyzed the capacity of current monitoring and inventory programs to support their evaluation. Where possible, the data available to support the indicators was tested in south-eastern British Columbia. This was designed to assess the capacity of the existing data sources to meet decision makers' climate change adaptation needs. The results of these tests showed that, while there are some relatively good data sources that can be used to support climate change adaptation in forests and rangelands, there are some indicators for which there is a paucity of data.

Through this research I have been successful in developing a solid foundation for increasing the information available to incorporate climate change adaptation considerations into British Columbia's forest and range management. My research also

offers an example to other sectors, countries and regions who are seeking to use their data to track climate change and better understand its impacts.

### Preface

This dissertation is original, unpublished, independent work by the author, Margaret Eddington.

### **Table of Contents**

Abstra	ct	ii		
Preface		iv		
Table of Contentsv   List of Tables				
Acknow	vledgements	xi		
Chapte	r 1 - Introduction	1		
1.1	CONTEXT	1		
1.2	RESEARCH OBJECTIVE AND QUESTIONS			
1.3	RESEARCH HYPOTHESES			
1.3	RESEARCH ASSUMPTIONS			
1.4	STUDY DESIGN			
Chapte	r 2 - Examples of environmental monitoring efforts	17		
2.1	INTRODUCTION			
2.2	EXAMPLES OF ECOLOGICAL MONITORING PROGRAMS			
2.5	DISCUSSION			
2.6	CONCLUSION			
Chapte	r 3 - Determining a key set of biophysical indicators for monitor	ing the effects		
of clima	ate change on British Columbia's forests and rangelands			
3.1	INTRODUCTION			
3.2	METHOD			
3.3	RESULTS	50		
3.4	DISCUSSION			
3.5	CONCLUSION			

Chapter 4 - Climate change adaptation monitoring and reporting information needs		
of forest	and range managers	78
4.1	INTRODUCTION	78
4.2	METHODOLOGY	80
4.3	RESULTS	84
4.4	DISCUSSION	98
4.5	CONCLUSION	.01
Chapter	• 5 - Development of approaches to measuring selected indicators, examination	on
of the da	ata collections available and regional level nilot testing	02
or the ut		
5.1	INTRODUCTION 1	.02
5.2	TRACKING CHANGES IN ECOSYSTEM DISTRIBUTION AND COMPOSITION	
	105	
5.3	AN APPROACH FOR ANTICIPATING AND RESPONDING TO CLIMATE	
CHAN	IGE BY TRACKING CHANGES IN FOREST PRODUCTIVITY 1	.21
5.4	EXAMINING THE IMPACT OF CLIMATE CHANGE ON SPECIES LEVEL	
DIVE	RSITY 1	.26
5.5	EXAMINING ECOSYSTEM CONNECTIVITY IN THE CONTEXT OF CLIMATE	
CHAN	IGE1	.29
5.6	TRACKING CHANGES IN FIRE SEASON LENGTH AND SEVERITY 1	56
5.7	EXAMINING INSECTS AND DISEASES AFFECTING FOREST HEALTH IN THE	3
CONT	EXT OF CLIMATE CHANGE 1	.64
5.8	CONCLUSION 1	.66
Chapter	6 - Conclusion1	69
6.1	KEY FINDINGS 1	.69
6.2	STATUS OF RELEVANT WORKING HYPOTHESES 1	.73
6.3	SIGNIFICANCE AND POTENTIAL APPLICATION OF THIS RESEARCH 1	76
6.4	FUTURE RESEARCH AND DEVELOPMENT 1	.77
6.5	CONCLUDING COMMENTS 1	.79
Bibliogr	aphy1	81

<b>Appendix A – Examples of climate change monitoring frameworks</b>	
Appendix B – Workshop activities	
Appendix C - Forest and range managers' survey	
<b>Appendix D – Process for monitoring ecosystem distribution and composition</b>	ition 226

### List of Tables

Table 2.1 – S	Some of the core biophysical attributes monitored in the indicator frameworks
Table 3.1	Workshop discussion relating to biodiversity indicators
Table 3.2	Workshop discussion relating to forest disturbance indicators
Table 3.3	Workshop discussion relating to water indicators
Table 3.4	Workshop discussion relating to soil/ geomorphological processes indicators 49
Table 4.1 change	Topic areas' perceived importance for monitoring in relation to climate adaptation information needs
Table 4.2 88)	Frequency of use of various data sources by forest and range managers (n=
Table 5.1	Area of BEC variants per plot 117

### **List of Figures**

Figure 4.1	Survey respondent locations
Figure 4.2	Main climate change adaptation information needs of respondents
Figure 4.3	Changes made to the indicator framework as a result of the workshop. 100
Figure 5.1	The Southern Interior of British Columbia 104
Figure 5.2	NFI Plot 1335001 mapped using VRI and TEM to BEC variant level 111
Figure 5.3	NFI Plot 1348756 mapped using VRI and TEM to BEC variant level 112
Figure 5.4	NFI Plot 1355646 mapped using VRI and TEM to BEC variant level 113
Figure 5.5	NFI Plot 1376296 mapped using VRI and TEM to BEC variant level 114
Figure 5.6	NFI Plot 1396936 mapped using VRI and TEM to BEC variant level 115
Figure 5.7	NFI Plot 1486426 mapped using VRI and TEM to BEC variant level 116
Figure 5.8	BEC zone areas and number NFI ground plots 120
Figure 5.9 Tl	ne Thompson Okanagan Eco-regions132
Figure 5.10 regions	BEC zones excluded and of interest in the Thompson Okanagan Eco- 
Figure 5.11	BEC zones within the Thompson Okanagan Eco-regions 134
Figure 5.12	'Roadedness' within the Thompson Okanagan Eco-regions 136
Figure 5.13	Private land located within the Thompson Okanagan Eco-regions 138
Figure 5.14 Okanag	Projected change in area for the Bunchgrass zone in the Thompson an Eco-regions

Figure 5.15	Overlap between the predicted Bunchgrass areas of the four time slices. 143
Figure 5.16	Projected change in area for the Interior Cedar Hemlock zone in the
Thompson	Okanagan Eco-regions
Figure 5.17 time slices	Overlap between the predicted Interior Cedar Hemlock areas of the four 145
Figure 5.18	Projected change in area for the Interior Douglas-fir zone in the Thompson
Okanagan	Eco-regions
Figure 5.19	Overlap between the predicted Interior Douglas-fir areas of the four time
slices	
Figure 5.20	Projected change in area for the Ponderosa Pine zone in the Thompson
Okanagan	Eco-regions
Figure 5.21	Overlap between the predicted Ponderosa Pine areas of the four time slices
Figure 5.22	Projected change in area for the Engelmann Spruce Subalpine Fir zone in
the Thomp	oson Okanagan Eco-regions
Figure 5.23 of the four	Overlap between the predicted Engelmann Spruce Subalpine Fir zone areas time slices
Figure 5.22	Projected change in area for the Montane Spruce zone in the Thompson
Okanagan	Eco-regions
Figure 5.23 slices	Overlap between the predicted Montane Spruce zone areas of the three time

### Acknowledgements

I would like to acknowledge the contributions of my committee, John Innes, Howard Harshaw and Kathy Martin. Thank you for your patience, constructive feedback and encouragement over the years. Helpful suggestions, support and data were provided by Peter Bradford, Kathy Hopkins, Graham Hawkins and Dr Xiaoping Yuan from the Ministry of Forests, Lands and Natural Resource Operations; as well as by Alanya Smith and Victoria Stevens from within the Ministry of Environment. I would like to acknowledge the funding received from the Future Forest Ecosystems Scientific Council of British Columbia and the FRBC Chair of Forest Management. Finally, thank you to my husband for the ongoing support and encouragement.

### **Chapter 1 - Introduction**

#### 1.1 CONTEXT

Decades of research and data have confirmed that climate change is occurring and poses significant risks for (and in many cases is already affecting) a broad range of human and natural systems (IPCC 2007a, b; NRC 2010b; USGCRP 2009). In addition to a rise in average global temperatures, discernable changes have been observed: in day, night and seasonal temperatures; 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 2007c). 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; NRC 2010b; Solomon et al. 2009; Weaver et al. 2007). 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; Gayton 2008; Latta et al. 2010; Lemmen & Warren 2008; Millar et al. 2007; Parmesan & Yohe 2003; Williamson et al. 2009).

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

#### **1.1.1 Defining climate change**

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods" (UNFCCC 2012). The International Panel on Climate Change (IPCC), by contrast, defines climate change as "a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use" (IPCC 2007a). The UNFCCC definition is thus more restrictive and is focused only of changes in climate that result from greenhouse forcing of the climate system. The IPCC definition refers to climate change more broadly and not just as a result of humans. For the purposes of my thesis I use the broader definition of the IPCC which removes the difficulties of clearly defining and separating the impacts of human-caused climate change above the impacts of human-caused variability which the region already experiences (Pielke 2005).

# **1.1.2** Impacts of climate change on the forest and rangeland environment of British Columbia, Canada

All reported temperature trends show that British Columbia, Canada has warmed in recent decades (Whitfield et al. 2002; Zhang et al. 2000). Moreover, records suggest

that the rate of temperature change in some parts of British Columbia during the Twentieth Century exceeded the global average. When global climate model projections are applied to data for British Columbia, forecasts show that winter and summer temperatures are likely to continue to increase, with some regional disparities. Warming is likely to be greater in northern British Columbia than in southern British Columbia and greater in winter than in summer. The winter minimum temperature in northern British Columbia 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 analyses of precipitation records suggests that British Columbia 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 of the Province (Rodenhuis et al. 2009). Predictions by season suggest that conditions will be wetter over much of the Province during winter but drier during summer in the south and on the coast. In addition, changes are expected in the form that precipitation takes, with more precipitation falling as rain and less falling as snow during the winter (Spittlehouse 2008). Increased occurrences of extreme weather events have been documented worldwide and climate models project a continuing rise in their frequency (IPCC 2007b). As such, extreme weather and weather-related events such as droughts and storms are likely to become more commonplace in British Columbia with subsequent increases in the frequency and intensity of precipitation events, windstorms, forest fires and landslides.

These and other forecasted changes in climatic conditions are likely to affect the ecological processes in British Columbia's forests and rangelands significantly. The most notable and catastrophic changes 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%) of the Province's forests being affected to some degree. Other less conspicuous, but possibly no less threatening, changes are being recorded and/or predicted, such as alterations in species and ecosystem distribution (Hebda 1997; Nitschke & Innes 2008b), fire regimes (Flannigan et al. 2002; Nitschke &

Innes 2008a; Soja et al. 2007), species phenology (Bunnell et al. 2008) and overall forest productivity (Boisvenue & Running 2006; Williamson et al. 2009).

### 1.1.3 Adapting to climate change

The question of how to address climate change and its impacts is being debated in multiple for a 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 minimize the adverse impacts of climate change exposure. Both of these courses of action are needed to manage and lessen the risks from climate change and both are being pursued by a variety of organisations. 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 thinking, decisions and activities of observed or expected changes in climate, with the goal 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 & Barnett 2009; Burton et al. 2002; Smit & Pilifosova 2001).

There are a multitude of different approaches to, and information about, climate change adaptation in forests and the environment. Generally, these approaches operate at different temporal and spatial scales and levels of specificity (Aaheim et al. 2011; Innes et al. 2009; Klenk et al. 2011; Rodriguez-Calcerrada et al. 2011; Serengil et al. 2011). Trees are long-lived compared to many rangeland species, meaning that the climatic conditions may differ widely over their lifespan.

Adaptation options have also been classified as being either proactive or reactive. Reactive adaptation measures occur after damage has occurred or is occurring. They include approaches such as: salvage harvesting, 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, involve undertaking anticipatory interventions at different levels and across different sectors. Examples include the diversification of 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 recognized as being more likely to avoid or reduce damage than reactive options that are made after damage has occurred or is occurring (Easterling et al. 2004; Lemprière et al. 2008; Ohlson et al. 2005).

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 & Barnett 2009). This is a particular risk with longer-lived species such as trees. 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 in order to determine whether management options are providing the favourable outcomes intended or where increased management responses may be required (Adger & Barnett 2009; Rosenzweig & Wilbanks 2010).

### **1.1.4 Forest monitoring**

Monitoring is a widely used and ambiguous term when applied in an environmental management context. It is used at a variety of geographical scales in reference to a vast array of activities (Bunnell 2009). One 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. They include:

- Implementation monitoring: 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 & Cooperrider 1994).

In discussing the monitoring of forest biodiversity, Gardner (2010) adds to these categories 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. He specifically comments 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).

My research focuses on surveillance monitoring as it is particularly well-suited to better understanding the effects of climate change on the forest and range 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" (p. 2). It also fits with the approach of 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.

The monitoring being discussed here differs from the monitoring associated with adaptive management. Adaptive management is effectively learning from doing; learning comes through the implementation of policies and strategies, so adaptive management complements research-based learning in order to ascertain which actions are most likely to best reach the stated objectives (Lee 1994; Lindenmayer 2009; McFadden et al. 2011). Monitoring the impacts of climate change refers to the planned observation 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 to three broad categories based on the impetus 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 coarse-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. The authors note that question-driven programs can provide better insights about the mechanisms or ecological processes giving rise to the emergent patterns.

# **1.1.5** Using existing forest monitoring undertaken through sustainable forest management to anticipate and respond to climate change

During the last several decades, forest managers have largely relied on sustainable forest management paradigms to set goals and inform forest management decisions. The concept of sustainable forest management is founded on the management of forests according to principles of sustainable development popularised through the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992. It refers to the stewardship and use of forests and forest lands in ways, and at rates that maintain their biodiversity, productivity, regenerative capacity and vitality (Anon 2003; FAO 2005). Sustainable forest management uses very broad social, economic and environmental goals. Monitoring is a key component of sustainable forest management 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 sustainable forest management is firmly entrenched in both British Columbian and Canadian forest management objectives (Bridge et al. 2005; CCFM 2006; Hickey & Innes 2008; Innes 2003; MFR 2006). For example, British Columbia's ongoing commitment to sustainable forest management is demonstrated through the production of its 'State of the Forest' report which is designed to assess forest resources every five years in order to determine the extent to which management practices are sustainable (MFR 2010).

When considering the goal of sustainable forest management, forest managers may assume that by restoring and maintaining historical conditions they are maximizing the chance of maintaining an ecosystem's sustainability into the future (Millar et al. 2007). However, as global and regional climates are pushed beyond the bounds of the last several centuries (IPCC 2007c), the applicability of forest management that focuses on the maintenance or restoration of 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 (Anon 2008a; 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 adaptation goals and needs (CCFM 2008; Ogden 2008; Spittlehouse & Stewart 2003; UNFF 2007). At the Canadian national level, sustainable forest management 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 in 2008 the CCFM noted that "consideration of climate change and future climatic variability is needed in all aspects of sustainable forest management" (CCFM 2008) (p.9). Further efforts to incorporate climate change adaptation into sustainable forest management at the national level ensued and are demonstrated by the recent production of the report 'Adapting Sustainable Forest Management to Climate Change: Preparing for the Future' (CCFM 2012). 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 sustainable forest management. This suggests that the criteria for the

conservation and sustainable management of boreal forests may be suitable objectives against which the performance of adaptation options can be assessed. Despite the recognized information needs and the connections that have been drawn between climate change adaptation and sustainable forest management, more detailed work is required to better incorporate climate change considerations into the actual monitoring of sustainable forest management on the ground.

Both the Canadian and British Columbia Governments have been working for approximately three decades to develop data sources and inventory programs for monitoring and reporting on sustainable forest management (CCFM 2006; MFR 2006; NFI 2010; VRI 2010). While these programs have not been designed with climate change in mind, they do contain valuable 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 British Columbia'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 adaptation monitoring (like all natural resource monitoring) would be infinitely more useful if it could be associated with existing baseline data that allow trends to be established and conclusions to be drawn regarding the speed and nature of the changes that are occurring (Gardner 2010; NRC 2000; 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 that have been recognized as key to the success of monitoring programs (Caughlan & Oakley 2001; Lindenmayer & Likens 2010b). That said, however, it is unlikely that the existing monitoring undertaken within the Province will be wholly adequate for monitoring the effects of climate change in its current format. Alterations and additions will need to be made in order to have acceptable information that meets the needs of decision makers in the timeframe necessary. More effort and thought are needed to examine the new questions that decision makers have in British Columbia with regard to climate change

adaptation and how the existing data sources can be modified and bolstered to meet these needs.

### **1.2 RESEARCH OBJECTIVE**

My research focused on developing a strategy designed to provide the information necessary to help anticipate and respond to the effects of climate change on British Columbia's forests. Rather than develop a completely new monitoring system, my work was intended to inform land mangers on climate change and its effects on the environment by bringing together existing monitoring and data collection programs available in the Province.

To do this, I first conducted an extensive summary of the examples of local, national and global efforts that have been used to monitor the effects of climate change on the environment (Chapter 2). I then identified a key set of biophysical indicators for monitoring the effects of climate change on British Columbia's forests and rangelands (Chapter 3). This work focused on answering the question: What are the most important biophysical attributes in the forest and range environment in British Columbia to monitor in light of climate change? It sought to engage a number of key experts in the Province with in-depth knowledge of appropriate methods for monitoring the biophysical aspects of forests and rangelands in British Columbia. I then continued this work by surveying Provincial forest and range managers to establish their specific information needs in light of climate change (Chapter 4). The final chapters of my thesis use a case study approach to test some of the indicators that were developed through these initial stages.

My research is intended to develop a scientifically defensible strategy for monitoring British Columbia's forests and rangelands in order to provide the information necessary to anticipate and respond to the effects of climate change. The project's genesis and rationale for the chosen study area (i.e. British Columbia) was formed as a result of a recognized need from the forest and range management community within the Province. Recognizing the strong scientific evidence that climate change will continue to impact the Province's forests and rangelands in 2005 British Columbia's Chief Forester launched the Future Forest Ecosystems Initiative (FFEI) to start the process of adapting BC's forest and range management framework to a changing climate. FFEI was to be implemented through programs in the Ministry of Forests, Lands and Natural Resource Operations in collaboration with external partners, including its primary partner, the Ministry of Environment. The third of six key objectives for the initiative was to "monitor key species and ecological processes to detect changes over time and determine the agents of change" (FFEI 2008). While my research necessarily focuses specifically on British Columbia, the processes and techniques I use also provide and test generic concepts that will help illuminate the way for others to establish monitoring programs designed to better incorporate climate change considerations into sustainable forest management and environmental decision-making as a whole. The key questions and hypotheses addressed within this body of research are outlined in the following section.

### **1.3 RESEARCH QUESTIONS AND HYPOTHESES**

Below, I provide hypotheses for each of my major research questions. The concluding chapter of this thesis further analyzes and discusses these hypotheses.

# **1.3.1** Question 1: What efforts have been made to date locally, nationally and internationally to monitor the effects of climate change on the environment?

<u>Hypothesis 1:</u> There are relevant and useful examples of terrestrial monitoring programs for determining the impacts of climate change on the environment.

**1.3.2** Question 2: What are the most important biophysical attributes in the forest and range environment in British Columbia to monitor in light of climate change?

<u>Hypothesis 2:</u> There are key biophysical attributes that need to be monitored in the forest and range environment in light of climate change.

# **1.3.3** Question 3: Over what geographical and temporal scales should the identified biophysical attributes be monitored?

<u>Hypothesis 3a:</u> Forest and range managers want to incorporate climate change considerations into their decision and policy making in the short to medium term.

<u>Hypothesis 3b:</u> Forest and range managers have specific geographical areas in the Province where they are particularly concerned about the impacts of climate change on key biophysical attributes.

# **1.3.4** Question 4: Are the attributes identified able to be monitored using existing data sources in British Columbia?

<u>Hypothesis 4a:</u> Changes to ecosystem distribution and composition resulting from climate change can effectively be monitored using existing data collections within British Columbia.

<u>Hypothesis 4b:</u> Changes in the productivity of forests resulting from climate change can effectively be monitored using existing data collections within British Columbia.

<u>Hypothesis 4c:</u> Changes in species range and phenology can effectively be monitored using existing data collections within British Columbia.

<u>Hypothesis 4d:</u> The interactions between ecosystem connectivity and climate change can effectively be monitored using existing data collections within British Columbia.

<u>Hypothesis 4e:</u> Changes in fire season length and severity can effectively be monitored using existing data collections within British Columbia.

<u>Hypothesis 4f:</u> Changes in the incidence of insects and disease damage can effectively be monitored using existing data collections within British Columbia.

### **1.3 RESEARCH ASSUMPTIONS**

For practical purposes, there was a need to make certain choices and assumptions beforehand in order to progress and move the debate forward. These assumptions and their justifications were as follows:

- Climate change is real and is already happening. As detailed in the previous section there is clear evidence that rapid, human induced climate change is now occurring and poses significant risks for a broad range of human and natural systems.
- Forest and range managers can play a vital role in assisting climate change adaptation in British Columbia. The research methods adopted within this thesis have sought to draw on the extensive knowledge and skill of forest and range practitioners currently working within British Columbia.
- Environmental policies and actions taken in the current and coming decades can have a substantial influence on the ecological, social and economic consequences of climate change. Literature to date suggests that well-informed adaptation measures adopted proactively are more likely to be successful in reducing the impact of climate change (Easterling et al. 2004; Johnson & Williamson 2007; Millar et al. 2007; Ohlson et al. 2005; Williamson et al. 2009).
- There are datasets that are available within the Province that can be utilised to provide climate change information. There are a number of long-term datasets within British Columbia that have been collected for other forest and range management purposes (such as for sustainable forest management). These are considered to contain valuable data for managing forests for climate change adaptation purposes.

### 1.4 STUDY DESIGN

In order to address the research objective and examine the questions posed above, a series of major steps or stages were undertaken, these stages are outlined below.

# **1.4.1** Stage 1 – Review of major initiatives at the local, national and international level for monitoring the biophysical aspects of climate change

This component of work was largely web-based and involved reviewing and identifying initiatives being used globally to track the effects of climate change on the environment. In some cases program websites were identified through internet search engines. In other cases programs were identified initially through the academic and 'grey' literature. The purpose of this stage was to become familiar with the key environmental monitoring and reporting initiatives that have been undertaken in the last few decades that might offer useful examples and contain useful data that could be used in the development of a climate change-monitoring program for British Columbia.

### 1.4.2 Stage 2 - Liaison and workshops with key experts

Work under this stage was initialized through the analysis of assessment reports prepared by vulnerability assessment teams involved in creating a climate change vulnerability assessment for British Columbia. I sought interviews with vulnerability assessment team leaders and other contacts from key monitoring and inventory groups. The findings of these interviews, along with the information generated from the preceding literature review phases, was key to the formation of a background report that was distributed to delegates attending an indicator development workshop held in Victoria, British Columbia in January 2009. At this workshop delegates were requested to develop a series of selection criteria for choosing indicators to determine the effects of climate change on the biophysical environment, identify those indicators considered most important for monitoring, and identify data sources for the suggested indicators that may not have been found through the previous stages of research.

# **1.4.3** Stage 3 – Survey forest and range managers to determine their monitoring and reporting information needs

A web-based survey was used to interview key forest and range managers to better identify and understand their key monitoring and reporting information needs with regard to climate change adaptation. The clear goal for this stage of my research was to develop from the outset a strong understanding of what information is likely to be most useful and usable in the eyes of the target audience. Survey respondents gave detailed feedback about which indicators they considered were most important for monitoring and also on how they should be monitored (including the time and geographical scales that they believed were of greatest relevance to their information needs). Respondents also commented on the level of data and analysis currently available to support indicators and the most effective conduits for receiving information.

# **1.4.4** Stage 4 – Review of the data sources available to support six of the indicators identified.

During this stage numerous data sources were investigated for their suitability for monitoring six of the indicators identified. These six indicators were selected for three reasons. Firstly, they were perceived as being of high importance for monitoring forests and rangelands in light of climate change. The level of importance was determined by the outcomes of the workshop and the survey of decision makers. Secondly, the data sources available to support them were likely to be particularly diverse (e.g., a large variety of sources of uncertain quality were potentially available to support the indicator) and more interpretation around the techniques and sources available to monitor them was required. Lastly, at the time of selection the data sources were not the subject of a major restructure or re-analysis.

Datasets were downloaded or otherwise obtained from their custodians and examined for their consistency and usability. This included gathering the key geographic information system (GIS) capable spatial datasets including for example: provincial and divisional boundaries (forest district, ecoprovinces, Biogeoclimatic Ecosystem Classification (BEC) zones), infrastructure and environmental features (roads, water courses, climate and weather stations), land tenures, and the vegetation resources inventory data. The British Columbia Government's Land and Resource Data Warehouse (LRDW) was a good source for these baseline datasets. However, some newly revised or not publically available datasets could only be accessed by contacting the relevant data custodians (for example the location of the National Forest Inventory Plots).

# **1.4.5** Stage 5 – Develop basic approaches to monitoring the indicators using the data sources available and undertake analysis of the proposed approach using the datasets available

This stage involved conducting research about the methods that have been used for monitoring the six indicators identified. This involved examination of what other researchers had reported in the academic literature (e.g., the approach developed for monitoring ecosystem connectivity) along with devising unique methods that had not yet been undertaken but which were based on well-established ecological monitoring techniques (e.g., the approach developed for monitoring ecosystem distribution and composition).

I ran a test analysis of the six indicators using the data available. While the key aim was to test the adequacy of the datasets, this exercise also enabled the identification of some of the key data gaps that were likely to be particularly problematic for analysis of the indicator. The approach and results for these analyzes are outlined in detail in Chapter 5. The approach taken differs depending on the data available and the established methods described in the academic literature.

### 1.4.6 Stage 6 – Make conclusions and review and report on findings

Over the course of the stages described above a series of reports and other documents were generated in order for the results to be extended to various audiences as they became available. The findings from some of the stages were also presented at various seminars and working groups including, for instance, the British Columbia Government's Climate Change Seminar Series, the Natural Resource Monitoring Community of Practice and the Climate Change Vulnerability Assessment Workshops. The main output from this research is this thesis, which is a comprehensive review and analysis of all the work that was undertaken.

### Chapter 2 - Examples of environmental monitoring efforts

### 2.1 INTRODUCTION

For centuries, monitoring and cataloging of the natural environment has been considered an important attribute of managing the environment. The advent of the United Nations Conference on Environment and Development (UNCED) (1992) and the development of subsequent conventions and agreements such as the United Nations Framework Convention on Climate Change (UNFCCC); the United Nations Convention on Biological Diversity (CBD); and the Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests (Forest Principles) formalized the concept of environmental monitoring and made it a recognized component of sound environmental management. Article 7 of the CBD highlights the need "to monitor, through sampling and other techniques, the components of biological diversity .... paying particular attention to those requiring urgent conservation measures and those which offer the greatest potential for sustainable use" (p. 5). Article 5 of the UNFCCC states the need to "support and further develop, as appropriate, international and intergovernmental programmes and networks or organizations aimed at defining, conducting, assessing and financing research, data collection and systematic observation" (p. 9). The Forest Principles recognized that "Sustainable forest management and use should be carried

out in accordance with national development policies and priorities and on the basis of environmentally sound national guidelines. In the formulation of such guidelines, account should be taken, as appropriate and if applicable, of relevant internationally agreed methodologies and criteria" (Article 8.(d)). As a result of UNCED, national governments responded to the call to establish sustainable development strategies and programs designed to monitor progress towards sustainable development. Many nations began to consider how they would measure and track their progress toward the goal of sustainability. These discussions focused on the need to establish mutually agreed upon features for monitoring that would provide a framework for data collection and evaluation and, to the extent possible, standardize reporting at a regional and national level so that global trends could be ascertained.

This chapter explores some of the key environmental monitoring and reporting initiatives that have been undertaken in the last few decades that might offer examples and contain useful data that could be used in the development of an ongoing climate change monitoring program for British Columbia. Some of these programs have been identified because they represent solid ongoing data collections that could be of use while others have been highlighted as relevant examples of drawing together a range of different data sources or unique and exemplary ways to display complex data. A more complete list of monitoring programs from which these examples were drawn is provided in Table 1, Appendix A. The last portion of the chapter examines some of the key challenges identified through this assessment and presents some strategies to mitigate and manage these issues.

### 2.2 EXAMPLES OF ECOLOGICAL MONITORING PROGRAMS

### 2.2.1 Monitoring programs in British Columbia

As in most developed countries the concept of sustainable development is a central pivot around which all government decision-making in British Columbia is increasingly required to revolve. It is not only natural resource management agencies that have firmly entrenched sustainable development principles stemming from UNCED agreements described above. The reach of these principles has now extended into

government agencies that previously would have no direct need to have regard to environmental considerations in exercising their statutory functions. The adoption of sustainable development principles has brought with it the need for ongoing monitoring and assessment in order to assess the extent to which these important principles are being met. For decades, initiatives within British Columbia have monitored environmental trends and this section briefly examines some of these initiatives. While the focus is largely concentrated on government-led initiatives some examples are also taken from non-government led initiatives.

The Indicators of Climate Change for British Columbia 2002 Report is the first example of a report in the Province that examined the implications of a rapidly changing environment for human systems as well as terrestrial, marine and freshwater ecosystems (Anon 2002). It reviewed indicators regionally and also explored the effects of climate change. This report represents one of British Columbia's earliest attempts to quantify and disseminate information on the effects of climate variability on ecosystems and human communities. Topic areas examined included: average temperature, maximum and minimum temperature, precipitation, snow, glacial retreat, freezing and thawing, timing and volume of river flow, river temperature, numbers of sockeye salmon stocks, growing-degree days and mountain pine beetle range. Unfortunately, no follow up assessment appears to have been undertaken. While the report offered a very good starting point for my research, the topic areas examined used were fairly broad and lacked the level of information needed on detailed ecological changes to fully respond to forest and range managers' needs. There are many other reports produced periodically that have evaluated changing environmental trends. The British Columbia Ministry of Environment State of the Environment (SoE) Report: Environmental Trends in British Columbia 2007 is the latest in a series of State of the Environment reports that have analyzed environmental trends over the last decade (MOE 2007). This knowledge builds on reporting and monitoring frameworks used to develop four previous environmental trend reports (in 1993, 1998, 2000, and 2002) for British Columbia. Substantial collaboration among federal and provincial agencies and many other organizations was necessary to produce these reports. Several chapters (e.g., climate change, ecosystems, fresh water, and species conservation) could be used to inform a climate change monitoring program as well as complement its implementation. Specifically, the assessment of long-term trends in air temperature and precipitation changes could provide vital information for understanding the context of climate changes in British Columbia. In a similar reporting framework, Environment Canada maintains a State of the Environment InfoBase in which British Columbia and the Yukon are assessed for climate changes. Ecosystems, wildlife species and related topic areas were also used to assess environmental trends, but not specifically in relation to climate change (EC 2012).

The British Columbia State of the Forests Report also offers considerable areas of overlap with climate change monitoring and reporting (MFR 2010). Several of the data collections that inform the chapters examining ecosystem diversity, ecosystem dynamics, species diversity, exotic species, genetic diversity, soil, water and air are potentially useful for a climate change monitoring framework such as used in my research. The purpose of the data collection associated with the SOF? report is designed to assess and monitor progress towards, and compliance with, sustainable forest management principles. This intent is, in many cases, slightly misaligned with monitoring the effects of climate change. For example, some of the indicators are associated with demonstrating sound forest management rather than monitoring environmental systems. In the case of monitoring soils and water, indicators often examine questions such as: How frequently are soil disturbance limits exceeded in harvesting areas? or What are the steps taken to protect water quality during forest operations?. Both of these questions are obviously relevant to the demonstration of sustainable forest management but are less relevant to climate change monitoring in this context (MFR 2010).

The Pacific Climate Impacts Consortium (PCIC) is a research group designed to facilitate collaboration on climate change research and information dissemination. The Consortium has published several reports that analyze the implications of climate variability and change on British Columbia's resources. It has also created a Regional Analysis Tool which allows the user to manipulate parameters of interest while focusing on local results from global climate model (GCM) data (PCIC 2008). These outputs

offer useful modeled data on the effects of climate change. Such outputs are useful for targeting which aspects of the natural environment should be assessed in light of climate change (i.e. choosing the data variable most suitable for monitoring). In addition, the modelling data can be compared and interpreted in the context of monitoring data (which would be the end result of a framework such as this one) providing breadth and depth to the analysis of the results.

#### 2.2.2 Monitoring programs in Canada

At the Canadian national level, *Canada's National Environmental Indicator Series 2003* demonstrated the efficacy of building on existing frameworks to meet public demand for information regarding the status of their environment. A number of national level environmental indicators are evaluated, covering numerous topics from ecosystem health to human well-being. All analyses are founded on existing information and monitoring systems (Anon 2008b). Also relevant is the Natural Resources Canada report *From Impacts to Adaptation: Canada in a Changing Climate 2007* (Walker & Sydneysmith 2008). This report presents an integrated analysis on a national scale, which is then broken down into regional assessments where overviews presenting regional challenges and adaptation opportunities for British Columbia and other Provinces and territories are identified. General indicators (i.e., temperature, precipitation, extreme weather and weather related events, and hydrology) are used to examine sectors such as forestry, agriculture and terrestrial ecosystems for vulnerabilities to climate change.

In the Canadian State of the Forests Reporting Series climate change and the implications for forest and rangeland ecosystems are mainly discussed in reference to the global carbon cycle at the national level (NRCAN 2012). Climate change is only discussed in detail in Criterion 4, while it is merely mentioned in other indicator analyses. However, the CCFM released: *A Vision for Canada's Forests. 2008 and Beyond*; this includes calls for consideration of climate variability in sustainable forest management. Goals include bolstering the forest sector to ensure its survival and leading the world in researching, adapting to and mitigating against the effects of

climate change on Canada's forests and forest communities. However, no specific details are described regarding the monitoring of forests for climate change (CCFM 2008). The Canadian Council of Ministers of the Environment (CCME) also assessed indicators of climate change in their report: *Climate, Nature, People: Indicators of Canada's Changing Climate*. This report uses twelve indicators to assess the state of Canada's environment and two of these are directly relevant to a terrestrial monitoring system: polar bears and plant development (CCME 2003).

#### 2.2.3 International climate change monitoring

Several datasets and indicator frameworks have contributed to initiatives that investigate and report the effects of climate change on ecological systems around the world. In the United States, a variety of studies have been conducted that have assessed climate change impacts using current monitoring frameworks. The United States Forest Service Forest Health Monitoring (FHM) Program tracks the status and trends of forest health across the country by integrating ground and aerial inventories from disparate monitoring initiatives. They are currently developing indicators specifically for climate change, and will continue to use and adapt existing monitoring frameworks for data (FHM 2012). The Long-term Ecological Research Network (LTER) integrates longterm biological research and monitoring at sites across the US and has a Global Change Research Branch that uses monitoring data from its research sites to address knowledge gaps. The network has an international arm (the International Long-term Ecological Research Network), that includes long-term study sites in a number of countries. There are a number of sites within the Province contributing data to this initiative. While these programs were set up specifically with climate change in mind, efforts are currently underway to ensure that climate change impacts can be included.

The US Environmental Protection Agency (EPA) conducts research on biological criteria and indicators, specifically for water resources. In 2009 a report examined the initial effects of climate change on indicator species and provided guidance to managers and monitoring programs on adaptation strategies. The study described and assessed the utility of potential indicators based on current literature and suggested indicators and

species traits that could be used in monitoring the effect of climate change on waterways (EPA 2009). Indicators put forward in this report include ratios of drought tolerant to intolerant mussel species and changes in community composition (such as shifts from cold- or cool-water fishes to warm-water fishes). The US Climate Change Science Program recently conducted a comprehensive assessment of the effects of climate change on agriculture, land and water resources, and biodiversity. It identified several problems within US monitoring systems and suggested that the National Ecological Observatory Network (NEON), a new long-term monitoring program designed to survey both climate and ecological variability in a systematic and allinclusive manner, may improve the ability of current monitoring systems to detect climate change impacts on natural resources. The United States Forest Service's 2010 National Report on Sustainable Forests used similar indicators to those of the Canadian Council of Forest Ministers, but incorporates climate change into its discussion (USFS 2010). It includes an extra section on climate change and discusses the possibility of developing a specific task force to analyze the particular indicators that are sensitive to a changing climate in a separate report.

Outside of North America, two key programs have been specifically designed to examine climate change impacts. The first is the Terrestrial Effects Monitoring Program developed in the United Kingdom in the early 1990s. This developed a series of indicators and monitoring protocols for environmental change, with climate change very much in mind. Although monitoring protocols were developed, implementation of the program appears to have faltered and I was unable to identify any reports. The second noteworthy program is the Langfristige Waldokősystem-Forschung (LWF) program of Switzerland, established in the mid-1990s and involving a network of 15 forest sites throughout Switzerland. The focus of this program is on monitoring external anthropogenic and natural stresses such as atmospheric deposition and climate; monitoring changes of relevant components of forest ecosystems; investigating the effects of external stresses on forest ecosystems; developing indicators of forest health and assessing the risks under different stress scenarios (LWF 2012).

Other international monitoring networks are also being modified to broaden scientific understanding of climatic variability on ecosystems. In the United Kingdom, the British Trust for Ornithology uses long-term data to evaluate the effects of climate change on birds and other migratory species. Considerable effort is being put into research assessing indicators covering a range of taxa including birds, marine and terrestrial mammals, fish, turtles, and bats (Newson et al. 2008). In Europe, the ICP Forests Programme (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests) was originally designed to detect changes in forests due to air pollution, but emphasis is now being placed on detecting changes from both air pollution and climate change (IPC 2012).

#### **2.2.4** Global climate change monitoring programs

There are also a number of programs monitoring the effects of climate change at the global level. Examples include the Global Climate Observing System's (GCOS) Essential Climate Variables, the National Aeronautics and Space Administration's Key Indicators of Climate Change, the National Oceanic and Atmospheric Administration's Arctic Indicators and the International Geosphere-Biosphere Programme's Climate Change Index. Some of these frameworks offer useful examples that could be adopted in a regional programme. The GCOS, for instance, is currently working to monitor a number of Essential Climate Variables, seventeen of which are focused on the terrestrial environment. These include relevant aspects such as land cover, fire disturbance and river discharge. The GCOS is relevant because it operates as a global level clearing house for climate related data and because it serves to report against a series of indicators using a compilation of different data sources (GCOS 2012). The Earth Geosphere-Biosphere Programme has created a Climate Change Index that brings together key climate change attributes namely, atmospheric carbon dioxide, temperature, sea level and sea ice. Their approach offers an annual representation of how the Earth's complex systems are responding to the changing climate. While the approach lacks the finer level complexity that is needed for the framework at hand, it does offer a useful example of how to display results in a manner which is easily

absorbed by a variety of audiences. It is also a successful example of how a variety of complex data sources can be assembled into a simplified format (IGBP 2012).

### 2.5 DISCUSSION

There is a diversity of biophysical indicators being analyzed in the frameworks described above. Some indicators are very specific and only regionally applicable but there are some common components and topic areas. These are listed in Table 2.1. Among the indicators listed, there are some core indicators that are used in almost every framework across all levels of environmental management. These include attributes that provide basic assessments of ecosystem cover and its nature (i.e. ecosystem distribution and composition). Many of the indicator frameworks examined also examine species diversity, soil, and water attributes.

Many of the frameworks examined cite difficulties with data supply, in particular the inability to determine trends. In a similar review of global monitoring frameworks, the Food and Agriculture Organization concluded that "...the climate observing system in the Terrestrial Domain remains the least well-developed component of the global system, whilst at the same time there is increasing significance being placed on terrestrial data for climate forcing and understanding, as well as for impact and mitigation assessment" (FAO 2005). Over a decade ago, the Government of Canada also assessed the country's monitoring systems to determine whether they could contribute data to the Global Climate Observing System (GCOS). In general, the existing atmospheric and oceanic components of the observing system were considered adequate. However, most terrestrial monitoring programs and databases, without further enhancement, could not be used for the GCOS due to gaps in coverage, continuity and detail. In some cases, specifically ecology-related databases, statistics were insufficient right from the start, inconsistent over time or space, or incomplete (Anon 1999).

It is evident that a number of factors are responsible such as lack of ongoing politicalwill along with the high cost of terrestrial monitoring have inhibited the development of adequate long-term, consistent, cohesive, and representative terrestrial surveillance
programs that are capable of monitoring subtle changes in the biophysical environment. While many of these issues have been identified in the literature (Caughlan & Oakley 2001; Failing & Gregory 2003; Legg & Nagy 2006; Lindenmayer & Likens 2010b), there are three key challenges which I consider to be most relevant to monitoring the effects of climate change in British Columbia. These are: maintaining ongoing political will and funding; overcoming obstacles within the institutional and social environment; and maintaining a representative viewpoint across such a broad and diverse land base. Each of these challenges is briefly described in the following paragraphs.

#### 2.2.1 Maintaining ongoing political will and funding

Paramount among the key challenges for surveillance monitoring frameworks is the need to foster the ongoing political support to secure the funding commitments necessary for long-term monitoring of climate change. This important issue has continually plagued the ability to successfully implement and conduct status or trend monitoring at all levels of environmental management. Government budgetary cycles, political party processes and organizational behaviours of government (such as various ministries dividing scarce resources by 'operating in silos') complicate the already difficult challenge of sustaining the funding impetus needed to collect and maintain ongoing biophysical records (Failing & Gregory 2003; Lindenmayer & Likens 2010a; Turnhout et al. 2007). In addition, while the need for ongoing environmental monitoring and reporting is in most cases understood by environmental managers, they often have to postpone any actions as a result of more immediate and striking necessities.

In order to reduce the effect of this key issue I think it is important, particularly while the framework is in its infancy, to ensure that strong synergies are sought with other existing projects and programs. It is also vital to make sure that any indicators chosen are highly selective, pragmatic, easily measured and, above all, cost-effective so that bipartisan political support for the framework is achieved and it is not seen as an easy target for reducing government expenditure.

#### 2.2.2 Overcoming obstacles within the institutional and social environment

Those government agencies with a responsibility for land and biodiversity management are often restructured, sometimes multiple times per decade. In British Columbia the lead agency responsible for forests, the Ministry of Forests, Lands and Natural Resource Operations, has undergone three restructures and subsequent name changes in the past decade. The priorities of restructured agencies are often cited as being 'less stable' than those of ongoing agencies, even for those activities that might be considered core business such as resource monitoring (Turnhout et al. 2007). In addition, the work groups conducting monitoring might have to move between agencies. This is a particular danger for the proposed climate change monitoring framework because it is to be reliant on data collected from multiple agencies. There is likely to be a high turn-over of various management structures and program managers which would need to be dealt with over the course of any long term monitoring program.

Reducing the effect of these obstacles within the institutional and social environment will involve being cautious in the choice of data sources that are relied upon and 'pick winners' that are already well developed and have a strong history of ongoing data collection (Lindenmayer & Likens 2010a). To the extent possible (without oversimplifying) in the initial stages it may also be prudent to reduce the complexity of each indictor so fewer data sources are necessary for reporting. Another key strategy for minimising institutional and social upheavals is to undertake sound record keeping procedures to address the impact of staff changes and the loss of key personnel.

Table 2.1 – Some of the core biophysical attributes monitored in the indicator frameworks

BIODIVERSTY	FOREST HEALTH	SOILS	HYDROLOGICAL FUNCTIONS
<ul> <li>Ecosystem diversity <ul> <li>Area and distribution of ecosystem types</li> <li>Ecosystem composition</li> <li>Age classes/growth stages</li> </ul> </li> <li>Species diversity <ul> <li>Species threatened or at risk</li> <li>Species population levels</li> <li>Reproduction rates of selected species</li> <li>Species distribution/range (including changes in seasonal distributions)</li> <li>Species phenology</li> <li>Habitat fragmentation</li> <li>Connectivity of habitat</li> <li>Invasive species</li> </ul> </li> <li>Genetic diversity <ul> <li>Levels of genetic variation for selected species/stands</li> </ul> </li> </ul>	<ul> <li>Fire <ul> <li>Severity</li> <li>Frequency</li> <li>Seasonality</li> </ul> </li> <li>Wind or storm damage <ul> <li>Wind-throw damage</li> <li>Snow loading</li> </ul> </li> <li>Alien/invasive species <ul> <li>Vertebrates</li> <li>Invertebrates</li> <li>Weeds</li> <li>Pathogens</li> <li>Invasion pathways</li> </ul> </li> <li>Dieback and mortality <ul> <li>Biotic and abiotic causes of tree and stand mortality</li> <li>Plantation failures</li> </ul> </li> </ul>	<ul> <li>Biological <ul> <li>Mean annual increment of trees</li> <li>Logging related disturbances</li> <li>Soil carbon content</li> </ul> </li> <li>Chemical <ul> <li>Soil nitrogen (in its multiple forms)</li> <li>pH</li> </ul> </li> <li>Physical <ul> <li>Erosion/mass movements (area and depth)</li> <li>Landslide frequency</li> <li>Temperature (continuous and discontinuous permafrost)</li> <li>Moisture</li> </ul> </li> </ul>	Precipitation  Quantity Frequency Form Seasonality Snow cover/depth Rain or snow events  Lakes and streams Flow rates Flow rates Flow rates Flow rates Flow rater quality Water quality Water quality Sediment/nutrient/oxygen levels Turbidity Lake freeze/thaw dates Spring freshet Catchment disturbance Changes in glacial mass balance

## 2.2.3 Maintaining a representative viewpoint across such a broad and diverse land base

In all of the initiatives and reports reviewed above it is evident that, while there is interest in monitoring and reporting the effects of climate change on forests, attempts to do so are constrained by the availability of sound and reliable field data. In this context 'data reliability' is referred to broadly as the spatial extent of the available data and the frequency with which they are collected. The review of the monitoring programs above reflects the uneven efforts put into monitoring, the short life of most 'long-term' monitoring projects and the difficulties involved in the compilation of data collected according to different protocols. In British Columbia, where the ability to access sites varies greatly, higher latitudes and altitudes have continually been recognized as being the 'poor cousin' in terms of data collection across the Province. Inaccessibility of these areas increases the cost and effort required for ongoing monitoring. Data collection effort also varies depending on the impetus for collection, with data for economically relevant resources more likely to be available than for those related to resources that are not merchantable. This is because the monitoring required for the harvesting and trade of environmental resources is often tied to either legislative requirements of sustainable management but also, increasingly, the requirement for providing a 'social licence' to purchasers of environmental products.

Again, in mitigating the effect of varying efforts put into monitoring and the difficulty of maintaining a representative viewpoint it is important to rely on well funded, provincial level datasets which have a strong history of being maintained over the long term. It is however, also very important to make use of opportunities and support agencies who wish to expand these datasets to make them more representative across both space and time. My research could involve play an important role in detailing where gaps are within the datasets and making recommendations to increase their breadth.

#### 2.6 CONCLUSION

In this chapter a number of different monitoring programs operating at a variety of levels, regions and countries have been identified. These different programs show that there is a strong need and recognition across the globe to better understand the impact that climate change is having on the natural environment and to start to incorporate some of the findings from these programs into a format that may result in management change and the integration of climate change considerations into political decision making. The diversity of the programs also illustrates that there is no universally applicable approach to monitoring. Differences in environmental factors, coupled with differing political, economic and social situations, makes it necessary to tailor a particular monitoring program to a particular region, depending on its unique needs and circumstances.

Despite the considerable effort that has been put into monitoring the environment there have also been a number of issues that have continually plagued the development of adequate, consistent and cohesive frameworks for monitoring the environment. This is particularly the case for frameworks that are capable of determining changes in the environment over time - precisely the type of information that is needed for determining the impact that climate change is having on the biophysical environment. I have identified three challenges that must be met and continually addressed, namely: maintaining ongoing political will and funding; overcoming obstacles within the institutional and social environment; and maintaining a representative viewpoint across the broad and diverse land base that is British Columbia. Core strategies to address these issues have also been outlined primarily these involve: building strong synergies with existing data sources while at the same time being careful to chose those sources that are likely to be maintained in the long term; encouraging the expansion of these datasets to make them more representative across both time and space; and maintaining sound record keeping practices.

The next two chapters of my thesis draw on the analysis above to assess specifically the indicators that are likely to be most appropriate for monitoring the biophysical effects of climate change in British Columbia.

## Chapter 3 - Determining a key set of biophysical indicators for monitoring the effects of climate change on British Columbia's forests and rangelands

#### **3.1 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 (Castañeda 1997; Howell et al. 2008; Prabhu et al. 2001; Raison et al. 2001; 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 (Niemeijer 2002; NRC 2000). Indicators are designed

to isolate key aspects from an otherwise overwhelming amount of information and help decision makers determine appropriate actions by highlighting higher level patterns. To develop and implement sound environmental policies, data are needed that capture the essence of the dynamic elements of environmental systems and changes in their function. These kinds of data then need to be incorporated into indicators (Hamblin 2001).

Indicators have been essential for increasing our understanding of the causes and effects of climate change, leading to the current state of knowledge regarding its existence and effects. Ongoing monitoring of broad indicators, such as carbon dioxide concentration, global surface temperature, arctic sea ice and land ice, and sea level, have helped to build a solid case that allows reasonable conclusions to be drawn regarding climate change trends. Now further, finer level, environmental indicators are needed to better understand the implication of these recorded changes and provide sound science for decision-making and on-the-ground management (EPA 2009). The choice of indicators for monitoring is fundamental to defining the approach to both monitoring and management (Caughlan & Oakley 2001). 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 an extensive 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. Developing scientifically sound, useful indicators for an area as physically and climatically diverse as British Columbia is also challenging. This difficulty is compounded immeasurably by the fact that forests are being altered in ways that are not well understood, such as the unknown effects of climate change on forest ecosystems and their productivity (Spittlehouse 2008). Despite this complexity and uncertainty, simple and effective provincial-scale indicators for monitoring the effects of climate change are needed because much of the environmental decision-making in British Columbia is implemented at the

provincial level. Thus, environmental managers working 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.

#### **3.2 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 4) was employed. While these two groups were not necessarily mutually exclusive, the first group contained a select group of individuals with 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 British Columbia. 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 outlined in the academic literature and organizational reports (e.g. Bossel 2001; Bridge et al. 2005; Bubb et al. 2005; Dale & Beyeler 2001; Gomontean et al. 2008; Niemeijer & de Groot 2008; NRC 2000; Oliver 2002; UNCSD 2007). In developing a process for 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 & Oakley 2001; Failing & Gregory 2003; Legg & Nagy 2006; Lindenmayer & Likens 2010b).

# **3.2.1** A conceptual understanding of the total system and identification of 'potential indicators'

An important component of the method employed in the selection and development of the indicators was the development of a set of potential-indicators to initiate the process of selecting indicators relevant for monitoring the forest environment in the context of climate change adaptation. Potential indicators are commonly employed to develop indicators and are simple first attempts generated by one or two people to initiate and generate discussion and to provoke the generation of a set of new and better indicators (Bridge et al. 2005; Bubb et al. 2005; CCFM 2002; Oliver 2002). In the present case they were developed to initiate and frame discussions with various forest and range experts, including those attending an indicator development workshop (described below). The potential indicators were developed through literature reviews, 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 (i.e. the work described in Chapter 2). In order to initiate the development of the potential indicators, I conducted 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 British Columbia's forest environment.

The results and preliminary findings of a climate change vulnerability assessment were also of great importance to the choice of indicators (Utzig & Holt 2009). Also of importance were one-on-one interviews conducted with each of the British Columbia 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 recognised through literature as having an in-depth knowledge of the effects of climate change on a particular biophysical attribute or because they were the registered custodian of a key source of data. Interviewees were asked questions specific to the data sources and/or in the case of subject matter experts which indicators they considered to be most valuable for monitoring in light of climate change. The interviews were conducted over the telephone using a qualitative interview approach. This type of approach is flexible, iterative, and continuous rather than prepared in advance and rigid (Rubin & Rubin 1995). In most cases interviews lasted between 30 - 60 minutes.

Notes on the responses to questions were taken and incorporated into a workshop background report, in particular within the rationale for the 22 potential indicators and the selection of data sources for monitoring certain topic areas.

In forming the potential indicators a 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. For a summary of some of the more relevant frameworks please see Chapter 2.

#### 3.2.2 Climate change monitoring indicator development workshop

An indicator development workshop held in Victoria, British Columbia 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. British Columbia's experts were identified during the first stage of the project. They were well known for their work in the field, having either produced publications of relevance to the project, or being the nominated custodian of a key dataset identified as having relevance to the assessment of the biophysical impacts of climate change on forests. Invitations were extended to over 90 experts, mainly from within the British Columbia Government but also from within academic organizations and non-governmental organizations. The workshop

was attended by 58 people who came from all over the Province and from a number of levels within the management hierarchy.

Delegates were sent a detailed information package, including a detailed transcript containing the potential indicators, ten days 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. These activities are expanded on in Appendix B. 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 small groups (each containing approximately twelve people) to determine a series of characteristics that made a topic relevant for examination in British Columbia in light of climate change. The groups were not pre-determined but were based rather on seating arrangements (with people sitting at the same table working together). Thus, groups were made up of a variety of different areas of expertise. The key attributes identified by each of these groups are outlined in Table 3.1. The findings of each group were then discussed in plenary and key characteristics of relevance were compiled through group consensus. These characteristics were:

- Fiscally cost effective to develop and operate over the entire course of the program's existence
- Use existing data sources and collections
- Use existing trend data to the extent possible
- Be based on available or easily obtainable, scientifically valid, empirical measurements that can be consistently repeated over time to observe trends
- Result in information that is able to support and inform policy and land management decisions
- Focus on factors that are sensitive or closely aligned to climate and hence are likely to quickly respond to change
- · Be scalable spatially to be relevant at various levels of land management

Table 3.1Attributes identified during the workshop as being important forindicators to be included in a climate change monitoring framework in BritishColumbia

ATTRIBUTE	Group 1	Group 2	Group 3	Group 4	Group 5
Fiscally cost effective to operate over					
the entire course of the program's existence	•	•	•	•	•
Use and leverage existing data sources and collections	•	•	•	•	•
Build on existing trend data	•		•	•	
Scalable (Able to be used at a number of deferring scales with data able to be combined and presented at the provincial level)			•	•	•
Flexible (Able to respond iteratively to new information needs or scientific data)	•	•	•		•
Sensitivity to climate change/ likely to respond quickly to change	•	•	•		
Predictive ability for the future	•				
Produces understandable and accessible information	•	•	•		•
Measurements that are repeatable over time		•			•
Relevance to current policy					•
Relevance to ecosystem function					•
Physical elements as well as biological processes			•		
Long term relevance to environmental management and society	•	•			
Links to modelling			•		

In the second workshop activity, delegates were split into two groups depending on their self-nominated area of expertise. One group examined those indicators focusing on biodiversity and forest and rangeland disturbance factors such as fire and insects (n=32). The other group focused on examining indicators related to soils and hydrology (n=26). The two groups, working concurrently in separate conference rooms, discussed each of the potential indicators in the context of the characteristics of relevance and identified any further areas required. 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 recorded in detail and some of the key discussion points raised for each indicator are described in Tables 3.1 - 3.4.

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 this resulted in a comprehensive list of data sources potentially suitable for supporting indicator evaluation. A draft title, rationale for monitoring, and a cost-benefit analysis were 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 and range experts who had been involved with the entire indicator selection process.

## Table 3.1Workshop 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 and associated concerns were discussed. Of particular note were the issues regarding the ability to track changes using existing data sources. Gaps in data coverage included northern areas, alpine areas and grasslands.	Biogeoclimatic Ecosystem Classification System, Vegetation Resources Inventory, National Forest Inventory, Terrestrial Ecosystem Mapping	This indicator was regarded as highly important and should be included for monitoring. 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 because it is a considered an aspect of forest and range management and decision making as opposed to something that could be influenced by climate change per se. 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.	

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME		
Levels of ecosystem fragmentation				
Delegates considered that this indicator should be monitored at the landscape level using coarse scale data and GIS-based assessments. This is primarily because data at the species level is not available and coarse scale assessments of fragmentation were considered to be more cost effective and accessible (through the use of using remotely sensed data). The indicator was re-worded to refer to ecosystem 'connectivity' as opposed to 'fragmentation'. As overarching examinations of landscape connectivity were considered to be more valuable than looking in detail at fragmentation (which was generally thought to refer to a more in depth spatial analysis of ecosystems).	Biogeoclimatic Ecosystem Classification system, Vegetation Resources Inventory, National Forest Inventory, Terrestrial Ecosystem Mapping	This indicator was regarded as moderately important and should be retained in its existing form if a cost-effective method for analysis could be derived using the existing data.		
Trends in population and range information for [animal] sp	pecies from a range of taxa and habitats			
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 field data and could not be assessed using remote sources.Some very coarse range maps were available for some species but 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,	This indicator regarded as important for monitoring in light of climate change. However, there were serious questions relating to the Province's capacity to do any monitoring of this indicator using existing data sources. The indicator was updated to include the phenology of individual species.		

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME	
Forest and range associated species at risk of losing their genetic diversity and forest management and conservation efforts for the 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 those species of financial interest to the Province.	Centre for Forest Conservation Genetics, the Ministry of Forests, Lands and Natural Resource Operations Research Branch - Forest Genetics Section, the Ministry of Forests, Lands and Natural Resource Operations Tree Improvement Branch - Headquarters Unit	Regarded as moderately important for monitoring. However, the indicator was not regarded as important as species-level assessments.	

## Table 3.2Workshop discussion relating to forest disturbance indicators

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME
Scale and severity of insects and pathogens adversely affect	ing 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 be the best data source for this indicator. Concerns were raised, however, that this method is only able to pick up insect and pathogen outbreak occurrences at a medium to large scale and that this would be problematic for acting on outbreaks (by the time they have been detected they are too big to control).	Forest Practices Branch (Forest Health)	Indicator is regarded as important and was 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 wind-throw in light of climate change and did not perceive this indicator as a key area for monitoring. This is because wind damage was considered of varying importance across the Province and because questions were raised regarding the adequacy of existing data sources. Some data sources were however identified; and if they were not able to supply the information needed, then the indicator should not be included within the framework.	The Ministry of Forests, Lands and Natural Resource Operations Forest Practices Branch, the Ministry of Forests, Lands 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.

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME
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 concluded that the indicator should focus on fire weather and its severity. The effects of climate change on fire season length were also recognized as important. The indicator title was altered to reflect these comments.
Scale and severity of unseasonable or unexpected weather of	conditions	
Delegates considered this indicator to be important but communicated 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.	Environment Canada Climate Network for British Columbia and Yukon (monitoring damage by snowpack). Forest Protection Branch (monitoring the effects of drought).	Indicator regarded as important for monitoring in light of climate change. However, there is a need to focus on the damage to forests and rangelands as a result of these events as opposed to just looking at the events themselves. Some questions were raised about the capacity of the current data sources to do this, especially for rangelands.

## Table 3.3Workshop 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 highly important as it related to many 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 that are not included within the current monitoring network (e.g., high elevation and high latitude areas were identified). Another data gap raised in relation to this indicator was transient snow zones where much climate change variability may be occurring (shifts in the form precipitation takes). There is currently some ongoing collaborative work designed to address this gap. With a number of organizations involved in a possible network of sites, database management was also seen as crucial to effective monitoring of this indicator. Being able to maintain and provide access to the data was regarded as critical. Another concern was that the Environment Canada Climate Network has also been reported as being in decline, the extent of this decline is not yet known.	Environment Canada Water Survey Environment Canada River Forecast Centre British Columbia Hydro's Regional Hydromet Data	Monitoring of precipitation was extended to include the form which precipitation takes.		

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME
Extent to which snowpack in forest and rangeland catchments has dev	viated 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 data supply organizations listed 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 British Columbia Hydro's Regional Hydromet Data	Indicator remained in framework.
Extent to which streamflow rates and timing in selected forest and ran	ngeland catchments has deviate	ed from the historic range
Delegates considered streamflow to be a very important attribute for monitoring and it was discussed at length. Forest and range experts 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, underrepresented in the network. In addition, most watersheds are monitored on a small scale (greater than 20km <sup>2</sup> ) while impacts are most likely to be felt at a large 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	The Ministry of Environment River Forecast Centre The Ministry of Environment Water Stewardship Division Sciences and Information Branch British Columbia Hydro's Regional Hydromet Data	Indicator remained in framework.
as opposed to being an indicator in itself. Monitoring ground water levels was also considered in discussion surrounding this indicator. However delegates concluded that ground water levels should not be included because the indicator was unable to meet the initial criteria established in the earlier workshop exercise (paucity of data and the relative difficulty of data collection).		

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME	
Extent to which temperatures in selected forest and rangeland stream	s and lakes have deviated from	the historic range	
Stream temperature was seen by delegates as important for monitoring but had to be considered in the context of other factors such as stream flow. It was not considered particularly useful if taken in isolation (i.e. 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 and apply rigorous technical collection standards to apply across the suite of current organizations collecting data on water temperatures.	The Ministry of Environment River Forecast Centre The Ministry of Environment Water Stewardship Division Sciences and Information Branch British Columbia Hydro's Regional Hydromet Data Assessment Network	Indicator remained in framework.	
Changes in glacial mass balance			
Delegates decided that this indicator should be monitored at the landscape level using coarse scale data and GIS based assessments. The indicator was only regarded as moderately important but was seen as a worthwhile analysis if existing data were available.	Canadian Glacier Information Centre (CGIC) Canadian Cryospheric Information Network (CCIN) Western Canadian Cryospheric Network	Indicator was regarded as moderately important and to be retained in its existing form if a cost-effective method for analysis could be derived using the existing data.	

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME
Water quality		
An indicator monitoring the effects of climate change on was seen as a potentially valuable addition to the framework however questions were raised about the extent to which such an indicator could be adequately assessed using the existing data collections.		A new indicator was created looking at changes in water quality although this may require reassessment depending on the data available.

## Table 3.4Workshop discussion relating to soil/ geomorphological processes indicators

NOTES FROM WORKSHOP DISCUSSIONS	DATA SOURCES	OUTCOME		
Scale and density of rapid mass movements and erosion events				
The indicator was only regarded by workshop delegates as moderately important but was seen as a worthwhile analysis if existing data were available.	Forest and Range Evaluation Program	Indicator was retained in the framework but is regarded as aspirational at this time.		
The Forest and Range Evaluation Program is in the process of developing the methodology for a pilot study examining the terrain stability at the landscape level. The approach offered considerable potential for supporting this indicator. This indicator may have the potential to develop more fully in the future but is regarded as somewhat aspirational at this time (it is unlikely to be successfully monitored using the data collections currently available).				
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 no soil inventories available to lend data to such an indicator.	Not applicable	Indicator was not regarded as important and was removed from the framework.		

#### 3.3 RESULTS

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. These indicators and the data sources identified as potentially available for supporting their analysis are detailed below. As a result of the work undertaken, a rationale for monitoring each indicator in British Columbia was developed and is provided in this section.

The indicator titles were reduced to refer only to the topic at hand rather than the approach taken to measure it. For example, terminology such as 'trends in population and range information for species from a range of taxa and habitats' was reduced to simply refer to 'species diversity'. Delegates in the final plenary session at the workshop commented that this would make the topic of analysis more quickly identifiable to a wider range of audiences. In line with this thinking, an approach to measurement section was developed which allowed for a broader interpretation of how an indicator would be monitored.

Some thirty data sources were identified. While these assessment programs were not designed with climate change in mind, it was thought that they may 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 British Columbia's forests. The suitability of some of these data sources are further explored in Chapter 5.

#### 3.3.1 Ecosystem distribution and composition

Rationale for monitoring in light of climate change

As climatic environments within British Columbia 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 (Hamann & Wang 2006; Hebda 1997). However, during the workshop, experts stressed 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(Lovejoy & Hannah 2005). 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, such as those monitoring species diversity and ecosystem productivity.

#### 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 requirements for field data, successful monitoring of this indicator would be largely reliant on building strong links with the programs identified in the 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 British Columbia and contains valuable baseline data for monitoring at the ecosystem level (Meidinger et al. 1991). 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 could be widely used to inform and target monitoring under this indicator. They could also aid in the analysis and interpretation of trend data and the formation of recommendations for management.

#### Potential data sources

The Ministry of Forests, Lands 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, Lands and Natural Resource Operations. The 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.

The Ministry of Forests, Lands 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.

#### 3.3.2 Forest 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 insects and diseases may result in changes in ecosystem productivity (Birdsley et al. 1995; Boisvenue & Running 2006; Perry et al. 1989). Some regions and ecosystems may experience enhanced productivity while others may experience declines. Measuring these trends also relates to determining how climate change affects growth of species at the margins of their range. Monitoring these changes in light of climate change over the coming decades will improve our understanding of the resilience of ecosystems and inform us of the nature of changes that are occurring.

#### Possible approach to monitoring

The National Forest Inventory (NFI) uses air photo and ground sampling that could be used to support reporting against this indicator. The NFI uses a system of air photo samples (2 km by 2 km) that are generally at a scale of 1:20,000. Information from ground samples includes estimates of growth by species (forest cover height, volume and changes over time) as well as above ground biomass information on tree and non-tree species. Estimates for tree heights and basal areas from the photo plots will be adjusted based on information from the ground plots.

Satellite remote sensing also offers a number of increasingly practical options for monitoring ecosystem productivity (e.g., 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.

Growth and Yield Permanent Sample Plots: These plots are long-term samples established for the purpose of providing information on the rates of growth, mortality and changes in stand structure from stand establishment to maturity. There are over 5000 plots Provincewide, ostensibly on a decadal re-measurement cycle.

#### 3.3.3 Species diversity

#### Rationale for monitoring in light of climate change

Climate change is anticipated to provide both opportunity and encumbrance for British Columbia's species. Opportunity may come in the form of increased potential habitats due to new climate regimes for some species that have restricted ranges. Encumbrances may come from factors such as reductions or alterations in ecosystems or habitats and invasive species moving into new ranges with many potential impacts and scenarios. 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. Delegates at the workshop indicated that there was 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, they proposed exploring information for the widest possible range of species. 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 address this potentially costly area of climate change monitoring by focusing on species found within ecosystems or relying on habitats reported, in time, to be vulnerable. However, this strategy requires a considerable level of expertise that may not be readily available. 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 British Columbia). At the expert workshop, it was emphasized that the monitoring of individual species would be seriously compromised by the inadequacy of current datasets in British Columbia.

#### Potential data sources

British Columbia Breeding Bird Atlas: This 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 British Columbia. Although a cause-and-effect relationship cannot be established with these data alone, the information could potentially be tied to other data sources to further scientific understanding of the vulnerabilities of birds to climate change.

British Columbia Conservation Data Centre: The Conservation Data Centre systematically collates and disseminates information on plants, animals, fish and ecosystems (ecological communities) at risk in British Columbia. This information is compiled and maintained in a database that provides a centralized source of information on the status, locations and level of protection of these organisms and ecosystems.

Canadian Community Monitoring Network (CCMN): Indicators include earthworms 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.

Environment Canada's Ecological Monitoring and Assessment Network (EMAN): EMAN is responsible for reporting on the status and trends of ecosystems across Canada. In 2001, EMAN partnered with Nature Canada to engage in the Canadian Community Monitoring Network.

Forest and Range Evaluation Program (FREP): 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 that address the conservation of wildlife habitat.

The Ministry of Environment Fisheries Inventory Data Queries (FIDQ): FIDQ provides access to the Fisheries Data Warehouse, which contains information on fish species and their habitats.

NatureCounts: This source, 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), British Columbia-Yukon Nocturnal Owl Survey, and the Canadian Migration Monitoring Network.

Nature Watch: This is another example of 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 (NFI): The NFI 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 the NFI would be able to provide data on species from both of these plot types.

Species Inventory (SPI): This 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 British Columbia.

#### **3.3.4** Genetic diversity

#### Rationale for monitoring in light of climate change

Species are prone to increased risk of extinction when a considerable 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) (Lindenmayer et al. 2007; Lovejoy & Hannah 2005; Svenning & Condit 2008). 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 would examine trends in the distribution, composition, and structure of forest and range genotypes. Monitoring for 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. Analyses might 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

University of British Columbia Centre for Forest Conservation Genetics (CFCG): The CFCG has a mandate to: study population genetic structure of forest trees using existing or new data; assess the current degree of gene conservation both in situ in existing reserves and ex situ in collections, and the need for additional protection and evaluate the current degree of maintenance of genetic diversity in breeding and deployment populations of improved varieties to meet current and future environmental challenges.

The Ministry of Forests, Lands and Natural Resource Operations Research Branch: The Forest Genetics Section of this Branch 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.

The Ministry of Forests, Lands and Natural Resource Operations Tree Improvement Branch: This Branch 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 datasets, map products and information management systems. 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).

#### 3.3.5 Ecosystem connectivity

#### Rationale for monitoring in light of climate change

This indicator examines the level of connectivity between forest and range ecosystems. Connectivity comprises the dispersion pattern of patches within the landscape . Distances from one patch to the next have been shown to interfere with pollination, seed dispersal, wildlife migration and breeding (Adler & Nuernberger 1994; Anderson & Danielson 1997; Brudvig et al. 2009; Fahrig & Merriam 1985; Lindenmayer et al. 2008; Long et al. 2010). 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 may become increasingly important (Kramer et al. 2010; Lovejoy & Hannah 2005). 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 changes in climate.

#### 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 are also of potential relevance:

British Columbia Parks: This group is responsible for the stewardship of crown-owned protected areas in British Columbia 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: This organization 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, the BC Ministry of Environment, 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: This is the agency responsible for the stewardship of national parks. They collect a range of data related to the ecological integrity of these areas which may prove useful for supporting analysis of this indicator.

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

#### 3.3.6 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 and abundant reproduction, and often high mobility make them able to adapt quickly to changing climatic conditions(Ayres & Lombardero 2000; Lovejoy & Hannah 2005). 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 British Columbia of insects and pathogens that are already affecting forest health as a result of the climatic changes that have taken place (e.g., Mountain Pine Beetle and Dothistroma Needle Blight). It is likely that the impacts of these agents will increase as the climate continues to change (Taylor et al. 2007; Welsh et al.

2009; Woods et al. 2005). 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 reports on the scale and severity of insects and pathogens adversely affecting forest and rangeland health. If utilising only data current being collected, this indicator would be monitored using Province-wide aerial surveys. However, this method is only able to identify medium- to large-scale insect and pathogen outbreaks. In order to be more useful to management, finer-scale monitoring is needed to collect data that would enable early warning of insect and pest outbreaks and allow for early and aggressive intervention to delay and possibly mitigate impacts.

#### Potential data sources

The Ministry of Forests, Lands 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.

Insect and pathogen monitoring is also 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, Lands and Natural Resource Operations.

#### 3.3.7 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 British Columbia coast and parts of
the Haida Gwaii are likely to be the most susceptible to these disturbances (Utzig & Holt 2009). Forests may also become increasingly susceptible to wind damage if stressed by other factors related to climate change, such as destabilizing soils (occurring from increased precipitation or melting permafrost) 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 amounts of 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 related to climate.

#### Potential data sources

The Ministry of Forests, Lands and Natural Resource Operations Forest Practices Branch has surveyed the majority of the forested land in the Province using aerial surveys 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 wind-throw monitoring protocol for cutblocks. A review of all FREP protocols is underway to see how to best to integrate wind-throw monitoring on sites visited for other resource value monitoring.

# 3.3.8 Fire season

# Rationale for monitoring in light of climate change

Climate change models project an increase in the number of fires and area burnt across western Canada (Flannigan et al. 2006; Gillett et al. 2004; Hawkes et al. 2005; Metsaranta

et al. 2011; Podur & Wotton 2010). 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 British Columbia 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 (Spittlehouse 2008). 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 by region for the whole Province using the date of the first and last reported fire in a given year. The seasonal severity of the fires should also be captured using the seasonal severity ratings determined by the Ministry of Forests, Lands and Natural Resource Operations Wildfire Management Branch.

#### Potential data sources

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

# 3.3.9 Mass movements

#### Rationale for monitoring in light of climate change

The frequency and extent of rapid mass movements of soil, rocks and other debris 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 change may result in variations in the magnitude and frequency of mass movements adversely affecting forest health (Guthrie & Brown 2008; Pike et al. 2010). 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 greater than 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 the forest canopy.

# Potential data sources

I was unable to find evidence of systematic programs directed at monitoring mass movement frequency and extent. Some studies have previously been done by the Ministry of Environment in areas on Vancouver Island and the Haida Gwaii.

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 and pipelines crossing British Columbia.

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 continue to report such disturbances, but the information is not collected systematically across the Province.

# 3.3.10 Precipitation

# Rationale for monitoring in light of climate change

Precipitation rates, timing and form are anticipated to vary as a result of climate change. Predictions show a shift to warmer, wetter years, more frequent wet years, greater year-toyear variability, and more extreme precipitation events. They also predict change in the form precipitation takes, with more precipitation falling as rain and less falling as snow during the cold season (Rodenhuis et al. 2009; Spittlehouse 2008). 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 facilitate the interpretation of the results.

#### Potential data sources

Environment Canada Climate Network for British Columbia and Yukon currently operates a network of approximately 500 climate stations in British Columbia 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.

British Columbia 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.

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

The Ministry of Environment 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.

# 3.3.11 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 (Mote et al. 2005). Changes in these and other climate properties will therefore affect snowpack. Reduced snowpack is already being reported and the snowline in mountainous areas is forecasted to rise in elevation (Knowles et al. 2006; McCabe & Wolock 2009; MOE 2007; Mote et al.

2005). Changes in the timing of the development and loss of the snowpack are rather uncertain but could have considerable effects on forest ecosystem processes.

## 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 facilitate the interpretation of the results.

#### Potential data sources

The Ministry of Environment 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.

#### 3.3.12 Streamflow

#### *Rationale for monitoring in light of climate change*

Predicted lower stream flows in summer 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 withdrawn for human use) (Rodenhuis et al. 2009; Whitfield et al. 2002; Zhang et al. 2001). Increased storms and precipitation amounts predicted as a result of climate change 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 dominated by rain or snowmelt) (Pike et al. 2010; Stewart et al. 2004; Wilby et al. 2010).

# 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 facilitate 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 British Columbia and Federal governments. The network was in decline for many years and by the late 1990s had been reduced by over 40 %. In the last decade substantial funding was committed for rebuilding the network (especially for climate change analysis purposes) although the current fiscal environment has made this commitment again uncertain.

British Columbia 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.

### **3.3.13** Water temperature

#### Rationale for monitoring in light of climate change

Increased water temperatures are predicted as a result of climate change especially in northern areas of BC. Warmer temperatures are expected to affect the fitness, survival, and reproductive success of certain fish and other aquatic species (Nelitz et al. 2008). 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 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 (Pike et al. 2010). 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 facilitate the interpretation of the results.

# Potential data sources

The Ministry of Environment River Forecast Centre conducts some water temperature monitoring although there is currently no systematic, continuous collection program in place. The Ministry of Environment Water Stewardship Division Sciences and Information Branch is currently conducting research into how water temperature monitoring can be improved (specifically for climate change analysis).

British Columbia Hydro's Regional Hydromet Data networks collect near real-time hydrometeorological data at various automated data collection stations in or near 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. Water temperature is only measured at some locations.

# 3.3.14 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 (Pike et al. 2010). They may also have some impact on the quality of water available for human use.

## Suggested approach to monitoring

The Ministry of Environment 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 a preliminary assessment it appears that monitoring levels of dissolved organic content may have potential for a future monitoring program.

# 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.

The Ministry of Environment 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.

The Ministry of Environment Water Stewardship Division Science and Information 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.

# 3.3.15 Glaciers

# Rationale for monitoring in light of climate change

Glacial retreat may cause changes in the flow patterns and possibly the water temperature of some forest and rangeland streams and rivers. These changes, along with other climatedriven changes to hydrological systems, are likely to have significant impacts on freshwater and estuarine ecosystems and aquatic species (Nelitz et al. 2008; Pike et al. 2010). In the short term, melting glaciers will likely discharge more water into some British Columbia 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 (Barnett et al. 2005b; Moore 2009).

#### Suggested approach to monitoring

The spatial extent 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.

The 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.

The 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 climate change and glacier fluctuations in western Canada.

# 3.3.16 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 (IPCC 2007b; Rodenhuis et al. 2009; Walker & Sydneysmith 2008). 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 assess 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 British Columbia and the Yukon and maintains an associated archive of historical weather information.

Environment Canada's Meteorological Service of Canada 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.

The Ministry of Forests, Lands and Natural Resource Operations Wildfire Management Branch reports annually on specific events. However, it is not set up to report on 'diffuse' events such as droughts. The 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 evaluate this indicator.

# 3.4 DISCUSSION

The development of a preliminary set of indicators to begin the process of selecting and developing indicators was highly valuable in initiating and framing discussions at the Indicator Development Workshop. Without this preliminary set of indicators I believe it would have been considerably more difficult and time consuming for workshop delegates to develop, propose and endorse the set of indicators that have been described in the results section above.

As detailed above, the Indicator Development Workshop resulted in the development of a set of key characteristics of relevance for climate change indicators which could be applied to test indicators to assess and chose indicators of greater relevance for inclusion in the framework. The most common characteristics identified by all of the smaller groups were the extent to which indicators were fiscally cost effective and used existing data sources. These attributes were considered at length by those at the workshop and were valuable in driving the choice of indicators.

The workshop and the other processes identified above were vital in fleshing out the data sources that were available to support the various indicators proposed. Many of the workshop delegates and other experts interviewed had an in-depth knowledge of the strengths (and weaknesses) of these data sources, having worked with them over many years. Workshop delegates emphasised clear concerns surrounding the extent of data available to specifically monitor changes in species ranges and phenologies. While this indicator was included in the post workshop indicator set for future development, there were other indicators which were excluded from further analysis because the data gaps were seen as being too difficult to overcome. This was the case for the proposed ground water and permafrost indicators.

The processes identified in this Chapter also showed that there are some clear topic areas that are considered to be vital for assessing the impacts of climate change on British Columbia's forests and rangelands. The first indicator identified as being of critical importance was changes in ecosystem distribution and composition. This indicator was widely regarded as being of critical importance to the interpretation of many indicators in the framework. For example, there are obvious and direct links between monitoring ecosystem distribution and composition, and other indicators such as forest productivity, species diversity, genetic diversity, and ecosystem connectivity. There are also indirect links between the ecosystem distribution and composition indicator and others such as streamflow and the levels of insects and pathogens adversely affecting forest and range health. Similarly, the indicator examining precipitation was also regarded as a 'keystone' indicator for assessing the effects of climate change on forest and range ecosystems. Assessment of this indicator has obvious connections to facets such as streamflow, stream temperature and water quality. Similarly, examination of variations in precipitation would also have connections to ecosystem-related indicators. Workshop delegates also regarded forest productivity as highly important because the indicator has strong links to the more social dimensions of climate change adaptation – with potential changes in forest productivity affecting the viability of forest-dependent communities in the Province. Those indicators regarded as most important relate closely with the indicators chosen for examination in the international frameworks examined in Chapter 2.

# 3.5 CONCLUSION

The approach adopted here of developing environmental monitoring indicators though a workshop engaging experts has been adopted by numerous organisations in developing their own indicator sets (CCFM 2002; Howell et al. 2008). The approach was useful in that it allowed for the development of a preliminary set of indicators for monitoring climate change to be developed with strong involvement and endorsement from many of those already involved in monitoring and researching the effects of climate change on British Columbia's environment. However, while considerable effort went into selecting these indicators, they can, by no means, be considered 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 British Columbia improves. Further work was undertaken to better refine this indicator set by broadening the range of people associated with their development and specifically better assess how well the indicators chosen fit with the information needs of British Columbia's environmental managers. In Chapter 4, further assessments were undertaken regarding the relative importance of the indicators and how, where and when they should be monitored to derive the information needed to incorporate climate change adaptation needs into decision making.

As detailed in Chapter 3, about thirty data sources were identified through this stage of the work. Without further assessments of the data sources it was difficult to determine the extent to which the indicators can be monitored and to identify the data gaps within the Province. In Chapter 5 some of the identified data sources have been examined further. The level of detail, geographic coverage and applicability of the data collections with respect to the indicator to be monitored were evaluated. Through this assessment, some of the data sources listed in this chapter proved to be of little value for the framework. In Chapter 5 efforts are made to determine the elements of monitoring that are or could be implemented

and to develop recommendations for the next several years to improve the monitoring network to better provide the information needed to assess the indicator set.

# Chapter 4 - Climate change adaptation monitoring and reporting information needs of forest and range managers

# 4.1 INTRODUCTION

As discussed in the previous chapter, monitoring and reporting information on the environment is a well-established activity in natural resource management (Busch & Trexler 2002; NRC 2000; Raison et al. 2001; Spellerberg 2005). Numerous scientificallybased 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 & Likens 2010b). While this success 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 ensure that the monitoring is suitable and that it is sufficiently selective to produce useful or usable information (Jacobs et al. 2005). In addition, it is also important to ensure that reporting is done in a way that is easily understood by environmental managers and decision makers (Holliday 2007; Jacobs et al. 2005; Lemos & Morehouse 2005; Liu et al. 2008; NRC 2000).

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 (NRC 2010c; Spies et al. 2010; Thiaw 2009). Many have noted that if early, defensible, proactive actions are taken and informed decisions can be made then the chances of increasing adaptation to climate change and mitigating its effects are likely to be enhanced (Easterling et al. 2004; Johnson & Williamson 2007; Millar et al. 2007; Ohlson et al. 2005; Williamson et al. 2009). A widely recognized 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 and determining a key set of questions of interest to them (Jacobs 2002; Joyce 2003; Lemos & Morehouse 2005).

Given that the focus of the monitoring framework developed and discussed in Chapter 3 was to inform forest and range management and decision-making, it was vital that the next stage in the development of the indicators incorporated a 'reality check' to assess how well the indicator framework matched up with the information needs of the intended target audience. Thus, in June 2010, an internet survey was distributed to over 450 forest and range managers operating in British Columbia. 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 was pivotal in influencing the design of the approach to measuring the individual indicators.

# 4.2 METHODOLOGY

The questionnaire comprised five sections, including an introductory section giving a short background on climate change adaptation. In the second section I sought to investigate the climate change adaptation information needs of environmental managers operating in the Province. One of the seven questions used in this section requested respondents to rate the importance of a series of topic areas by assigning one of four 'importance' levels. These indicators correlated to the indicators identified in Chapter 3, although the facets of what made up a single indicator in Chapter 3 were drawn out so that each component of the indicator could be examined individually. For example, the indicator examining ecosystem distribution and composition was separated into its respective components: 'ecosystem distribution' and 'ecosystem composition'.

### 4.2.1 Survey design

Care was taken to limit the number of response options available to survey respondents. Firstly, I considered it imperative that the number of response options should be limited to make the survey as uncomplicated as possible. While more options would have allowed me to better assess the variability of responses given the number of large topic areas I asked people to assess, fewer response options (i.e. four) were selected to make the survey less complicated for respondents. A rating approach (as opposed to a ranking approach) was used for the same reason, namely 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. Four options were chosen because this forced respondents away from the neutral or middle response (Iarossi 2006). Although the options were 'unbalanced', I was trying to obtain a degree of discrimination between 'levels of importance', and the lack of balance was not considered to be an issue (Brace 2004). Another reason for choosing four options was because it was the maximum number of categories that could be used without respondents having to scroll across the horizontal landscape of the screen when using the web-based survey program

with which the survey was created. Dillman (2007), who commented extensively on the need for surveys to be visually appealing and 'respondent friendly' to increase participant numbers, discourages the design of survey forms that require respondents to scroll across the screen (Dillman 2007; Schaefer & Dillman 1998). Dillman also indicates that this need to scroll may cause a bias by encouraging respondents to choose the more accessible response categories.

This section of the questionnaire also included open-ended 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 of the Province that were the most important 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 their 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 of information in their decision making. Respondents were also asked to choose 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, and scale and focus of their work. For further reference a copy of the survey is included in Appendix C.

# 4.2.2 Survey implementation

As the survey only targeted environmental managers and decision-makers in British Columbia it was sent to those within a British Columbia Government database of 450 people from both government and non-government organizations actively engaged in environmental management in the Province. Data were collected through an online survey that was administered between May and July 2010. While the majority of the email addresses from the database belonged to employees within the Ministry of Forests, Lands and Natural Resource Operations and the Ministry of Environment, other groups represented included the Ministry of Transportation and Infrastructure, the Ministry of Energy and Mines and the Ministry of Agriculture (note that several government reorganizations during the period 2009–2011 resulted in a number of name changes), First Nations groups including the First Nations Forestry Council, other non-profit organizations including the Nature Conservancy of Canada, and professional organizations including those representing professional foresters and biologists.

I pre-tested the survey in May 2010 and received valuable feedback from eight unaffiliated respondents. 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 appropriate to make such requests) (Dillman 2007). Following the delivery of the survey on 10 June 2010, a reminder was sent to all recipients 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.

#### 4.2.3 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 was categorized and organized according to a series of topics developed through constant comparison or a process 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 & Corbin 1998). Each response received was read thoroughly in order to ascertain and distil the key messages within. These messages were categorized and sorted into groups depending on the response received.

For the two questions containing quantitative data with four-point response options each response option was weighted, in order to determine a mean score for each topic area or information source. The weighted standard deviation of each response option was also calculated as an indication of the degree to which respondents agreed on a particular point (Barnett et al. 2005a).

#### 4.2.4 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 versus late respondents, as late respondents may be treated as proxies for non-respondents (Armstrong & Overton 1977). Thus, to assess the effect of non-response bias I compared the answer patterns of the first 22 respondents with those 22 responses that were received after the reminder email was sent in the final week of the survey; these numbers also corresponded with the first and last 25 % of respondents. 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 of the survey was my reliance on a self-reporting method of data collection; 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 number and email address and encouraged respondents to contact me directly if they had questions regarding the survey. However, no calls or emails with questions were received.

Another issue with the approach chosen stemmed from the use of the British Columbia Government contacts database to generate the survey mailing list. While this database provided possibly the most comprehensive and up-to-date collection of names of those actively engaged environmental management in the Province, the list contained only emails and did not contain other data attributes, for example, the organisations to which recipients belonged where they worked or other details. I was therefore unable to determine if the likelihood of response to the survey between certain groups of individuals varied.

As detailed above, the survey was distributed under the name of the Province's Chief Forester. While this may have increased the response rate it may also have introduced a bias where survey respondents were more likely to say what they believed 'the authority' wanted to hear. In an attempt to address this and encourage the free expression of viewpoints, survey respondents were assured that any personal information that they provided would remain confidential and that data would only be reported in a way that made it impossible to determine the identities of individuals. The other issue is that individuals from organisations (that were not the responsibility of the Chief Forester) may have disregarded the survey. Unfortunately, there is no way of telling the extent to which this may have affected the responses because I could not examine the responses received against those in the original database to whom the survey was sent.

# 4.3 RESULTS

A response rate of approximately 20% was achieved with a total of 88 individuals responding to the survey. Dillman (2007) suggests that response rates for surveys differ widely depending on a variety of factors such as whether the respondent is familiar with the research or has received prior warning of the survey in another form. The response rate was above the average rate for web-based surveys (Sanchez-Fernandez et al. 2012). Almost all of the responses received were complete and all returned surveys were used in the analysis of the results.

# 4.3.1 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.

#### Organization

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% of British Columbia's forests and rangelands (Anon 1996; MFR 2010). A number of respondents indicated that they were from the British Columbia Ministry of Environment (17%), the other key government agency with a strong interest in the management of forests and rangelands. Also represented in the following proportions were: other British Columbia government ministries (6%), industry groups (6%), First Nations groups (5%), academia (4%), and civil society and community organizations (2%).

# Location

One third of respondents (33%) were based in Victoria, the capital city of British Columbia, while the remaining respondents were spread relatively evenly across other areas of the Province (Figure 4.1). Most forest districts within British Columbia were represented by survey respondents.



Figure 4.1 Survey respondent locations

# 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%).

# 4.3.2 Monitoring information needs

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

# The importance of various topic areas

When taken as a whole group respondents considered forest productivity the most important attribute for monitoring, closely followed by ecosystem distribution and composition (Table 4.1). However, when respondents were broken down by organisation the Ministry of Environment staff ranked water-related topic areas more highly with water temperature and streamflow timing featuring in the top quartile of choices for this group. Unlike their counterparts within the Ministry of Forests, Lands and Natural Resource Operations, the Ministry of Environment staff ranked ecosystem connectivity highly. Both of these main respondent groups considered ecosystem distribution and composition to be highly important. Interestingly, staff from the Ministry of Forests, Lands and Natural Resource Operations believed that species ranges were more important for monitoring in light of climate change adaptation than those in the Ministry of Environment. Respondents who were not associated with either of these government ministries rated precipitation and other water-related topic areas highly but also considered ecosystem distribution and composition and species ranges to be important.

	Extremely	Very	Important	Not very			
Topic Area	Important %	Important %	%	important %	Mean	SD	n
Forest productivity	38.1	34.5	21.4	6.0	3.05	0.92	88
Ecosystem distribution	29.4	44.7	18.8	7.1	2.96	0.88	88
Ecosystem composition	26.2	45.2	23.8	4.8	2.93	0.83	88
Precipitation timing	31.0	39.3	21.4	8.3	2.93	0.93	88
Precipitation rate	25.9	36.5	25.9	11.8	2.85	0.89	88
Species' ranges	30.6	35.3	21.2	12.9	2.84	1.01	88
Snowpack extent and depth	27.1	34.1	29.4	9.4	2.79	0.95	88
Insect incursions	29.8	27.4	33.3	9.5	2.77	0.99	88
Precipitation form	25.9	36.5	25.9	11.8	2.76	0.97	88
Streamflow rate	20.2	35.7	33.3	10.7	2.65	0.92	88
Streamflow timing	17.9	41.7	28.6	11.9	2.65	0.91	88
Pathogen incursions	22.6	32.1	32.1	13.1	2.64	0.98	88
Fire season severity	23.8	29.8	31.0	15.5	2.62	1.02	88
Species phenology	19.3	37.3	25.3	18.1	2.58	1.00	88
Water quality	19.5	31.7	32.9	15.9	2.55	0.98	88
Ecosystem connectivity	20.0	29.4	35.3	15.3	2.54	0.98	88
Species population levels	21.7	25.3	37.3	15.7	2.53	1.00	88
Mass movement and erosion	15.7	33.7	37.3	13.3	2.52	0.92	88
Genetic diversity	20.0	28.2	35.3	16.5	2.52	1.00	88
Water temperature	21.7	27.7	28.9	21.7	2.49	1.06	88
Unseasonable or unexpected weather	16.5	30.6	35.3	17.6	2.46	0.97	88
Fire season length	16.7	22.6	41.7	19.0	2.37	0.98	88
Wind-throw damage	10.7	23.8	38.1	27.4	2.18	0.96	88
Extent of glaciers	12.2	24.4	29.3	34.1	2.15	1.03	88

# Table 4.1Topic areas' perceived importance for monitoring in relation to climate change adaptation information needs

MINISTRY OF FORESTS, LANDS AND NATURAL			MINISTRY OF ENVIRONMENT				OTHER GROUPS				
Topic Area	Mean	SD	n	Topic Area	Mean	Mean SD		Topic Area	Mean	SD	n
Forest productivity	3.11	0.96	57	Ecosystem connectivity	3.44	0.78	10	Precipitation timing	3.39	0.70	21
Ecosystem distribution	2.93	0.88	57	Water temperature	3.33	0.67	10	Precipitation rate	3.22	0.73	21
Insect incursions	2.84	0.95	57	Ecosystem distribution	3.22	0.93	10	Ecosystem composition	3.17	0.86	21
Species ranges	2.81	1.03	57	Streamflow timing	3.22	0.73	10	Snowpack extent and depth	3.17	0.99	21
Precipitation timing	2.80	0.96	57	Ecosystem composition	3.11	1.00	10	Ecosystem distribution	3.00	0.97	21
Ecosystem composition	2.79	0.80	57	Snowpack extent and depth	3.00	0.93	10	Species ranges	3.00	0.97	21
Precipitation rate	2.75	0.91	57	Forest productivity	2.89	1.01	10	Precipitation form	3.00	1.08	21
Precipitation form	2.68	0.95	57	Species ranges	2.89	0.83	10	Streamflow rate	2.94	0.94	21
Pathogen incursions	2.68	1.01	57	Precipitation form	2.89	1.00	10	Insect incursions	2.89	0.96	21
Snowpack extent and depth	2.67	0.95	57	Precipitation timing	2.89	0.71	10	Streamflow timing	2.89	0.90	21
Fire season severity	2.61	1.02	57	Streamflow rate	2.89	0.71	10	Forest productivity	2.88	0.93	21
Species phenology	2.56	1.00	57	Precipitation rate	2.78	0.93	10	Fire season severity	2.83	0.99	21
Genetic diversity	2.56	0.98	57	Species population levels	2.67	1.00	10	Ecosystem connectivity	2.78	1.06	21
Streamflow rate	2.52	0.93	57	Water quality	2.67	0.93	10	Species phenology	2.78	1.00	21
Species population levels	2.49	1.00	57	Extent of glaciers	2.67	0.97	10	Pathogen incursions	2.78	0.88	21
Streamflow timing	2.48	0.91	57	Mass movement and erosion	2.63	0.93	10	Genetic diversity	2.72	1.13	21
Mass movement and erosion	2.48	0.93	57	Species phenology	2.56	0.87	10	Water quality	2.72	1.13	21
Water quality	2.48	0.97	57	Fire season severity	2.33	0.78	10	Water temperature	2.67	1.19	21
Fire season length	2.43	1.01	57	Unseasonable weather	2.33	0.67	10	Mass movement events	2.61	0.98	21
Ecosystem connectivity	2.37	0.90	57	Genetic diversity	2.22	0.50	10	Species population levels	2.56	1.04	21
Water temperature	2.31	1.03	57	Fire season length	2.11	0.87	10	Unseasonable weather	2.56	0.98	21
Wind-throw damage	2.21	0.97	57	Insect incursions	2.00	0.74	10	Fire season length	2.33	0.91	21
Unseasonable weather	2.49	1.00	57	Pathogen incursions	2.00	0.71	10	Extent of glaciers	2.29	1.05	21
Extent of glaciers	2.07	1.05	57	Wind-throw damage	1.67	0.71	10	Wind throw damage	2.22	0.94	21

# Table 4.2 Perceived importance of topic areas for monitoring in relation to climate change adaptation information needs<sup>1</sup>

<sup>1</sup> 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 but 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% 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 effects of climate change on the biophysical aspects of forests and rangelands. Others (16%) 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, I 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 openended 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 4.3 presents a breakdown of the reported information needs.



Figure 4.2 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.

Closely tied to species range and suitability were changes in ecosystem distribution and composition, which some respondents (17%) also listed as a key information need. In this case a number of respondents expressed a need for more information to help develop and change operational practices to better account for 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. For instance, it was considered important to know 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 in relation to key climate change information needs identified

Respondents were asked to choose the timeframe in which they were most interested in relation to the climate change adaptation information needs they had identified in the aforementioned questions. This was specifically in relation to the information they had supplied in response to prior sections of the questionnaire. 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 % choosing timeframes within the next 20 years. Most opting for sooner timeframes commented that they needed advice on what to do now and the sooner information could be provided to them the better. 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, 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 adaptation. While a large proportion of the respondents (36%) 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, 28% nominated the southern interior region of British Columbia as the most important area to target, while fewer thought that the coastal (11%) and northern interior (8%) regions warranted additional attention. Those identifying northern regions reasoned that they believed particular attention should be given to regions of the north because there was currently a paucity of data collected in this region, not because they were more worthy of analysis in light of climate change. These results may have been influenced by the fact that there were fewer respondents representing northern areas. The other 53% 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, transitional zones between different

ecosystems, regions identified as being most vulnerable to climate change and those forests containing larger proportions of merchantable tree species.

# **4.3.3** Perceived suitability of the current data collection and analysis framework

This section of the questionnaire contained two-open ended questions. The first sought to assess whether there is enough data currently collected to understand how to manage forest and rangelands to adapt to climate change. Here only 9% of the forest and range managers who responded to the survey believed that there were enough data available to manage forests and rangelands in light of climate change. Most (71%) believed that there was not enough data currently collected. Others (15%) responded that they were not sure or felt unqualified to answer. Many data gaps were identified and the majority commented on the inadequacy of forest inventory data (35%), with many particularly concerned about the inability to determine the rate, direction, timing and magnitude of changes in ecosystem distribution (21%), species ranges (21%), forest health and survival (5%). The other key information gap identified was the capacity of the current climate monitoring network in the Province to provide reliable monitoring results across the entire Province (8%).

District level respondents were considerably more unsure when considering whether there are enough data collected to manage forests and rangelands to adapt to climate change than the other groups surveyed. Almost one-third (28%) recorded that they felt 'unsure' or 'didn't know' about the data available to support their decision making. In contrast, only 12% of regional level respondents detailed that they did not know about the data available.

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 and rangelands in light of climate change adaptation. Here, respondents were somewhat more confident with 46% believing that the correct type of analysis was being

done on existing data sources for climate change adaptation purposes. Twenty-one 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 the various monitoring and inventory programs. Again, a number of respondents (33%) were unsure or said they did not know what, if anything, is being done. Again, the proportion of those who were unsure was much greater for district level managers with some 54% reporting that they did not know what is being done.

#### 4.3.4 Receiving information

Finally, in the last section of the survey, two questions were used to ascertain how forest and range managers in British Columbia currently received and incorporated scientific information into their decision making. Table 4.2 shows the results of this analysis. There was little disagreement between respondents that the Internet, technical articles and government reports, and briefings were the sources that forest and range managers most often use.

	Frequentl	Sometime	Rarely	Never		
	y Used	s Used	Used	Used		
Topic Area	%	%	%	%	Mean	SD
Internet	51.8	42.2	6.0	0	3.46	0.61
Technical articles	41.2	55.3	3.5	0	3.38	0.56
Government reports and	40.5	54.8	4.8	0		
briefings					3.36	0.57
Journal articles/academic	34.5	46.4	17.9	1.2		
literature					3.14	0.75
Face-to-face extension	23.2	52.4	20.7	3.7	2.95	0.77
Corporate databases	36.1	28.9	24.1	10.8	2.90	1.02
Professional association(s)	16.9	48.2	27.7	7.2	2.75	0.82
Seminars	7.3	51.2	37.8	3.7	2.62	0.68
Webinars/e-lectures	9.5	46.4	33.3	10.7	2.55	0.81
Consultants	14.5	38.6	32.5	14.5	2.53	0.92
Newspapers/magazines	10.8	39.8	41.0	8.4	2.53	0.80

# Table 4.2Frequency of use of various data sources by forest and range<br/>managers (n= 88)

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%) responded that they needed access to the actual scientific data and results.
#### 4.4 **DISCUSSION**

The results of the survey led to further refinements of the monitoring framework. This reorganization is shown in Figure 4.3. Overall, the response rate for the survey was considered good with respondents coming from a variety of regions throughout the province and from a variety of levels of forest and range management. In terms of specific information needs, enhancing and maintaining forest and range productivity seemed to be the impetus behind many of the respondents' key climate change information needs. This is no surprise, given that many of the forest and range managers who responded to the survey represented the then Ministry of Forests and Range, whose stated purposes and functions under the Ministry of Forest and Range Act 1996 were 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). When the other respondent groups were considered, the importance of forest productivity was reduced and a number of the water-related topic areas were rated more highly. All respondents regarded ecosystem distribution and composition as important for monitoring in light of climate change. This is in line with the broad use of this indicator throughout many of the indicator frameworks examined in Chapter 2. Species range and phenology was also noted as being of strong importance to all groups who responded to the survey. Issues with the capacity of existing data sources to support monitoring of this indicator was once again raised as an issue. Survey respondents also noted the need for increased contextualisation of the indicators. This need was addressed through the addition of an indicator specifically focused on the examination of temperature trends.

Another notable finding from this phase of the research was the need to supply climate change adaptation information to forest and range managers relatively quickly. The vast majority of respondents indicated that they were greatly in favour of earlier timeframes with many commenting that they needed monitoring information to be supplied to them as soon as possible so that they could start to incorporate data from the framework into decision making in the province. This finding influences the scale at which the indicators should be monitored and reflects the need to produce approaches to measuring the indicators that will produce information within relatively short timeframes. This factor was strongly considered when developing the indicators in Chapter 5.

Many forest and range managers confirmed that there were persistent and crucial gaps in the data available for managing forests and rangelands in British Columbia in light of climate change. The specific gaps that forest and range managers identified coincide well with the areas they identified as being most critical for monitoring (see section 4.3.3). This finding confirms the results of my preliminary investigation of the data available to support the indicators in the forest and range climate change monitoring framework. It highlights that 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 the Climate Related Monitoring Program, which is currently working to address gaps in the meteorological monitoring network.

Data gaps aside, a surprising number of respondents 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 indicate that the climate change information, initiatives and tools currently in operation in British Columbia 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. It may also show that there is a strong need for a framework to pull together a variety of these disparate data sources and present them in a cohesive format accessible to all environmental managers.

PRE-SURVEY (2009)	POST SURVEY (2010)	
Ecosystem drivers:	Climate change in context: • Temperature	
<ul><li>Precipitation</li><li>Snow pack</li></ul>	<ul> <li>Precipitation frequency, timing and form</li> </ul>	
• Water temperature	• Frequency of extreme, unseasonable or unexpected weather conditions	
• Water quality	Drivers of change:	
Glaciers	Streamflow rates and timing	
• Unseasonable or unexpected weather conditions	• Water temperature	
Natural Disturbances:	• Snowpack depth	
• Insects and diseases	• Water quality	
• Wind-throw	Spatial extent of glaciers	
• Fire	• Frequency and extent of landslides and other mass movement events	
• Mass movements <b>Biodiversity:</b>	• Fire season length and severity	
	• Extent of wind-throw damage	
• Distribution and composition of ecosystems	• Severity and frequency of attack by insects and pathogens	
• Forest productivity	Effects of climate change on biota:	
• Ecosystem connectivity	• Distribution and composition of ecosystems	
• Species diversity	Forest productivity	
• Genetic diversity	Ecosystem connectivity	
	• Range and phenology of key species	
	• Range and diversity of tree genotypes	

Figure 4.3 Changes made to the indicator framework as a result of the workshop

#### 4.5 CONCLUSION

As detailed above the results of this survey led to macro-level refinements of the monitoring framework including the re-organization of indicators under different criteria level headers and the development of a criterion examining the context of climate change in British Columbia. The following chapter of my thesis leads to further micro-level refinements to the framework through the assessment of how well the indicators are able to be monitored using several of the data sources that are currently available in the Province. In developing the approaches to measuring the indicators, I have taken account of the information reporting needs that were identified though this survey and I have also been mindful of the need for information to be derived from methods that would allow results to be presented and analyzed relatively quickly and in a format which is likely to be understood by forest and range managers.

# Chapter 5 - Development of approaches to measuring selected indicators, examination of the data collections available and regional level pilot testing

#### 5.1 INTRODUCTION

This chapter presents a first approximation examination of the extent to which six of the indicators identified and developed in Chapters 3 and 4 are able to be monitored using the data sources available in the Province. An in-depth analysis of the data sources available to monitor each indicator was undertaken and gaps and issues with these data were identified. Where data were available, the approaches developed for each indicator were pilot tested regionally in order to better determine the extent to which each indicator could be monitored.

This approach of undertaking a first approximation assessment of indicators before attempting to monitor them in their entirety was guided by thinking in many international and national criteria and indicator movements where there has been considerable effort put into the practical implementation of criteria and indicators, even though there is recognition that they may still be imperfect and incomplete. It is considered this will productively lead to refinement and improvement based on experience (Howell et al. 2008; ODF 2000; USFS 1997).

A small scope testing approach was adopted in order to further examine the data available to support the indicators that had been identified during the previous stages. This approach was selected because it provides a mechanism to examine the feasibility of the indicators and develop possible approaches to monitoring them without committing extensive resources to their analysis. The small scope tests involved conducting a preliminary test of the data collection tools and procedures available and sought to identify issues that might arise when examining the indicators at the provincial scale. My tests involved simulating the actual data collection process to get feedback about whether the instruments are likely to work as expected in a 'real world' situation. Tests were undertaken in various areas within the Southern Interior of British Columbia (Figure 5.1). This region was identified through a recent climate change vulnerability assessment as being a region where impacts of climate change on ecological systems are likely to be severe (Utzig & Holt 2009). While this area was used for testing, the datasets used and tested in the ensuing chapter were also examined for their capacity to assess the indicator on a province wide basis.

Indicators were selected for further analysis because they were perceived as being: of high importance for the framework, the data sources available to support them were likely to be particularly complicated (e.g., a large variety of sources available to support the indicator of uncertain quality) and were not the subject of an ongoing restructure or re-analysis (at the time this was the case for many of the climate and hydrological data sources identified).



Figure 5.1 The Southern Interior of British Columbia

## 5.2 TRACKING CHANGES IN ECOSYSTEM DISTRIBUTION AND COMPOSITION

#### 5.2.1 Context for monitoring this indicator

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 (Hebda 1997; Rizzo & Wiken 1992). The lives of animals, plants, and microorganisms that make up ecosystems are strongly attuned to changes in climate and a number 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 (Bunnell et al. 2008; Gregory et al. 2009; Parmesan & Yohe 2003; Soja et al. 2007). While the global climate has always been subject to 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 (IPCC 2007b; Moberg et al. 2005). 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.

The results of previous research conducted through Chapters 3 and 4 show that tracking changes in the distribution and composition of ecosystems is considered to be a core indicator for monitoring the effects of climate change in British Columbia. 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 British Columbia (Chapter 4), monitoring changes in ecosystem composition and distribution was regarded as extremely important for monitoring in light of climate change. Specifically, many of those 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 health.

Ecosystems can be classified at almost any scale, from global classifications down to local assemblages of species. In British Columbia, the Biogeoclimatic Ecosystem Classification (BEC) system is a highly regarded hierarchical classification system that stratifies the landscape in map units according to a combination of ecological features, primarily climate and physiography (Meidinger et al. 1991; Pojar et al. 1987). 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 focal level of my analysis.

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 (Hamann & Wang 2006; Hebda 1997; Nitschke & Innes 2008b; Rizzo & Wiken 1992). 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 the Alpine Tundra and Spruce – Willow – Birch zones, which are projected to decrease by 97 and 99 % respectively (Hamann & Wang 2006). Researchers point out, however, that the individual species that make up current ecosystems will be affected differently by climate change (Rizzo & 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 shifts of ecosystems to areas that are better suited (NRC 2008; Rizzo & Wiken 1992). 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. In this section of my thesis I present the proof of concept for an approach that could be used to direct the current forest monitoring and inventory programs available in British Columbia to such an analysis. My preliminary results show that, while some bolstering of the existing monitoring undertaken within the Province is required, the Province does have the existing institutional capacity to start to examine how ecosystem distribution and composition is changing with climate change.

#### 5.2.2 Assessment of the data sources available for monitoring this indicator

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 it is the only inventory program operating in British Columbia that is consistent over both space and time. The NFI offers a scientifically defensible distribution of plots across the Province and an ongoing re-measurement strategy that collects data for both the ground plots and the photo plots every ten years. When examined together and combined with other data sources available in British Columbia, namely the Terrestrial Ecosystem Mapping (TEM) or Vegetation Resources Inventory (VRI) mapping, in my opinion 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. 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 British Columbia 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 20 km by 20 km grid with each plot measuring 2x2 km. In British Columbia they are currently identified based on conventional, mid-scale aerial photography (Gillis et al. 2005).

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: 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 British Columbia 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 plots 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.

Two suitable mapping systems are currently being used in British Columbia 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 communities. TEM and VRI are suitable for my approach to monitoring ecosystem distribution and composition because they are designed for use at larger scales where more detailed information is required. In order to be able to effectively supply information to decision-makers, the subtle changes that are occurring over relatively small timeframes need to be able to be recognised.

Administered by the Ecosystems Branch of the 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. 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 estimates to produce final maps (TEM 1998; VRI 2010).

The proposed method uses 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, 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. One hectare sized cells were chosen because this is the level of detail that can be interpreted from aerial photographs and changes overtime can be quickly and easily determined by comparing the differences in cell values. 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 can also be analyzed 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 in section 5.2.1 above.

#### 5.2.3 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. The location of these plots was supplied by the National Forest Inventory. These six plots were selected because each 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. A detailed account of the approach used is provided in Box 1, Appendix D.

The results of this analysis are shown in Figures 5.3 - 5.8. Table 5.1 provides the areas of BEC variants found within each of the plots.



Figure 5.2 NFI Plot 1335001 mapped using VRI and TEM to BEC variant level



Figure 5.3 NFI Plot 1348756 mapped using VRI and TEM to BEC variant level



Figure 5.4 NFI Plot 1355646 mapped using VRI and TEM to BEC variant level



Figure 5.5 NFI Plot 1376296 mapped using VRI and TEM to BEC variant level



Figure 5.6 NFI Plot 1396936 mapped using VRI and TEM to BEC variant level



Figure 5.7 NFI Plot 1486426 mapped using VRI and TEM to BEC variant level

### Table 5.1Area 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

#### 5.2.3 Extent to which the indicator can be monitored using existing data

The tests show 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. Further analysis and discussion between the relevant organizations may be required in order to obtain the most accurate baseline possible. To develop 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 useful for responding to climate change information needs and also for better addressing some of the indicators used in provincial, national and international reporting initiatives. These include those indicators examined through the British Columbia 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 the proposed approach as it means that a number of broad ecosystem groupings in British Columbia 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 determined the extent of NFI ground plots by BEC zone. As shown in Figure 5.10, 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 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 composition using aerial imagery along with the procedure described above.



Figure 5.8 BEC zone areas and number NFI ground plots

### 5.3 AN APPROACH FOR ANTICIPATING AND RESPONDING TO CLIMATE CHANGE BY TRACKING CHANGES IN FOREST PRODUCTIVITY

#### 5.3.1 Context for monitoring this indicator

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 (Boisvenue & Running 2006; Case & Peterson 2009; Perry et al. 1989). For the propose of this indicator forest productivity is referred to in its broadest sense and includes the ability of the forest to deliver all the vital 'ecosystem services' required for human and environmental well-being. 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). 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 production of such services.

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 changes 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 forest productivity (NRC 2008; Parry et al. 2001; Rosenzweig & Wilbanks 2010).

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 & Running 2006). For instance, studies that incorporate higher temperatures, increased  $CO_2$  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 (Latta et al. 2010;

Lemmen & Warren 2008). In any case, there is no doubt that climate change will affect – and is indeed already affecting - forest productivity.

In my survey (Chapter 4) many environmental managers working in British Columbia rated forest productivity as the single most important topic they 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 indirect impacts of climate change on forest productivity in British Columbia have already been encountered. As mentioned in Chapter 1, the mountain pine beetle infestation, triggered by warmer winters, impacted more than 14.5 million hectares of forest in B.C. between 1990 and 2008, having profound effects on ecosystems, community economic viability and the provincial economy (MOE 2010). Estimates of forest productivity drive timber supply analyses and forest planning endeavours such as standards for species selection, seed transfer and stocking (Spittlehouse & 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 commonly used traditional methods are measures of overall forest volume and the use of a site index. This chapter outlines my 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 British Columbia, may be useful for tracking trends in the growth rates of tree species - particularly merchantable tree species. Further details of these datasets and an assessment of their capacity to be used to monitor the forest productivity indicator is provided below.

#### 5.3.1 Assessment of the data sources

#### Vegetation Resources Monitoring Program

In 2003, British Columbia completed the first Provincial component of the NFI photo database and the corresponding ground sample component was completed in 2006. The photo database was then updated for disturbance changes in 2006 and 2009. The resulting database was the British Columbia 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 prepared a report on the VRMP which details the information that can be generated from the VRMP photo plot database. This includes: 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 British Columbia has already been tested by the Forest Analysis and Inventory Branch in order to generate estimates of forest resource changes due to natural and human induced disturbances and growth for the period of 2000–2009 (Yuan 2010). 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 British Columbia during this timeframe is -320.7 million m<sup>3</sup>. This net loss of forest volume can be largely attributed to harvesting, fires and mortality caused by the Mountain Pine Beetle. The report further comments that these totals are significantly greater than the corresponding increases due to forest growth (Yuan 2010).

Although further scientific research would be needed to credibly link reported changes in forest productivity to climate change (such as that linking Mountain Pine Beetle tree mortality with climate change) the VRMP has obvious relevance for climate change monitoring. 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 for 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. It would be a valuable addition and would present an improved measure of forest productivity over time.

The Forest Analysis and Inventory Branch allowed me to use the VRMP database to assess how practical it was for reporting on changes in forest resource volume. I received the VRMP database information on 22 October 2011. Using the database I was able to quickly and easily obtain the same figures as listed in the report above. However, it was necessary to use only a large (i.e. ecoprovince or above) area for analysis because the data could not accurately report at the forest district level or below and therefore have limitation when being used in decision making occurring at this level.

#### Growth and Yield Permanent Sample Plots in British Columbia

Growth and Yield Permanent Sample Plots in British Columbia are long-term monitoring plots established in forest stands for the purpose of providing information on the rates of growth, mortality and changes in stand structure from stand establishment to maturity. As detailed in Chapter 3, 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 British Columbia through the calculation of site index. Site index as a measure of forest site productivity is a universal concept that is practiced in all forest regions globally with minor variations (Avery & Burkhart 2002). In British Columbia, site index is defined as the diameter 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). 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.

A further analysis of the Permanent Sample Plots as a data source was conducted to expose any issues related to its use for assessing the impacts of climate change on forest productivity. This assessment showed that there are a number of adverse issues with the dataset, leading me to exclude it from further pilot testing. 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. However, the ages listed in the current dataset have been shown to be inaccurate when verified against dendrochronological samples (Kevin Hardy, PSP Data Custodian, Ministry of Forests, Land and Natural Resource Operations). There has been some past work undertaken collecting dendrochronological samples to verify the age of Permanent Sample Plots trees, although this was restricted to coastal areas (outside my study area). Another issue is that a number of the plots may be in areas that have been damaged (e.g., from pests and disease or wind throw damage) and thus they should be excluded from the dataset. These plots need to be excluded from the current dataset in order for it to be accurate enough to be useful in determining an accurate site index.

These issues make it difficult to use the PSP data in its current format, however it is still regarded as useful and, with some development, this source of data is likely to be an valuable source of climate change adaptation information. Recommended development includes: isolating the tree species data that may best be examined, determining which plots have an existing long-term historical record, examining which plots occur within close proximity to a weather station, and collecting dendrochronological samples for a selected sub-set of plots identified.

#### 5.3.2 Extent to which the indicator can be monitored using existing data

Overall there are a number of data sources available to support this indicator. 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 Permanent Sample Plots dataset, despite its current shortcomings, appears to have

potential for climate change and tree growth analyzes. Given the high ranking of forest productivity information improvement of the Permanent Sample Plots data are highlighted as an important area for future development.

# 5.4 EXAMINING THE IMPACT OF CLIMATE CHANGE ON SPECIES LEVEL DIVERSITY

#### 5.4.1 Context for monitoring this indicator

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 (Parmesan & Yohe 2003; Root et al. 2003; Walther et al. 2002). Range shifts towards the poles and higher altitudes have been reported frequently in the scientific literature (Colwell et al. 2008; Crimmins et al. 2009; Hickling et al. 2006; Svenning & Condit 2008; Wilson et al. 2007) along with phenological changes such as delays in autumn events and advances in spring events (Crimmins et al. 2009; Kullman 2007) and migration dates (Both & te Marvelde 2007; Gienapp et al. 2007; Gordo 2007; Jonzén et al. 2007; Knudsen et al. 2007; Mustin et al. 2007; Pulido 2007; Rubolini et al. 2007). In some cases, these range and phenological changes are leading to alterations in resource availability and uncoupling of relationships (Cresswell et al. 2008; Post & Forchhammer 2002; Tremblay & Boudreau 2011).

In British Columbia 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 British Columbia species, pressure may come from factors such as reductions or alterations in suitable ecosystems or habitats and/or 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 & Hannah 2005). 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; Rosenzweig & Wilbanks 2010; Wilson et al. 2005).

#### 5.4.2 Assessment of the data sources

In the initial phase of this research, this indicator was proposed to be assessed by looking at trends in range and phenology for species from a range of taxa and habitats. However during the indicator development workshop (Chapter 3), concerns were raised about the availability of data for such an analysis. Further examination of the available data sources indicated that these concerns were well-founded. When this indicator was initially proposed, over ten different data sources were identified as having potential for supporting an analysis of changes in species' ranges and phenologies. Many of the data sources belonged to the British Columbia Government's Ministry of Environment and included the Conservation Data Centre, Ecocat, British Columbia 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 the 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 range and phenology were established and studied to a level that the data could be used 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 be in the order of 6 km per decade, as suggested in the academic literature (Lovejoy & Hannah 2005; Parmesan & Yohe 2003). While some of the data sources do provide some locations where species have been they do not represent a comprehensive distribution for the recorded. species/ecological community and without a good idea of the current known range of a species, any changes in range are unlikely to be picked up. 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 datasets including the British Columbia 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 that would be of use in assessing changes in species range and phenology. The exception is birds for which there are data collected by the public and stored in the British Columbia Breeding Bird Atlas, eBird and Nature Counts. Good collections of data about birds appear to be an international trend, with a variety of other climate change researchers commenting that bird monitoring datasets represent the most comprehensive time-series environmental data in existence (Cox 2010; Lovejoy & Hannah 2005; Newman et al. 2010). Moller and Fiedler (2010) note that this type of publically collected data is an under-utilised resource. However, they also comment extensively on the reliability of such data and point out the many potential errors and biases that can occur. They note that for bird observation databases (such as the British Columbia Breeding Bird Atlas), the most concerning errors and biases include: change in observer effort, spatial and temporal variation in observer effort and change in the quality of observers. Errors associated with temporal and spatial variations in observer effort are particularly concerning for British Columbia with a large proportion of the Province relatively remote from human population centres. In examining the data available from this dataset and the data needs for this framework, there are also more specific issues regarding the method of data collection that arise. For example, whether the path over which a particular bird species flies over is identified as part of its range or suitable habitat – which is currently the case. The other major difficultly with such datasets is cross-validation and critical tests of data quality. Despite these issues, there has been evidence of researchers accounting for such errors and using such publically collected bird data to draw conclusions regarding changing bird ranges, arrival dates, departure dates, and over-wintering population levels (Bunnell et al. 2008).

#### 5.4.3 Extent to which the indicator can be monitored using existing data

The results of the forest and range decision-maker survey showed clearly that, while both species' ranges and phenologies were of great interest to survey respondents, this interest was often framed in the context of the need to enhance and preserve forest and range productivity and/ or improving the understanding of the ecosystem level changes resulting from climate change (see Chapter 4 for further information). Given that there are few data sources currently available to exploit in this area and the need to constrain and target the collection of data to support the framework as much as possible, it may be appropriate in the preliminary stages that further efforts to examine this indicator be combined initially into the monitoring/assessments conducted through the previously examined indicators (ecosystem distribution and composition and forest productivity). Concentrating on the bolstering and better use of the data sources associated with those indicators; in particular, the NFI and Permanent Sample Plots datasets (described in Sections 5.1 and 5.2), could lead to strong improvements in the capacity to monitor at least a small selection of plant species effectively under this indicator.

## 5.5 EXAMINING ECOSYSTEM CONNECTIVITY IN THE CONTEXT OF CLIMATE CHANGE

#### 5.5.1 Context for monitoring this indicator

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 (Adler & Nuernberger 1994; Anderson & Danielson 1997; Brudvig et al. 2009; Fahrig & Merriam 1985; Lindenmayer et al. 2008; Long et al. 2010). Climate change creates new challenges for biodiversity conservation and the need to preserve and manage ecosystem connectivity has taken on a renewed importance (Kramer et al. 2010; Lovejoy & Hannah 2005). In a review of over one 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 & 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 (Bunnell et al. 2008; Gregory et al. 2009; Parmesan & Yohe 2003; Soja et al. 2007). 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 (Hamann & Wang 2006; Hebda 1997; Rizzo & Wiken 1992). Successful colonization

of new habitat will depend in part on the degree of landscape connectivity (Kindlmann & 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 measures the connectivity between ecosystems in order to determine and isolate those areas that are particularly vulnerable in a climate change environment. In the scientific literature ecosystem connectivity is described as the degree to which a landscape facilitates or impedes movement of organisms among patches (Fahrig & Merriam 1985; Taylor et al. 1993); or more simply; the ease with which individuals can move about within the landscape (Kindlmann & 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 in the direction of the poles or to higher altitudes) (Donald & Evans 2006). Corridors are continuous areas of habitat that have been traditionally thought of as structurally connecting two otherwise noncontiguous 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 been extended to include the concept of a 'temporal corridor' (Rose & Burton 2009). A temporal corridor is identified as the intersection of an ecological feature's current distribution with its distribution predicted as a result of bioclimate envelope modelling (Rose & Burton 2009). The concept of bioclimate envelope modelling and the recent work of researchers in British Columbia were 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 & Wang 2006; Rose & Burton 2009; Virkkala et al. 2008; 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 & Dawson 2003). Model outputs 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 Wang (2012) was used to analyze temporal corridors for various BEC zones within my study area. In order to add some further context to this information I used additional data, namely the British Columbia roads layer and tenure layer.

#### 5.5.2 Assessment of the data sources

The area of interest for the case study was the Thompson Okanagan Eco-region in the south east of British Columbia (Figure 5.11). This area was chosen for preliminary analysis because there was strong interest in my project work from the district level environmental managers in the region. As with all of the indicators tested, the data sources are available provincially and such an analysis could effectively be undertaken anywhere in the Province.



### Figure 5.9 The Thompson Okanagan Eco-regions

#### Determining the BEC zones of interest in the area

To determine which of the BEC zones to use in the analysis, the BEC dataset was downloaded on June 2010 in order to examine the zones falling within the Thompson Okanagan Eco-regions. Ten BEC zones were recorded in the area. However, some of these only occupied very marginal territory on the border of the region (Figures 5.11, 5.12). These marginal areas were excluded from my analysis because their inclusion was likely to be the result of slight differences in boundaries delineated in the GIS datasets used. This left only the six main BEC zones in the region which were examined.



Figure 5.10 BEC zones excluded and of interest in the Thompson Okanagan Eco-regions

#### Bioclimate envelope model

The latest bioclimatic envelope models prepared by Wang (2012) from the University of British Columbia (designed for FFEI project grantees) were 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.


Figure 5.11 BEC zones within the Thompson Okanagan Eco-regions

#### Roadedness

In order to better understand and visualise the effects of these predicted ecosystem changes due to climate change and 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, Ministry of Environment 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 (Crist et al. 2005; Noss & Cooperrider 1994). Roads can also facilitate transport for some species and can potentially benefit predators. 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 (MOE 2012; Noss & Cooperrider 1994).

In order to develop the roadedness layer, the provincial roads dataset (obtained from the Land and Resource Data Warehouse in October 2010) and input into Arc GIS's "Kernel Density" tool. This raster output represents 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 but other distances could be used depending on the scale of analysis). 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 results of my analysis are shown in Figure 5.13 with the more roaded areas appearing as the darker areas on the map.



Figure 5.12 'Roadedness' within the Thompson Okanagan Eco-regions

## Tenure

In addition to roads I also looked at the land tenure within the study area. Those areas under private ownership were considered to be potentially more vulnerable to future land use change as they could not as easily be subjected to changes in their tenure/reservation status. I could not locate a private land spatial dataset for British Columbia in any of the key data warehouses and therefore developed one by excluding those areas held in publically-owned tenures or which were in some way the responsibility of the Crown. It is presented in Figure 5.14.



Figure 5.13 Private land located within the Thompson Okanagan Eco-regions

#### 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.

#### **Bunchgrass**

Using Wang's BEC modelling data, the area of Bunchgrass in the Thompson Okanagan Eco-regions is projected to increase slightly, particularly in the northeastern portion of its range in the region (Figure 5.16) (Wang et al. 2012). 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 will 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 5.17). Of the predicted 2080s area of 2,192,353 km<sup>2</sup>, 26% 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.

#### Interior Cedar Hemlock

Using Wang's BEC modelling data, the area of Interior Cedar Hemlock (ICH) in the Thompson Okanagan Eco-regions is projected to increase, particularly in the southern portion of its range in the region (Figure 5.18). There are few roads in the region of these major increases. However, despite these predicted gains, there appear to be few persistent temporal corridors to facilitate movement into the new range. This may

indicate that the rise of this ecosystem type in the new climatic zone may not be feasible. Of the predicted 2080s area of 7,436,058 km<sup>2</sup>, only 8% of the climatically suitable range for ICH is predicted to remain constant between the three time slices and that area is limited to the northeastern edge of the Eco-regions (Figures 5.19).

### Interior Douglas-fir

Using Wang's BEC modelling data, the area of Interior Douglas-fir (IDF) in the Thompson Okanagan Eco-regions is projected to increase in the near future (2020s) and then decrease back to slightly below its current range in the region by 2080 (Figure 5.20). 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 2080s range of 13,624,544 km<sup>2</sup> appears to be persistent across the three time slices (Figure 5.21).

#### Ponderosa Pine

Using Wang's BEC modelling data, the area of Ponderosa Pine (PP) in the Thompson Okanagan Eco-regions is projected to increase, particularly in the north-eastern portion of its range in the region (Figure 5.22). Some of the area in which these predicted increases occur is heavily roaded, which may prove to be an issue for the ecosystems in the area. In addition, it appears there may be few persistent temporal corridors to facilitate movement of genetic material into the new range. This may indicate that expansion of this ecosystem type in the new climatic zone may not be feasible. Of the predicted 2080s area of, 9,050,664 km<sup>2</sup> only 9% of the climatically suitable range for PP is predicted to remain constant between the three time slices. In addition, this persistent area is in heavily roaded areas and mainly occurs on private land (Figure 5.23).

## Engelmann Spruce Subalpine Fir

Using Wang's BEC modelling data the area of Engelmann Spruce Subalpine Fir (ESSF) in the Thompson Okanagan Eco-regions is projected to decrease markedly to

almost nothing by the 2080s (Figure 5.24). 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<sup>2</sup> of the ESSF range remaining in the 2080s over 80% is consistent across the three time zones. However, this is only because the range has contracted so extensively elsewhere in the region (Figure 5.25).

#### Montane Spruce

Using Wang's BEC modelling data, the area of Montane Spruce (MS) in the Thompson Okanagan Eco-regions is also projected to decrease markedly to almost nothing by the 2080s (Figure 5.26). 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<sup>2</sup> of the MS range remaining in the 2080s is consistent across the three time zones (Figure 5.27).



Figure 5.14 Projected change in area for the Bunchgrass zone in the Thompson Okanagan Eco-regions



Figure 5.15 Overlap between the predicted Bunchgrass areas of the four time slices



Figure 5.16 Projected change in area for the Interior Cedar Hemlock zone in the Thompson Okanagan Eco-regions



Figure 5.17 Overlap between the predicted Interior Cedar Hemlock areas of the four time slices



Figure 5.18 Projected change in area for the Interior Douglas-fir zone in the Thompson Okanagan Eco-regions



Figure 5.19 Overlap between the predicted Interior Douglas-fir areas of the four time slices



Figure 5.20 Projected change in area for the Ponderosa Pine zone in the Thompson Okanagan Eco-regions



Figure 5.21 Overlap between the predicted Ponderosa Pine areas of the four time slices



Figure 5.22 Projected change in area for the Engelmann Spruce Subalpine Fir zone in the Thompson Okanagan Eco-regions



Figure 5.23 Overlap between the predicted Engelmann Spruce Subalpine Fir zone areas of the four time slices



Figure 5.22 Projected change in area for the Montane Spruce zone in the Thompson Okanagan Eco-regions



Figure 5.23 Overlap between the predicted Montane Spruce zone areas of the three time slices

#### 5.5.4 Extent to which the indicator can be monitored using existing data

The approach that I have tested in the Thompson Okanagan Eco-region 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, tested here, builds nicely on Wang's bioclimatic modelling work and offers a very useful analysis for highlighting the likely extent of overlap between the climatically suitable range of an ecosystem and the likelihood that an ecosystem's connectivity will be affected negatively by climate change. The use of additional spatial datasets, such as the roadedness and tenure information presented here, provides considerably more depth 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 categorizes the extent of roadedness. For example, the areas that I have classified here as being 'most roaded' may not be categorized as such when working with provincial level data. In addition, I used only one distance (5km) for all roads when creating the roadedness layer. This distance should be, in essence, the distance from which the impact of the road on the BEC zone in question becomes zero. However, roads have varying effects depending on their size i.e. a large four lane highway is likely to have a greater effect on ecosystem connectivity than a smaller local road (MOE 2012). 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 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.

## 5.6 TRACKING CHANGES IN FIRE SEASON LENGTH AND SEVERITY

#### 5.6.1 Context for monitoring this indicator

There is relatively high uncertainty associated with most studies examining the effect of climate change and forest fires. However, 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 of the fire season length (Flannigan et al. 2006; Gillett et al. 2004; Hawkes et al. 2005; Metsaranta et al. 2011; Podur & Wotton 2010). In particular, southern and central parts of British Columbia 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 and loads. Other factors that influence fire seasons include wind, lightning frequency and fire management regimes.

In my survey of environmental managers working in British Columbia, information on fire season severity was rated as being moderately important for bringing climate change considerations into forest management and operational practices in the Province. In comparison, fire season length was seen as being of lower importance (Chapter 4). 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.

From 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 for 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).

#### 5.6.2 Assessment of the data sources

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 from the Ministry of Forests, Land and Natural Resource Operations 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 spreadsheet. Using pivot tables I was able to plot 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. As was the case with the other indicators examined, this study area could be readily substituted with any other region in the Province as the dataset covers the entire Province. While there were a number of stations in this district, I only examined the data from four: Creston, Duncan, Goatfell and Howser; these stations had the longest historical records. I plotted 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.

#### Creston

The Creston Fire Weather Station has very good fire weather data that stretch from 1983 through to 2009. Records are missing for the years 1985 - 1989 in addition to a few other daily records. Trends for the station over the data collection time period show increasing fire weather severity rankings across all fire season months (July – September) (Figure 5.27). The fire season length also appears to be increasing in the area with the Creston station experiencing a trend towards a moderate fire weather danger class ranking in July and September over the last few years (2007 - 2009) where previously very low and low fire danger classes were recorded.

#### Duncan

The Duncan Fire Weather Station also has good fire weather data that stretch from 1981 through to 2009. Data are missing for the period 1983 – 1988 in addition to a scattering of 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 5.28).

#### 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 over this time period show a slight upward trend in fire weather severity rankings across all fire season months (July – September) (Figure 5.29). The fire season length also appears to be increasing in the area with the Goatfell station experiencing a moderate fire weather danger class ranking in July and September over the last few years where previously a low fire danger class was recorded.

#### 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 5.30

shows trends for the station over this time period and reveals 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 a moderate fire weather danger class ranking in July and September over the last few years where previously a low fire danger class was recorded.





Figure 5.26 – Creston seasonal severity rankings for fire season months and record counts 1983, 1984, 1990 – 2009



Figure 5.27 – Duncan seasonal severity rankings for fire season months and record counts 1981, 1982, 1989 – 2009



Figure 5.28 – Goatfell seasonal severity rankings for fire season months and record counts 1986 – 2009



Figure 5.29 – Howser seasonal severity rankings for fire season months and record counts 1980 - 1984, 1986 - 2009

#### 5.6.3 Extent to which the indicator can be monitored using existing data

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. 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 that I have described above with the dates of the first and last recorded fire (of a certain severity) of the season. These data were requested from the Wildfire Management Branch but they were unable to supply such information at the time.

# 5.7 EXAMINING INSECTS AND DISEASES AFFECTING FOREST HEALTH IN THE CONTEXT OF CLIMATE CHANGE

#### 5.7.1 Context for monitoring this indicator

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; Hansen et al. 2001a; Innes et al. 2009; Logan & Powell 2005). 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 (Ayres & Lombardero 2000; Lovejoy & Hannah 2005). 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 British Columbia where insects and pathogens are already affecting forest health as a result of the climatic changes (i.e. Mountain Pine Beetle and Dothistroma Needle Blight) (Taylor et al. 2007; Welsh et al. 2009; Woods et al. 2005). 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 my survey of environmental managers working in British Columbia, 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. Pathogen incursions were seen as being of a lower importance.

#### 5.7.2 Assessment of the data sources

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 (approximately 9 different species) and defoliators (approximately 21 different species) is recorded. Twelve different diseases are monitored.

The Ministry of Forests, Land and Natural Resource Operations Forest Practices and Investment Branch produces an annual summary of aerial overview surveys for Southern British Columbia (MFR 2012a). Although no summaries are produced for other areas, these data are gathered provincially so regional summary reports could be generated. The summary report for 2010 gives a detailed analysis for the Southern British Columbia region. It concluded that the 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 insect. Other insects 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 insects and diseases, the success, or otherwise, of various treatments applied are also reported.

#### 5.7.3 Extent to which the indicator can be monitored using existing data

As with the fire data, the baseline data available for monitoring the effects of insects and diseases are very good. The issue with monitoring this indicator will be drawing cross linkages between the data recorded for monitoring forest insects 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 Northwest in recent years (e.g., Woods et al. 2005 and Taylor et al 2005).

#### 5.8 **DISCUSSION**

This small scope testing approach, where the data to support a selection of the indicators has been directly tested in a real world environment, has been vital for developing a better understanding of the strengths and weaknesses of the data available to support the indicators. Without this type of testing it is difficult to determine the extent to which the data sources are accurate and comprehensive enough to be used in the ongoing assessment of the indicators at the required scales.

This study has also shown that there are some strong data collections held provincially that could be used as a basis for providing the information necessary to respond to climate change adaptation information needs. These include datasets collected and analyzed by both Provincial and Federal Governments. In some cases these datasets can be used effectively at a more localised scale (e.g., PSP), but others (e.g., VRMP) cannot. While this research has shown that many of these datasets do have the capacity to be used with only slight augmentation, there are some indicators for which there is a paucity of data. Key among these is the indicator examining species diversity. Respondents to the survey (Chapter 3) very clearly indicated that they wanted more data

about the adaptability of tree and grass species to climate change. The Province appears to be lacking any long-term species level data that can be readily used to respond to this identified information need. In terms of tree species, a more purposeful and streamlined PSP dataset could be a solution. Key improvements may include a rationalisation of the existing number of plots with a greater focus on producing more targeted, quality data including, most critically, more accurate assessments of the exact age of trees verified against dendrochronological samples. Similarly, having three different government agencies maintain three different ecosystem, distribution and composition datasets seems to be a triplication of effort. Combining resources may lead to a better and more useful end product with greater coverage, accuracy and depth.

Issues also remain with correctly 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 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 examining the effects of climate change on British Columbia's environment. Because of a recognized need to make climate change policy and decisions at a provincial level, the focus of this research has been mainly on 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 my thesis. 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.

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. Modelling the possible future distributions of the BEC zone climates is a prime example (Hebda 1997; Nitschke & Innes 2008b; Rizzo & Wiken 1992) but there is also strong modelling work being done in the area of insects and diseases (Taylor et al. 2007; Woods et al. 2005), stream temperature (Nelitz et al. 2008) and fire (Nitschke & Innes 2008b). Strong linkages between the data collected under this monitoring framework and the type of data generated by this type of modelling work may serve to better verify the extent to which predicted changes have actually occurred and to calibrate models to more accurately predict future changes.

## 5.9 CONCLUSION

This chapter has shown that there are a number of very strong data collections within the Province that could be mobilised to better examine the effects of climate change and start to supply the information that is needed to bring climate change considerations into forest and range management. The approaches to monitoring that have been developed and described in the above chapter have already been the subject of discussion with many concerned parties within the Provincial government many of whom who have expressed interest in further developing the data sources available in line with the recommendations supplied. The following chapter provides a conclusion and summary of the research findings of the project in its entirety and presents recommendations for further research that could be used to extend the results of this project including further development of the data sources I have undertaken through this chapter.

## **Chapter 6 - Conclusion**

In this chapter I highlight the key findings from the previous chapters I also provide commentary on the status of relevant hypotheses outlined in the introductory chapter. The overall significance of the research and the potential future applications are identified along with possible future research needs.

## 6.1 KEY FINDINGS

The following key findings are intended to summarize the main conclusions reached from this study. These findings are based on the results of this study and also draw from broader literature in this area.

6.1.1 Key finding #1: Diverse ecological and other biophysical data are increasingly being relied upon by forest and range managers in many areas to determine the effect climate change is having on the natural environment (Chapter 2, 3 and 4).

Research undertaken in the initial stages of this project explored some of the key environmental monitoring and reporting initiatives that have been undertaken in the last few decades. Over thirty different monitoring programs operating at a variety of levels, regions and countries have been identified. These different programs show that there is a strong drive across the globe to better understand the impact that climate change is
having on the natural environment and to start to incorporate some of the findings from these programs into political decision making.

The diversity of the programs identified in Chapter 2 and coupled with those identified through additional research in Chapters 3 and 4 illustrates that there is no universally applicable approach to monitoring. Differences in environmental factors, coupled with differing political, economic and social situations, makes it necessary to tailor a particular monitoring program to a particular region, depending on its unique needs and circumstances.

6.1.2 Key finding #2: There are some clearly identifiable topic areas which forest and range managers in British Columbia want information on in order to better introduce climate change considerations into their decision making (Chapter 3 and 4).

The Indicator Development Workshop (Chapter 3) and the Forest and Range Mangers Climate Change Information Needs Analysis Survey (Chapter 4) highlighted that there are some very clear information requirements that are needed in order to better incorporate climate change considerations into forest and range management. In most cases forest and range managers' information needs reflected a strong emphasis on enhancing information that will allow them to proactively respond to the reported and predicted changes in climate through their management regimes and actions. Key among these was the need for information on the effects of climate change on ecosystem distribution and composition and species range and suitability. 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. The overarching effects of climate change and a better ability to put climate change in context was also an expressed information need this included recording and examining factors such as temperature, precipitation and the incidence and severity of extreme events (such as storms and droughts). 6.1.3 Key finding #3: Forest and range managers believe it is important to start incorporating climate change considerations into their decisions and actions as soon as possible. However, many forest and range decision makers are not currently getting the information they need to incorporate climate change into their decision making and/or are not aware of what information is available to them.

Forest and range managers responding to my survey indicated strongly that they saw an immediate need to start incorporating climate change considerations into their decision making. Many survey respondents commented that they need advice on what to do now and the sooner information could be provided to them the better.

Research undertaken and described in the previous chapters showed that the majority of forest and range mangers in British Columbia did not feel confident that they had the information they needed to incorporate climate change considerations into their decision making. The survey showed that there were multiple reasons behind this. Substantive issues include the genuine data gaps and lack of analyses undertaken within the Province. A more pressing and possibly more easily mitigated issue, however, appeared to be that many forest and range mangers were not aware of what, if any, information is currently available to them. There appears to be a strong need for a framework such as this one to summarize, analyze and incorporate information in a format that is useful and easily consumed by them. This issue was particularly pronounced for those managers operating at the district level.

6.1.4 Key finding #4: There are a number of data sources that are currently collected in the Province that could be used to better manage forests in light of climate change with little or no augmentation.

My Chapter 5 study of the data sources available to support the analysis of a selection of the indicators has shown that there are some very strong data collections held provincially that could be used to meet climate change adaptation information needs. While this research has shown that many provincial datasets do have the capacity to be used in their current format, others need to be augmented slightly to be able to be effective (e.g., the PSP). Overall, while some datasets are very strong and unique (e.g., fire and pest and disease data), there appears to be a lack of communication between some of the other data holders that is causing a duplication of effort. For instance, the case study undertaken on ecosystem distribution and composition data in British Columbia showed that there are three different government organizations in the Province holding ecosystem distribution and composition data (NFI, VRI, TEM). Small modifications to link the NFI data to those long-term data held provincially would vastly improve the capacity to determine ecosystem-level change at a scale and rate relevant to forest and range decision makers. Better collaboration between these organizations would be worthwhile in order to increase the ability of these datasets to maintain accuracy and coverage and solidify data collection programs in the long-term.

# 6.1.5 Key finding #5: There are persistent gaps in British Columbia's biophysical data that make it difficult to monitor some of the key climate change related concerns.

Chapter 5 assessments of existing data sources show that there is currently a paucity of trend information from which meaningful assessments of the impacts of climate change on forests and rangelands could be developed. With the exception of the datasets identified for monitoring the effects of fire, and insect and pathogen damage, there were few solid ongoing data collections which could be used to ascertain to what extent climate change was affecting British Columbia's forest and rangelands. For some indicators (e.g., ecosystem distribution and composition), minor bolstering of the existing monitoring may adequately fill this information gap. By contrast, for other indicators this data gap was larger and could not be easily ameliorated. For example, aside from the publically collected data on birds, I could not find any species whose ranges and phenologies were established and periodically studied to a level that the data could be used in determining the effect that climate change is having on species in question at the provincial scale.

#### 6.2 STATUS OF RELEVANT WORKING HYPOTHESES

In this section, I revisit the hypotheses put forward in Chapter 1 and the major research questions that were outlined and addressed through my research.

# 6.2.1 Question 1: What efforts have been made to date locally, nationally and internationally to monitor the effects of climate change on the environment?

<u>Hypothesis 1:</u> There are relevant and useful examples of terrestrial monitoring programs for determining the impacts of climate change on the environment.

As detailed in Chapter 2, there have been considerable efforts to date to incorporate climate change considerations into environmental monitoring. The number and diversity of these attempts illustrate that climate change is now taken seriously and there are efforts to better account for it in environmental monitoring occurring at a variety of levels. While many of the monitoring frameworks do serve as useful examples, the extent to which these efforts are genuinely successfully determining the impacts of climate change on the environment and passing on useful information that can be used by environmental managers is not known. Further research is needed to assess whether or not these frameworks (many of which are only in their infancy) are generating the required information and the extent to which they are able to consistently deliver that information over the coming century.

### 6.2.2 Question 2: What are the most important biophysical attributes to monitor in the forest and range environment in British Columbia in light of climate change?

<u>Hypothesis 2:</u> There are key biophysical attributes that need to be monitored in the forest and range environment in light of climate change.

The results in Chapters 2, 3 and 4 address this hypothesis. Seventeen key biophysical attributes were identified as being of importance for further examination in light of climate change. These varied in their overall importance to forest and range managers in

British Columbia. Those topic areas identified as being of greatest importance are identified in 6.1.2 above.

# 6.2.3 Question 3: Over what geographical and time scales do forest and range managers feel the identified biophysical attributes should be monitored?

<u>Hypothesis 3a:</u> Forest and range managers are concerned about climate change and do not want to wait any longer to start to incorporate climate change considerations into their decision and policy making.

<u>Hypothesis 3b:</u> Forest and range managers have specific areas in the Province where they are particularly concerned about the impacts of climate change on key biophysical attributes.

As noted above (6.1.4), forest and range managers indicated strongly that they saw an immediate need to start incorporating climate change considerations into their decision making. The findings of this thesis thus support Hypothesis 3a. In the survey many forest and range managers identified a particular geographical area on which climate change monitoring should focus. While the Southern Interior was the most popular region identified by survey respondents, many respondents were in favour of other 'less defined' geographical areas. The most popular of these being transitional zones between different ecosystems, regions identified as being most vulnerable to climate change and those forests containing larger proportions of merchantable tree species.

# 6.2.4 Question 4: Are the topic areas identified able to be monitored using existing data sources in British Columbia?

<u>Hypothesis 4a:</u> Changes to ecosystem distribution and composition resulting from climate change can effectively be monitored using existing data collections within British Columbia.

Section 5.2 of this thesis has highlighted a number of existing data sources that could be used to monitor ecosystem distribution and composition. The recent advent of the NFI

and the data that should come from it will provide a feasible approach for determining changes in ecosystem distribution and composition. Further research and development is needed to ensure that the data sources identified are compatible and can be used together to more effectively monitor change at a level that is relevant to provincial level managers and the assessment of climate change. Building on the current datasets available to monitor this indicator is unlikely to represent a fiscal burden for the Province and would be extremely valuable for managing forests for climate change (as well as for other purposes). Hypothesis 4a is thus only partially supported through my research.

<u>Hypothesis 4b:</u> Changes in the productivity of forests resulting from climate change can effectively be monitored using existing data collections within British Columbia.

Section 5.3 of this thesis has shown that broad scale Province-level changes in forest productivity can be monitored using the VRMP dataset. This dataset, however, would not be able to give any insight on the finer changes that are taking place in forest productivity. The PSP dataset has the capacity to provide this level of data. However, the dataset needs further refinement in order to be able to be effectively used by decision makers. Hypothesis 4b is also only partially supported by the research described in this thesis.

<u>Hypothesis 4c:</u> Changes in species range and phenology can effectively be monitored using existing data collections within British Columbia

Research described in Section 5.4 does not support this hypothesis. There are currently no datasets in the Province which can be used to effectively monitor change in species range and phenology.

<u>Hypothesis 4d:</u> The interactions between ecosystem connectivity and climate change can effectively be monitored using existing data collections within British Columbia.

Ecosystem connectivity can be monitored and measured at various scales using a variety of approaches. In Section 5.5 of this thesis one approach has been identified that would

be appropriate for monitoring landscape level connectivity using modelling data available within the Province. This approach is recommended for further provincial level study and, based on the results of my small scale tests, it appears feasible to use the data currently available in the Province. This hypothesis is therefore supported by my research.

<u>Hypothesis 4e:</u> Changes in fire season length and severity can effectively be monitored using existing data collections within British Columbia.

Section 5.6 of this thesis has shown that 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, thus supporting Hypothesis 4e. There are long-term fire data available from a number of monitoring sites well distributed across the Province.

<u>Hypothesis 4f:</u> Changes in the incidence of insects and disease damage can effectively be monitored using existing data collections within British Columbia.

The baseline data available for monitoring the effects of insects and diseases described in Section 5.7 are very good thus supporting Hypothesis 4f. Further effort is needed, however, to effectively link changes in the effects of insects and diseases to climate change.

### 6.3 SIGNIFICANCE AND POTENTIAL APPLICATION OF THIS RESEARCH

Forest and range managers in British Columbia have stated that they believe it is time to start accounting for the impacts of climate change in their management decisions and practices. As it currently stands, their capacity to do this is limited because information is not being made readily available to them. My research has determined what information is required by managers and what data are currently available to supply those information needs. While the study focused on climate change, the results have broader implications. Many of the data sources examined here have been developed because they are needed for ecologically sustainable management. Any improvements in their capacity and/or quality world prove valuable for managing British Columbia's environment even without a climate change lens applied.

The results of my research also have broader applications for environmental monitoring. It may offer an example to other regions seeking to use their data to track climate change and better understand its impacts. The approach used to determine the indicators and check them against environmental managers' needs offers a useful case study to follow when developing a framework of their own. The indicator level assessments and approaches I have developed also provide useful examples that could be applied to regions outside British Columbia. The case study on monitoring ecosystem distribution and composition is particularly useful in this regard as it represents a much needed approach for tracking ecosystem change over time. Being able to effectively monitor ecosystem change has been a broader goal of sustainable forest management since its inception. Many institutions world-wide are attempting to develop cost-effective, reasonable mechanisms to track ecosystem change at a time-scale appropriate to make effective environmental management decisions. The approach presented here, while simple, would be able to do this and could be effectively implemented by any country or region. For those areas without substantial existing data collections remote sensing methods may offer a way to fill in some trend data (Johansen et al. 2007).

The framework that has been developed has been of great interest to the British Columbia Government. An additional phase of research was recently funded to examine the capacity of the Province to report on all the other indicators in the framework. In addition, there has been national level interest in the framework. A jointly funded (British Columbia Government/Canadian Government) project examining this framework's applicability for assessing how climate change considerations can be better incorporated into the CCFM framework was also undertaken.

#### 6.4 FUTURE RESEARCH AND DEVELOPMENT

Broadly, the next key steps for this research are implementation of some indicators, the preparation of data sources and/or working to better address the data gaps and

inefficiencies identified. Suggestions for further research and development are elaborated in more detail below.

- Indicator selection and development processes are iterative and the framework must be allowed to evolve as data availability and knowledge of climate change and its impacts on forests and rangelands in British Columbia improves. Ongoing effort is needed to incorporate important research findings as they become available.
- 2. Better extension and use of all provincially gathered datasets is an area requiring much more detailed research and action. It appears that much of the climate change information, initiatives and tools currently in operation in British Columbia are not effectively reaching, or being used by, many of the Province's forest and range managers (especially those working at the district level). Further research on their knowledge and use of these products is needed.
- 3. More research is needed to assess the extent to which the ecosystem distribution and composition datasets in the Province are overlapping and could be brought together. Increased depth of information and specialist expertise regarding the distinctiveness of the BEC zones and the species found within them would also be valuable additional information for interpreting the results of both this indicator and the ecosystem connectivity indicator. The NFI ground plots would (in time) be a good source of data to support this indicator but the NFI data needs to be shared between federal and provincial level organizations and linked to the BEC level mapping and analyzes.
- 4. Where plot data has been identified, in most cases, further assessment is needed to determine the extent to which monitoring stations form a strong complementary network. There is a need to determine which plots have a comprehensive long-term historical record and which plots occur within close proximity to a weather station. This analysis would be useful for identifying where increased monitoring is required, as well as the type of additional monitoring that is needed.
- 5. While some of the key avenues for information distribution have been identified through this research, further consideration needs to be given to how the

recommended indicators are reported on and the extent to which information will be made available. For instance, it is highly likely that there will be a need for information generated by the monitoring framework to be made available online – as this was recorded in Chapter 3 as the most frequently used medium by forest and range mangers. It is important that any database or information housing options be considered in light of this. There is also considerable potential to utilize existing sustainability reporting mechanisms currently in place at both the provincial and federal government levels (such as the British Columbia State of the Forest report and reporting conducted by the CCFM). Where necessary, linkages should be developed with these programs to ensure that data are able to be presented in a format that is compatible with theirs.

#### 6.5 CONCLUDING COMMENTS

Climate change is anticipated to have implications for many aspects of biological diversity including ecosystems, species genetic diversity and ecological interactions. The IPCC has recently concluded that the resilience of many forest ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated impacts (e.g., drought, wildlife and insects), and other global change drivers (e.g., land-use change, pollution, over-exploitation of resources) (Adger & Barnett 2009; IPCC 2007a). The implications of these impacts are considerable for the longterm stability of the natural world and for the many benefits and services that humans derive from it. Now is the appropriate time to make decisions on how to adjust current land and resources management policies and practices in anticipation - and in some cases in reaction to – climate change. Through this research, forest and range managers in British Columbia have voiced their desire to build climate change considerations into their decision and policy making. They want to be able to do this sooner rather than later so that they can take a more proactive approach towards climate change adaptation. Being a Province in one of the world's wealthiest countries, coupled with its longstanding ethos of sustainable environmental management, means that British Columbia has a relative plethora of monitoring data that can be built on and effectively relied upon to deliver at least some of the information required by land managers to appropriately

modify their management practices and policies. As these volumes of data continue to grow, however, so do the challenges of distilling from them that information that allows us to understand what is happening in the environment and what the implications are for managing and mitigating climate change impacts. Despite British Columbia's relatively wealthy position, not all data are available and there is a need for better monitoring to adapt successfully to climate change – especially at the species level.

#### **Bibliography**

- Aaheim, A., R. Gopalakrishnan, R. K. Chaturvedi, N. H. Ravindranath, A. D. Sagadevan, N. Sharma, and T. Y. Wei. 2011. A macroeconomic analysis of adaptation to climate change impacts on forests in India. Mitigation and Adaptation Strategies for Global Change 16:229-245.
- Adger, W. N., and J. P. Barnett. 2009. Four reasons for concern about adaptation to climate change. Environment and Planning **41**:2800 2805.
- Adler, F. R., and B. Nuernberger. 1994. Persistence in Patchy Irregular Landscapes. Theoretical Population Biology **45**:41-75.
- Anderson, G. S., and B. J. Danielson. 1997. The effects of landscape composition and physiognomy on metapopulation size: the role of corridors. Landscape Ecology 12:261-271.
- Anon. 1996. Ministry of Forest and Range Act. Queen's Printer, British Columbia, Canada.
- Anon. 1999. The Canadian National Report on Systematic Observations for Climate. The Canadian Global Climate Observing System (GCOS) Program. Accessed 2012 at: <u>http://unfccc.int/resource/docs/gcos/cangcose.pdf</u>.
- Anon. 2002. Indicators of Climate Change for British Columbia. British Columbia Ministry of Water, Land and Air Protection.
- Anon. 2003. Montreal Process First Forest Overview Report. Montréal Process on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests, Montreal, Canada.
- Anon. 2008a. Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health: A Review of Science, Policies and Practices. Forest Adaptation 2008 Umeå, Sweden.
- Anon. 2008b. Canada's National Environmental Indicator Series. Environment Canada. Accessed 2011 at: <u>http://www.ec.gc.ca/indicateurs-indicators/</u>.
- Armstrong, J. S., and T. S. Overton. 1977. Estimating Nonresponse Bias in Mail Surveys. Journal of Marketing Research 14:396-402.

Avery, T., and H. Burkhart 2002. Forest measurements. McGraw-Hill, Boston, MA.

- Ayres, M. P., and M. A. J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. Science of The Total Environment 262:263-286.
- Babbie, E., editor. 2007. The Practice of Social Research Wadsworth Publishing.
- Barnett, R. A., M. R. Ziegler, and K. E. Byleen 2005a. Finite Mathematics for Business, Economics, Life Sciences, and Social Sciences 10 E. Pearson Prentice Hall, New Jersey.
- Barnett, T. P., J. C. Adam, and D. P. Lettenmaier. 2005b. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438:303-309.
- Berry, P. M., T. P. Dawson, P. A. Harrison, R. Pearson, and N. Butt. 2003. The sensitivity and vulnerability of terrestrial habitats and species in Britain and Ireland to climate change. Journal for Nature Conservation **11**:15-23.
- Birdsley, A., R. Haynes, L. Heath, and L. Joyce 1995. Productivity of America's Forests and Climate Change. Diane Pub Co.
- Boisvenue, C., and S. Running. 2006. Impacts of climate change on natural forest productivity; evidence since the middle of the 20th century. Global Change Biology **12**:862-882.
- Bossel, H. 2001. Assessing viability and sustainability: a systems-based approach for deriving comprehensive indicator sets. Conservation Ecology **5**(2).
- Both, C., and L. te Marvelde. 2007. Climate change and timing of avian breeding and migration throughout Europe. Climate Research **35**:93-105.
- Brace, I. 2004. Questionnaire Design: How to Plan, Structure and Write Survey Material for Effective Market Research. Market Research in Practice Series.
- Bridge, S. R. J., D. Cooligan, D. Dye, L. Moores, T. Niemann, and R. Thompson. 2005. Reviewing Canada's national framework of criteria and indicators for sustainable forest management. Forestry Chronicle 81.
- Brooke, C. 2008. Conservation and Adaptation to Climate Change. Conservation Biology **22**:1471-1476.

- Brudvig, L. A., E. I. Damschen, J. J. Tewksbury, N. M. Haddad, and D. J. Levey. 2009. Landscape connectivity promotes plant biodiversity spillover into non-target habitats. Proceedings of the National Academy of Sciences of the United States of America 106:9328-9332.
- Bubb, P., J. Jenkins, and V. Kapos. 2005. Biodiversity Indicators for National Use: Experience and Guidance. UNEP-WCMC, Cambridge, UK.
- Bunnell, F. L., M. I. Preston, and A. C. M. Farr. 2008. Avian response to climate change in British Columbia – toward a general model. Pages 9-27 in F. Dallmeier, A. Fenech, D. MacIver, and R. Szaro, editors. Climate change, biodiversity and sustainability in the Americas. Smithsonian Institution Scholarly Press.
- Bunnell, F. L. a. D., G.B. (eds.). 2009. Forestry and biodiversity. Learning how to sustain biodiversity in managed forests. University of British Columbia Press, Vancouver, BC.
- Burton, I., S. Huq, B. Lim, O. Pilifosa, and E. L. Schipper. 2002. From impacts assessment to adaptation priorities: the shaping of adaptation policy. Climate Policy 2:145 159.
- Busch, D. E., and J. C. Trexler 2002. Monitoring Ecosystems Interdisciplinary Approaches for Evaluating Ecoregional Initatives. Island Press, Washington, DC.
- Case, M. J., and D. L. Peterson. 2009. Growth-climate Relations of Lodgepole Pine in the North Cascades National Park, Washington. Northwest Science **81**:62-75.
- Castañeda, F. 1997. Criteria and indicators for sustainable forest management: international processes, current status and the way ahead. Unasylva **203**.
- Caughlan, L., and K. L. Oakley. 2001. Cost considerations for long-term ecological monitoring. Ecological Indicators 1:123-134.
- CCFM. 2002. CCFM C&I Indicator Review, A Process for Technical Working Groups to Review the Indicators in the CCFM C&I Framework for Sustainable Forest Management.
- CCFM. 2005. Criteria and Indicators of Sustainable Forest Managment in Canada in N. R. C. Canadian Forest Service, editor, Ottawa, ON.
- CCFM. 2006. Criteria and Indicators of Sustainable Forest Management in Canada: National status 2005 in C. F. S. Natural Resources Canada, editor, Ottawa, ON.

- CCFM. 2008. A vision for Canada's Forests 2008 and beyond in N. R. Canada, editor, Ottawa, ON.
- CCFM. 2012. Adapting Sustainable Forest Management to Climate Change: Preparing for the Future. Canadian Forest Service, Ottawa, Ontario.
- CCME. 2003. Climate, Nature, People: Indicators of Canada's Changing Climate. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.
- Coakley, S., H. Scherm, and S. Chakraborty. 1999. Climate change and plant disease management. Annual Review of Phytopathology **37: 399-426**.
- Colwell, R. K., G. Brehm, C. L. Cardelús, A. C. Gilman, and J. T. Longino. 2008. Global Warming, Elevational Range Shifts, and Lowland Biotic Attrition in the Wet Tropics. Science **322**:258-261.
- Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.
- Cox, G. W. 2010. Bird migration and global change. Island Press, Washington, DC.
- Cresswell, K., J. Wiedenmann, and M. Mangel. 2008. Can macaroni penguins keep up with climate- and fishing-induced changes in krill? Polar Biology **31**:641-649.
- Crimmins, T. M., M. A. Crimmins, and C. David Bertelsen. 2009. Flowering range changes across an elevation gradient in response to warming summer temperatures. Global Change Biology **15**:1141-1152.
- Crist, M. R., B. O. Wilmer, and G. H. Aplet. 2005. Assessing the value of roadless areas in a conservation reserve strategy: biodiversity and landscape connectivity in the northern Rockies. Journal of Applied Ecology 42:181-191.
- Dale, V., L. Joyce, S. McNulty, R. Neilson, M. Ayres, M. Flannigan, P. Hanson, L. Irland, A. Lugo, C. Peterson, D. Simberloff, F. Swanson, B. Stocks, and B. Wotton. 2001. Climate Change and Forest Disturbances. Bioscience. 51(9) :723-734.
- Dale, V. H., and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1:3-10.
- Dillman, D. A. 2007. Mail and internet surveys, The Tailored Design Method Second Ed. John Wiley & Sons, Inc., Hoboken, New Jersey.

- Donald, P. F., and A. D. Evans. 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. Journal of Applied Ecology 43:209-218.
- Easterling, W. E., W. H. Hurd, and J. B. Smith. 2004. Coping with global climate change: the role of adaptation in the United States. Pew Centre on Global Climate Change, Arlington, VA.
- EC. 2012. Environment Canada Environmental Sustainability Indicators. Government of Canada.
- EPA 2009. Climate Change Effects on Stream and River Biological Indicators: A Preliminary Analysis (Final Report), Global Change Research Program, National Center for Environmental Assessment, Washington, DC.
- ESWG. 1995. A National Ecological Framework for Canada in R. B. Agriculture and Agri-Food Canada, and Centre for Land and Biological Resources Research, editors. Report and national map at 1:7500 000 scale., Ottawa.
- Fahrig, L., and G. Merriam. 1985. Habitat Patch Connectivity and Population Survival. Ecology **66**:1762-1768.
- Failing, L., and R. Gregory. 2003. Ten common mistakes in designing biodiversity indicators for forest policy. Journal of Environmental Management **68**:121-132.
- FAO. 2005. Global Forest Resources Assessment Progress Towards Sustainable Forest Management, Food and Agriculture Organization of the United Nations, Rome 2006.
- FFEI. 2008. Future Forest Ecosystems Strategic Plan 2007/08 2009/10 in G. o. B. C. Ministry of Forests and Range, editor, Victoria, BC.
- FHM. 2012. Forest Health Monitoring Program website [Accessed May 2012] http://www.fhm.fs.fed.us/
- Flannigan, M., B. Amiro, K. Logan, B. Stocks, and B. Wotton. 2006. Forest Fires and Climate Change in the 21ST Century. Mitigation and Adaptation Strategies for Global Change 11:847-859.
- Flannigan, M., M. Wotton, B. Todd, H. Cameron, and , and K. Logan. 2002. Climate change implications in British Columbia: Assessing past, current, and future fire occurrence and fire severity in BC. Reported submitted to B.C. Ministry of Forests, Protection Program, 2002.

- Fussel, H., and R. Klein. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change **75**:301-329.
- Gardner, T. 2010. Monitoring forest biodiversity: improving conservation through ecologically-responsible management. Earthscan, London.
- Gayton, D. V. 2008. Impacts of Climate Change on British Columbia's Biodiversity A Literature Review, Forrex Forest Research Extension Partnership. Forrex Series 23, Kamloops, BC.
- GC. 2012. Government of Canada Termium Plus Website, Accessed 2012 at: <u>http://www.termiumplus.gc.ca/tpv2alpha/alpha-</u> eng.html?lang=eng&i=1&index=alt&srchtxt=SEASONAL%20SEVERITY%20 <u>RATING</u>.
- GCOS. 2012. Global Climate Observing System Website <u>http://www.wmo.int/pages/prog/gcos/index.php?name=ObservingSystemsandDa</u> <u>ta</u> [Accessed May 2012].
- Gienapp, P., R. Leimu, and J. Merilä. 2007. Responses to climate change in avian migration time—microevolution versus phenotypic plasticity. Climate Research **35**:25-35.
- Gillett, N. P., A. J. Weaver, F. W. Zwiers, and F. M. D. 2004. Detecting the effect of climate change on Canadian forest fires. Geophysical Research Letters **31**.
- Gillis, M. D., A. Y. Omule, and T. Brierley. 2005. Monitoring Canada's Forests: The National Forest Inventory. The Forestry Chronicle **81**:214-221.
- Gomontean, B., J. Gajaseni, G. Edwards-Jones, and N. Gajaseni. 2008. The development of appropriate ecological criteria and indicators for community forest conservation using participatory methods: A case study in northeastern Thailand. Ecological Indicators **8**:614-624.
- Gordo, O. 2007. Why are bird migration dates shifting? A review of weather and climate effects on avian migratory phenology. Climate Research **35**:37-58.
- Gregory, R. D., S. G. Willis, F. Jiguet, P. Voříšek, A. Klvaňová, A. van Strien, B. Huntley, Y. C. Collingham, D. Couvet, and R. E. Green. 2009. An indicator of the impact of climatic change on european bird populations. PLoS ONE 4:e4678.
- Guthrie, R. H., and K. J. Brown. 2008. Denudation and landslide in coastal mountain watersheds: 10 000 years of erosion. Geograph. Helvetica 63:26–35.

- Hamann, A., and T. L. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology **87**:2773-2786.
- Hamblin, A. 2001. Sustainability Indicators: Measuring Progress Towards Sustainability in J. Venning, and J. Higgins, editors. Towards Sustainability -Emerging Systems for Informing Sustainable Development. University of NSW Press Ltd, Sydney, Australia.
- Hansen, A., R. Neilson, V. Dale, C. Flather, L. Iverson, D. Currie, S. Shafer, R. Cook, and P. Bartlein. 2001a. Global change in forests: Responses of species, communities, and biomes. BioScience 51: 765–779.
- Hansen, M. J., S. E. Franklin, C. G. Woudsma, and M. Peterson. 2001b. Caribou habitat mapping and fragmentation analysis using Landsat MSS, TM, and GIS data in the North Columbia Mountains, British Columbia, Canada. Remote Sensing of Environment 77:50-65.
- Hawkes, B., M. Flannigan, and B. Todd. 2005. Climate change and forest fire in British Columbia. In Proc. Conf. Implications of Climate Change in British Columbia's Southern Interior Forests, Revelstoke, BC.
- Hebda, R. J. 1997. Impact of climate change on biogeoclimatic zones of British Columbia and Yukon in E. T. a. B. T. (editors), editor. Responding to global climate change in British Columbia and Yukon. Environment Canada, Vancouver, B.C.
- Heller, N. E., and E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation 142:14-32.
- Hickey, G. M., and J. L. Innes. 2008. Indicators for demonstrating sustainable forest management in British Columbia, Canada: An international review. Ecological Indicators 8:131-140.
- Hickey, G. M., J. L. Innes, R. A. Kozak, G. Q. Bull, and I. Vertinsky. 2005. Monitoring and information reporting for sustainable forest management: An international multiple case study analysis. Forest Ecology and Management 209:237-259.
- Hickling, R., D. B. Roy, J. K. Hill, R. Fox, and C. D. Thomas. 2006. The distributions of a wide range of taxonomic groups are expanding polewards. Global Change Biology **12**:450-455.
- Holliday, L., editor. 2007. Strengthening science-based decision making in developing countries. The National Academies Press, Washington, D.C.

- Howell, C. I., A. D. Wilson, S. M. Davey, and M. M. Eddington. 2008. Sustainable forest management reporting in Australia. Ecological Indicators 8:123-130.
- Iarossi, G. 2006. The Power of Survey Design: A User's Guide for Managing Surveys, Interpreting Results, and Influencing Respondents. The World Bank, Washington, D.C.
- IGBP. 2012. International Geosphere-Biosphere Programme Website
- Innes, J. L. 2003. The incorporation of research into attempts to improve forest policy in British Columbia. Forest Policy and Economics **5**:349-359.
- Innes, J. L., L. A. Joyce, S. Kellomaki, B. Louman, A. E. Ogden, J. Parrotta, and I. Thompson. 2009. Management for adaptation. Pages 135 - 186 in S. Kellomaki, A. Buck, and P. Katila, editors. Adaptation of forests and people to climate change - a global assessment. IUFRO, Helsinki.
- IPC. 2012. International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests Website <u>http://icp-forests.net/</u> [Accessed May 2012].
- IPCC, editor. 2001. Annex B: Glossary of terms; Climate change 2001: The scientific basis (contribution of working groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change).
- IPCC, editor. 2007a. Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.
- IPCC 2007b. The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
- IPCC 2007c. Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
- Jacobs, K. 2002. Connecting Science, Policy, and Decisionmaking: A Handbook for Researchers and Science Agencies in O. o. G. Programs, editor. National Oceanic and Atmospheric Administration.
- Jacobs, K., G. Garfin, and M. Lenart. 2005. More than just talk: Connecting science and decisionmaking. Environment **47** pp. 6-21.

- Johansen, K., N. C. Coops, S. E. Gergel, and Y. Stange. 2007. Application of high spatial resolution satellite imagery for riparian and forest ecosystem classification. Remote Sensing of Environment **110**:29-44.
- Johnson, M., and T. Williamson. 2007. A framework for assessing climate change vulnerability of the Canadian forest sector. The Forestry Chronicle **83**:358-361.
- Jonzén, N., T. Ergon, A. Lindén, and N. Stenseth. 2007. Introduction. Climate Research **35**:1-3.
- Joyce, L. A. 2003. Improving the flow of scientific information across the interface of forest science and policy. Forest Policy and Economics **5**:339-347.
- Kindlmann, P., and F. Burel. 2008. Connectivity measures: a review. Landscape Ecology 23:879-890.
- Klenk, N. L., B. W. Adams, G. Q. Bull, J. L. Innes, S. J. Cohen, and B. C. Larson. 2011. Climate change adaptation and sustainable forest management: A proposed reflexive research agenda. Forestry Chronicle 87:351-357.
- Knowles, N., M. Dettinger, and D. Cayan. 2006. Trends in snowfall versus rainfall for the Western United States. J. Climate **19(18):4545–4559.**
- Knudsen, E., A. Lindén, T. Ergon, N. Jonzén, J. Vik, J. Knape, J. Røer, and N. Stenseth. 2007. Characterizing bird migration phenology using data from standardized monitoring at bird observatories. Climate Research 35:59-77.
- Kramer, K., B. Degen, J. Buschbom, T. Hickler, W. Thuiller, M. T. Sykes, and W. de Winter. 2010. Modelling exploration of the future of European beech (Fagus sylvatica L.) under climate change--Range, abundance, genetic diversity and adaptive response. Forest Ecology and Management 259:2213-2222.
- Kullman, L. 2007. Tree line population monitoring of Pinus sylvestris in the Swedish Scandes, 1973–2005: implications for tree line theory and climate change ecology. Journal of Ecology 95:41-52.
- Latta, G., H. Temesgen, D. Adams, and T. Barrett. 2010. Analysis of potential impacts of climate change on forests of the United States Pacific Northwest. Forest Ecology and Management **259**:720-729.
- Lawler, J. J. 2009. Climate Change Adaptation Strategies for Resource Management and Conservation Planning. Annals of the New York Academy of Sciences 1162:79-98.

- Lee, K. 1994. Compass and Gyroscope: Integrating Science And Politics For The Environment. Island Press, Washington, DC.
- Legg, C. J., and L. Nagy. 2006. Why most conservation monitoring is, but need not be, a waste of time. Journal of Environmental Management **78**:194-199.
- Lemmen, D. S., and F. J. Warren, editors. 2008. Introduction: in from Impacts to Adaptation: Canada in a changing Climate 2007. Government of Canada, Ottawa, ON.
- Lemos, M. C., and B. J. Morehouse. 2005. The co-production of science and policy in integrated climate assessments. Global Environmental Change Part A **15**:57-68.
- Lemprière, T. C., P. Y. Bernier, A. L. Carroll, M. D. Flannigan, R. P. Gilsenan, D. W. McKenney, E. H. Hogg, J. H. Pedlar, and D. Blain. 2008. The importance of forest sector adaptation to climate change. Canadian Forest Service, Edmonton, AB.
- Lindenmayer, D., R. J. Hobbs, R. Montague-Drake, J. Alexandra, A. Bennett, M. Burgman, P. Cale, A. Calhoun, V. Cramer, P. Cullen, D. Driscoll, L. Fahrig, J. Fischer, J. Franklin, Y. Haila, M. Hunter, P. Gibbons, S. Lake, G. Luck, and C. MacGregor. 2008. A checklist for ecological management of landscapes for conservation. Ecology Letters 11:78-91.
- Lindenmayer, D., R. J. Hobbs, and Zoological Society of London. 2007. Managing and designing landscapes for conservation : moving from perspectives to principles. Blackwell Pub., Malden, MA.
- Lindenmayer, D. B. 2009. Forest Wildlife Management and Conservation. Pages 284-310. Year in Ecology and Conservation Biology 2009. Blackwell Publishing, Oxford.
- Lindenmayer, D. B., and G. E. Likens 2010a. Effective Ecological Monitoring. CSIRO Publishing, Australia.
- Lindenmayer, D. B., and G. E. Likens. 2010b. The science and application of ecological monitoring. Biological Conservation **143**:1317-1328.
- Liu, Y., H. Gupta, E. Springer, and T. Wagener. 2008. Linking science with environmental decision making: Experiences from an integrated modeling approach to supporting sustainable water resources management. Environmental Modelling & Software 23:846-858.

- Logan, J., and J. Powell. 2005. Ecological consequences of climate change altered forest insect disturbance regimes in F. Wagner, editor. Climate warming in western North America: evidence and environmental effects. University of Utah Press, Salt Lake City, Utah.
- Long, J. A., T. A. Nelson, and M. A. Wulder. 2010. Characterizing forest fragmentation: Distinguishing change in composition from configuration. Applied Geography 30:426-435.
- Lovejoy, T. E., and L. Hannah, editors. 2005. Climate Chnage and Biodiversity. Yale University Press, New Haven & London.
- LWF. 2012. Langfristige Waldokősystem-Forschung (LWF) Website <u>http://www.wsl.ch/dienstleistungen/inventare/lwf/index\_EN</u> [Accessed May2012].
- MA 2006. Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Synthesis. Island Press, Washington, D.C.
- McCabe, G. J., and D. M. Wolock. 2009. Recent Declines in Western U.S. Snowpack in the Context of Twentieth-Century Climate Variability. Earth Interactions **13**:1-15.
- McFadden, J. E., T. L. Hiller, and A. J. Tyre. 2011. Evaluating the efficacy of adaptive management approaches: Is there a formula for success? Journal of Environmental Management **92**:1354-1359.
- Meidinger, D. V., J. Pojar, and British Columbia. Ministry of Forests. 1991. Ecosystems of British Columbia. Research Branch, Ministry of Forests, Victoria, B.C.
- Metsaranta, J. M., C. C. Dymond, W. A. Kurz, and D. L. Spittlehouse. 2011. Uncertainty of 21st century growing stocks and GHG balance of forests in British Columbia, Canada resulting from potential climate change impacts on ecosystem processes. Forest Ecology and Management 262:827-837.
- MFR. 2006. The State of British Columbia's Forests. Forest Practices Branch, Ministry of Forests and Range, Victoria, BC.
- MFR. 2010. The State of British Columbia's Forests. Forest Practices Branch, Ministry of Forests and Range, Victoria, BC.
- MFR. 2012a. Forest Practices Branch Website Forest Health Aerial Overview Survey.

MFR. 2012b. Ministry of Forests and Range Research Branch Website Victoria, BC.

- Millar, C., N. Stephenson, and S. Stephens. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications **17(8)**:pp. 2145-2151.
- Moberg, A., D. M. Sonechkin, K. Holmgren, N. M. Datsenko, and W. Karlén. 2005. Highly variable Northern Hemisphere temperatures reconstructed from low- and highresolution proxy data. Nature 433:613-617.
- MOE. 2007. Environmental trends in BC 2007 in B. G. M. o. Environment, editor.
- MOE. 2010. Preparing for Climate Change British Columbia's Adaptation Strategy in M. o. Environment, editor, Victoria.
- MOE. 2012. State of the Environment Reporting. Ministry of Environment, BC.
- Montenegro, A., V. Brovkin, M. Eby, D. Archer, and A. J. Weaver. 2007. Long term fate of anthropogenic carbon. Geophysical Research Letters **34**:L19707.
- Moore, R. D., S.W. Fleming, B. Menounos, R. Wheate, A. Fountain, K. Stahl, K. Holm, and M. Jakob. 2009. Glacier change in western North America: implications for hydrology, geomorphic hazards and water quality. Hydrol. Process **23:42–6**.
- Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86:39-49.
- Mustin, K., W. Sutherland, and J. Gill. 2007. The complexity of predicting climateinduced ecological impacts. Climate Research **35**:165-175.
- Nelitz, M., R. Moore, and E. Parkinson. 2008. Developing a Framework to Designate 'Temperature Sensitive Streams' in the B.C. Interior Final report prepared by ESSA Technologies Ltd for BC Forest Science Program and Pricewaterhouse Coopers, Vancouver BC.
- Nelson, D. R., W. N. Adger, and B. K. 2007. Adaptation to environmental change: Contributions of a resilience framework. Review Environmental Resources 32:395-419.
- Newman, J., M. Anand, H. Henry, S. Hunt, and Z. e. Gedalof 2010. Climate Change Biology CABI, Cambridge, MA.

- Newson, S., N. Dulvy, G. Hays, J. Houghton, F. Gerard, A. Hutson, C. Macleod, S. Mendes, R. Robinson, T. Sparks, G. Pierce, and H. Crick. 2008. Indicators of the Impact of Climate Change on Migratory Species, BTO Research Report 495. British Trust for Ornithology, Norfolk, UK.
- NFI. 2009a. Canada's National Forest Inventory National Standard for Ground Plots: Data Dictionary 5.0. National Forest Inventory, Victoria, BC.
- NFI. 2009b. National Forest Inventory Photo Plot Data Dictionary For Remeasurement Version 5.1.2 in N. F. Inventory, editor. National Forest Inventory, Victoria, BC.
- NFI. 2010. Canada's National Forest Inventory Website. National Forest Inventory.
- Niemeijer, D. 2002. Developing indicators for environmental policy: data-driven and theory-driven approaches examined by example. Environmental Science & Policy 5:91-103.
- Niemeijer, D., and R. S. de Groot. 2008. A conceptual framework for selecting environmental indicator sets. Ecological Indicators 8:14-25.
- Nitschke, C. R., and J. L. Innes. 2008a. Integrating climate change into forest management in South-Central British Columbia: An assessment of landscape vulnerability and development of a climate-smart framework. Forest Ecology and Management **256**:313-327.
- Nitschke, C. R., and J. L. Innes. 2008b. A tree and climate assessment tool for modelling ecosystem response to climate change. Ecological Modelling **210**:263-277.
- Noss, R. F. 2001. Beyond Kyoto: Forest Management in a Time of Rapid Climate Change. Conservation Biology **15**:578-590.
- Noss, R. F., and A. Y. Cooperrider 1994. Saving Nature's Legacy. Island Press., Washington, D.C.
- NRC 2000. Ecological Indicators of the Nation. National Academy Press, Washington, DC.
- NRC 2008. Ecological Impacts of Climate Change. The National Academies Press, Washington, D.C.
- NRC 2010a. Adapting to the Impacts of Climate Change. National Academies Press, Washington D.C.

- NRC 2010b. Advancing the science of climate change. National Research Council, Washington, D.C.
- NRC. 2010c. Informing an Effective Response to Climate Change America's Climate Choices: Panel on Informing Effective Decisions and Actions Related to Climate Change. The National Academies Press, Washington, DC.
- NRCAN. 2012. The State of Canada's Forests Series. Natural Resources Canada, Ottawa, ON.
- ODF. 2000. First Approximation Report for Sustainable Forest Management in Oregon.
- Ogden, A. E. E. 2008. PhD Thesis Climate Change Adaptation and Sustainable Forest Managment in the Boreal Forest. University of British Columbia, Vancouver, BC.
- Ohlson, D. W., G. A. McKinnon, and K. G. Hirsch. 2005. A structured decision-making approach to climate change adaptation in the forest sector. Forestry Chronicle **81**:97-103.
- Oliver, I. 2002. An expert panel-based approach to the assessment of vegetation condition within the context of biodiversity conservation: Stage 1: the identification of condition indicators. Ecological Indicators **2**:223-237.
- Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature **421**.
- Parry, M., N. Arnell, T. McMichael, R. Nicholls, P. Martens, S. Kovats, M. Livermore, C. Rosenzweig, A. Iglesias, and G. Fischer. 2001. Millions at risk: defining critical climate change threats and targets. Global Environmental Change 11:181-183.
- PCIC. 2008. Pacific Climate Impacts Consortium Website.
- Pearson, R. G., and T. P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography **12**:361 371.
- Perry, D., R. Meurisse, B. Thomas, R. Miller, and J. Boyle 1989. Maintaining the Long Term Productivity of Pacific Northwest Forest Ecosystems. Timber Pr.
- Pielke, R. A. 2005. Misdefining ,"climate change": consequences for science and action. Environmental Science & Policy 8:548-561.

- Pike, R. G., K. E. Bennett, T. E. Redding, A. T. Werner, D. L. Spittlehouse, R. D. Moore, T. D. Murdock, J. Beckers, B. D. Smerdon, K. D. Bladon, V. N. Foord, D. A. Campbell, and P. J. Tschaplinski. 2010. Climate Change Effects on Watershed Processes in British Columbia
- . Land Managment Handbook No. 66, Compendium of Forest Hydrology and Geomorphology in British Columbia Volume 1 of 2. Government of British Columbia.
- Podur, J., and M. Wotton. 2010. Will climate change overwhelm fire management capacity? Ecological Modelling **221**:1301-1309.
- Pojar, J., K. Klinka, and D. V. Meidinger. 1987. Biogeoclimatic ecosystem classification in British Columbia. Forest Ecology and Management **22**:119-154.
- Post, E., and M. C. Forchhammer. 2002. Synchronization of animal population dynamics by large-scale climate. Nature **420**:168-171.
- Prabhu, R., H. J. Ruitenbeck, T. J. B. Boyle, and C. J. P. Colfer, 2001. 2001. Between Vodoo Science and adaptive management: the role and research needs for indicators of sustainable forest management. Pages pp. 39-66. in R. J. Raison, A. G. Brown, and D. W. Flinn, editors. Criteria and Indicators for Sustainable Forest Management. CAB International Publishing, London, U.K.
- Pulido, F. 2007. Phenotypic changes in spring arrival: evolution, phenotypic plasticity, effects of weather and condition. Climate Research **35**:5-23.
- Raison, R. J., A. G. a. Brown, and D. W. Flinn, . In 2001. Application of criteria and indicators to support sustainable forest management: some key issues. . Pages pp. 2-18 in R. J. Raison, A. G. Brown, and D. W. Flinn, editors. Criteria and Indicators for Sustainable Forest Management. CAB International Publishing, London, U.K.
- Rizzo, B., and E. Wiken. 1992. Assessing the sensitivity of Canada's ecosystems to climatic change. Climatic Change **21**:37-55.
- Rodenhuis, D. R., K. E. Bennett, A. T. Werner, T. Q. Murdock, and D. Bronaugh. 2009. Hydro-climatology and future climate impacts in British Columbia. Pacific Climate Impacts Consortium, University of Victoria, Victoria BC.
- Rodriguez-Calcerrada, J., I. M. Perez-Ramos, J. M. Ourcival, J. M. Limousin, R. Joffre, and S. Rambal. 2011. Is selective thinning an adequate practice for adapting Quercus ilex coppices to climate change? Annals of Forest Science 68:575-585.

- Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. Nature 421:57-60.
- Rose, N.-A., and P. J. Burton. 2009. Using bioclimatic envelopes to identify temporal corridors in support of conservation planning in a changing climate. Forest Ecology and Management 258:S64-S74.
- Rosenzweig, C., and T. Wilbanks. 2010. The state of climate change vulnerability, impacts, and adaptation research: strengthening knowledge base and community. Climatic Change **100**:103-106.
- Rubin, H. J., and I. Rubin 1995. Qualitative interviewing: the art of hearing data. Sage Publications, Thousand Oaks, CA.
- Rubolini, D., A. Møller, K. Rainio, and E. Lehikoinen. 2007. Intraspecific consistency and geographic variability in temporal trends of spring migration phenology among European bird species. Climate Research **35**:135-146.
- Sanchez-Fernandez, J., F. Munoz-Leiva, and F. J. Montoro-Rios. 2012. Improving retention rate and response quality in Web-based surveys. Computers in Human Behavior **28**:507-514.
- Schaefer, D., and D. A. Dillman. 1998. Development of a standard e-mail methodology: Results of an experiment. Public Opinion Quarterly **62**, **378-397**.
- Scheller, R. M., and D. J. Mladenoff. 2007. An ecological classification of forest landscape simulation models: tools and strategies for understanding broad-scale forested ecosystems. Landscape Ecology 22:491-505.
- Serengil, Y., A. Augustaitis, A. Bytnerowicz, N. Grulke, A. R. Kozovitz, R. Matyssek, G. Muller-Starck, M. Schaub, G. Wieser, A. A. Coskun, and E. Paoletti. 2011. Adaptation of forest ecosystems to air pollution and climate change: a global assessment on research priorities. Iforest-Biogeosciences and Forestry 4:44-48.
- Singh, S., S. Davey, and M. Cole. 2010. Implications of climate change for forests, vegetation and carbon in Australia. New Zealand Journal of Forestry Science **40**:141–152.
- Smit, B., and O. Pilifosova, editors. 2001. Adaptation to Climate Change in the Context of Sustainable Development and Equity. Cambridge University Press, Cambridge, UK.

- Soja, A. J., N. M. Tchebakova, N. H. F. French, M. D. Flannigan, H. H. Shugart, B. J. Stocks, A. I. Sukhinin, E. I. Parfenova, F. S. Chapin Iii, and J. P. W. Stackhouse. 2007. Climate-induced boreal forest change: Predictions versus current observations. Global and Planetary Change 56:274-296.
- Solomon, S., G. Plattner, R. Knutti, and P. Friedlingsteind. 2009. Irreversable climate change due to carbon dioxide emissions. Proceedings of the National Academy of Sciences of the United States of America **106(6)**.
- Spellerberg, I. 2005. Monitoring Ecological Change (2nd Ed.). Cambridge University Press, Cambridge, U.K.
- Spies, T., T. Giesen, F. Swanson, J. Franklin, D. Lach, and K. Johnson. 2010. Climate change adaptation strategies for federal forests of the Pacific Northwest, USA: ecological, policy, and socio-economic perspectives. Landscape Ecology 25:1185-1199.
- Spittlehouse, D. 2008. Climate Change, impacts, and adaptation scenarios: climate change and forest and range management in British Columbia. Ministry of Forests and Range, Victoria, B.C. .
- Spittlehouse, D. L. 2005. Integrating climate change adaptation into forest management. The Forestry Chronicle **81**:691 - 695.
- Spittlehouse, D. L., and R. B. Stewart. 2003. Adaptation to climate change in forest management. BC Journal of Ecosystems and Management **4**.
- Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western North America under a "business as usual" climate change scenario. Climatic Change 62:217-232.
- Strauss, A., and J. Corbin 1998. Basics of Quantitative Research: Techniques and Proceedures for Developing Grounded Theory. Sage., Thousand Oaks, CA.
- Svenning, J.-C., and R. Condit. 2008. Biodiversity in a Warmer World. Science **322**:206-207.
- Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. Oikos **Vol. 68** pp. 571-573.
- Taylor, S. W., A. L. Carroll, R. I. Alfaro, and L. Safranyik. 2007. Forest, climate and mountain pine beetle outbreak dynamics in Western Canada. Pages 67-94. Canadian Forest Service, Victoria.

- TEM. 1998. Standard for Terrestrial Ecosystem Mapping in British Columbia. Ecosystems Working Group, Terrestrial Ecosystems Task Force, Resource Inventory Committee, Victoria, BC.
- Thiaw, I., editor. 2009. Climate information and capacity needs for ecosystem management under a changing climate. United Nations Environment Program.
- Tremblay, G. D., and S. Boudreau. 2011. Black spruce regeneration at the treeline ecotone: synergistic impacts of climate change and caribou activityThis article is a contribution to the series Tree recruitment, growth, and distribution at the circumpolar forest-tundra transition. Canadian Journal of Forest Research **41**:460-468.
- Turnhout, E., M. Hisschem<sup>1</sup>ller, and H. Eijsackers. 2007. Ecological indicators: Between the two fires of science and policy. Ecological Indicators **7**:215-228.
- UNCSD, editor. 2007. Indicators of Sustainable Development: Guidelines and Methodologies. United Nations New York.
- UNFCCC. 2012. United Nations Framework Convention on Climate Change. United Nations.
- UNFF. 2007. Forests and Climate Change: Mitigation and Adaptation through Sustainable Forest Management, Remarks presented by Mr. Pekka Patosaari, Director, UN Forum on Forests Secretariat. United Nations 60th Annual DPI / NGO Conference, Climate Change: How it Impacts Us All Roundtable on Coping with Climate Change: Best Land Use Practices New York.
- USDA. 2010. National Report on Sustainable Forests in U. F. Service, editor. <u>http://www.fs.fed.us/research/sustain/2010SustainabilityReport/documents/draft</u> <u>2010sustainabilityreport.pdf</u> [Accessed March 2012].
- USFS. 1997. Montreal Process First Approximation Report. United States Forest Service, Washington DC.
- USFS. 2010. National Report on Sustainable Forests. USDA Forest Service, Washington DC.
- USGCRP. 2009. Our changing planet. The U.S. climate change science program for fiscal year 2009. United States of America Government, Washington D.C.
- Utzig, G. F., and R. F. Holt. 2009. Climate Change and B.C.'s Forest and Range Ecosystems: A Vulnerability Assessment, Step 1: Ecological Impacts and Vulnerabilities. Research Branch, Ministry of Forests and Range, Victoria, BC.

- Virkkala, R., R. K. Heikkinen, N. Leikola, and M. Luoto. 2008. Projected large-scale range reductions of northern-boreal land bird species due to climate change. Biological Conservation 141:1343-1353.
- Vos, C. C., P. Berry, P. Opdam, H. Baveco, B. Nijhof, J. O'Hanley, C. Bell, and H. Kuipers. 2008. Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones. Journal of Applied Ecology 45:1722-1731.
- VRI. 2010. Ministry of Forests and Range Vegetation Resources Inventory Website, Victoria, BC.
- Walker, I. J., and R. Sydneysmith. 2008. British Columbia in F. J. W. edited by D.S. Lemmen, J. Lacroix and E. Bush, editor. From Impacts to Adaptation: Canada in a Changing Climate. Government of Canada, Ottawa, ON.
- Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416:389-395.
- Wang, T., E. M. Campbell, G. A. O,ÄôNeill, and S. N. Aitken. 2012. Projecting future distributions of ecosystem climate niches: Uncertainties and management applications. Forest Ecology and Management 279:128-140.
- Weaver, A. J., K. Zickfeld, A. Montenegro, and M. Eby. 2007. Long term climate implications of 2050 emission reduction targets. Geophysical Research Letters 34:L19703.
- Welsh, C., K. Lewis, and A. Woods. 2009. The outbreak history of Dothistroma needle blight: an emerging forest disease in northwestern British Columbia, Canada. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 39:2505-2519.
- Whitfield, P. H., K. Bodtker, and A. J. Cannon. 2002. Recent variations in seasonality of temperature and precipitation in Canada 1976-1995. International Journal of Climatology v.22:1617-1644.
- Wijewardana, D. 2008. Criteria and indicators the road travelled and the way ahead. Ecological Indicators 8 (2008):115-122.
- Wilby, R. L., H. Orr, G. Watts, R. W. Battarbee, P. M. Berry, R. Chadd, S. J. Dugdale, M. J. Dunbar, J. A. Elliott, C. Extence, D. M. Hannah, N. Holmes, A. C. Johnson, B. Knights, N. J. Milner, S. J. Ormerod, D. Solomon, R. Timlett, P. J. Whitehead, and P. J. Wood. 2010. Evidence needed to manage freshwater

ecosystems in a changing climate: Turning adaptation principles into practice. Science of The Total Environment **408**:4150-4164.

- Williamson, T. B., S. J. Colombo, P. N. Duinker, R. J. Hennessey, D. Houle, M. H. Johnston, A. E. Ogden, and D. L. Spittlehouse. 2009. Climate change and Canada's forests: From impacts to adaptation. Canadian Forest Service, Edmonton AB.
- Wilson, R. J., D. Gutiérrez, J. Gutiérrez, D. Martínez, R. Agudo, and V. J. Monserrat. 2005. Changes to the elevational limits and extent of species ranges associated with climate change. Ecology Letters 8:1138-1146.
- Wilson, R. J., D. GutiÉRrez, J. GutiÉRrez, and V. J. Monserrat. 2007. An elevational shift in butterfly species richness and composition accompanying recent climate change. Global Change Biology 13:1873-1887.
- Woods, A., K. D. Coates, and A. Hamann. 2005. Is an Unprecedented Dothistroma Needle Blight Epidemic Related to Climate Change? BioScience **55**:761-769.
- Yuan, Y. 2010. Reporting and monitoring British Columbia's Forest Resources (2000 -2009). Ministry of Forests and Range Forest Analysis and Inventory Branch, Victoria BC.
- Zhang, L. A. Vincent, W. D. Hogg, and A. Niitsoo. 2000. Temperature and precipitation trends in Canada during the 20th century; Atmosphere-Ocean. v. 38:395–429.
- Zhang, X., K. D. Harvey, W. D. Hogg, and T. R. Yuzyk. 2001. Trends in Canadian streamflow. Water Resources Research **37**:987-998.
- Zheng, C., J. Pennanen, and O. Ovaskainen. 2009. Modelling dispersal with diffusion and habitat selection: Analytical results for highly fragmented landscapes. Ecological Modelling 220:1495-1505.

Appendix A – Examples of climate change monitoring

frameworks

### Table 1: Examples of climate change monitoring frameworks and tools

Monitoring Framework or Program	Characteristics	Link
Local and Regional		
Indicators of Climate Change for British Columbia 2002	Assessment describes trends in indicators of environmental, economic and societal values that are considered sensitive to climate change. Broad topic areas of indicators include climate change drivers, climate change and freshwater ecosystems, marine ecosystems, terrestrial ecosystems and human communities. Many indicators assessed have considerable synergies with FFEI. Examples of indicators in the ecosystem section include: the status of grassland habitats in southern interior British Columbia, area of protected grasslands in British Columbia, status of British Columbia forests, and trend in the number of road crossings of streams in British Columbia, 2000 to 2005.	British Columbia Ministry of Water, Land and Air Protection http://www.env.gov.bc.ca/air/climate/indicat/
Environmental Trends in British Columbia: 2007	The most recent MoE State of the Environment Report that assesses environmental changes in six topic areas, each with a distinct set of indicators. This information builds on reporting and monitoring frameworks used to develop four previous Environmental Trend reports for British Columbia. Topic areas include population and economic activity, air quality, water quality, climate change, contaminants, ecosystems, and species conservation. Over 44 indicators and 25 supplementary measures were analyzed and adaptation is addressed in action plans for each topic area. Several indicators and data sources could supplement the FFEI monitoring program.	British Columbia Ministry of Environment (MoE) State of the Environment Reporting http://www.env.gov.bc.ca/soe/
British Columbia Coast and Marine Environment Project 2006	Review of how climate change is impacting British Columbia's coastal and marine environment. Indicators include long-term trends in annual and seasonal air temperature, frost-free days, precipitation, coastal ocean temperature change and its effects along the British Columbia coast, and rise in sea level and its effects on British Columbia shore zones.	British Columbia Ministry of Environment State of the Environment Reporting http://www.env.gov.bc.ca/soe/

Monitoring Framework or Program	Characteristics	Link
Pacific Climate Impacts Consortium (PCIC)	<ul> <li>PCIC is a research group designed to encourage collaboration between government, academic institutions and industry while producing policy-relevant information to inform decision-making. It has created a Regional Analysis Tool which facilitates the comparison of past climate trends and future climate scenarios using GCM regional data. Water, biodiversity, hydro-climatology, and regions such as British Columbia's Southern Interior forests are among the research projects and impact assessments that have been conducted, and which could be relevant to the FFEI monitoring program. For example, the objective of the Preliminary Analysis of British Columbia Climate Trends for Biodiversity project was to develop an index of climate change for biodiversity.</li> <li>A Forest Health Database has been compiled and most of the following datasets are available for research purposes: CRU climate data (TS2.1), CANGRID climate data, NCEP Reanalysis climate data, NARR climate data, PRISM climate normals, PRISM climate normals computed using ClimateBCsoftware (CRU 1 degree data downscaled to 400 m), Canadian Digital Elevation Data (CDED) data, regridded for British Columbia, Climate timeseries computed using ClimateBC(CRU 0.5 degree data downscaled to 400 m), Presence plot data, Vegetation resources inventory data, Forest inventory data and BIOSim pest outbreak simulation and historical climate data.</li> </ul>	Pacific Climate Impacts Consortium (PCIC) University of Victoria, Center for Global Studies http://www.pacificclimate.org/
Pacific Institute for Climate Solutions	Research group producing White Papers. To date, one focused on forestry: Carbon Sequestration in British Columbia's Forests and Management Options	Pacific Institute for Climate Solutions, University of Victoria http://www.pics.uvic.ca/
Climate Impacts Group	Interdisciplinary research group studying implications of climate variability and change on four components of the Pacific Northwest environment: water resources, aquatic ecosystems, forests, and coasts. The Forest research group is currently focused on fire-climate relationships, climate impacts on Douglas-fir growth rates,	Climate Impacts Group, University of Washington http://cses.washington.edu/cig/

Monitoring Framework or Program	Characteristics	Link		
	insect outbreaks, tree species distributions, forest productivity and forest ecosystem carbon storage. Hydrology, salmon, agriculture and forests were among relevant topic areas recently assessed in a report titled "A Comprehensive Assessment of Climate Change on the State of Washington".			
Forest Management in a Changing Climate: Building the environmental information base for Southwest Yukon	Climate-related indicators developed for the Southwest Yukon: temperature, precipitation, drought index, Frost free days, lightning, beetle infestation, forest fire occurrence, fire weather index, and potential forest fire behaviour.	http://yukon.taiga.net/swyukon/index.cfm		
National				
EMAN (Ecological Monitoring and Assessment Network)	Ecological Monitoring network that coordinates collaboration between federal, provincial and municipals governments, communities, academic establishments, non-governmental organizations, student groups, volunteer groups and anyone else involved in ecological monitoring. It partners with the ILTER network (see below) and has facilitated the establishment of the CCMN and NatureWatch.	EMAN, Environment Canada http://www.eman-rese.ca/eman/		
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.	Canadian Community Monitoring Network http://www.ccmn.ca/english/		
NatureWatch	Citizen-science monitoring coordinated by EMAN and Nature Canada. Programs include FrogWatch, WormWatch, IceWatch, PlantWatch. Programs in development stage include lichens, tree health and benthic macro-invertebrates.	NatureWatch http://www.eman- rese.ca/eman/naturewatch.html		
Pacific and Yukon Region	Environment Canada's State of the Environment assessment for the Pacific and	Environment Canada		

Monitoring Framework or Program	Characteristics	Link
Environmental Indicators	Yukon region includes a special section for addressing climate change. Indicators include average temperature for regions of British Columbia and the Yukon, change in the number of frost-free days, and trend in annual precipitation. Other indicators assessed in the report include shellfish closures, seabirds, toxic contaminants from biomagnification in birds and eggs, waterfowl species, several wildlife species, sensitive ecosystems, porcupine caribou, Fraser Valley smog, stratospheric ozone thickness, nitrate levels in ground water and waste water and use.	http://ecoinfo.org/env_ind/indicators_e.cfm
National Environmental Indicator Series – Climate Change	Indicators cover aspects from human well-being, health and activities, to natural resources and ecological life support systems. Forestry, agricultural soils, biodiversity, protected areas, acid rain, toxic substances, and climate change are general indicators and each is comprised of several supporting indicators. Examples of supporting indicators include CO <sub>2</sub> , greenhouse gases emissions, temperature and precipitation, weather related disasters, population status of forest bird species, number of forest fires in Canada, consecutive years of spruce budworm defoliation, trend in lake acidity, wet nitrate deposition, etc.	Environment Canada, State of the Environment Infobase http://www.ec.gc.ca/soer- ree/English/Indicator_series/default.cfm#pic
Climate, Nature, People: Indicators of Canada's Changing Climate	Indicators were analyzed over two time periods (1950-2000, and 1900-2000) and regionally. Indicators include sea level rise, sea ice, river and lake ice, glaciers, polar bears, plant development, traditional ways of life, drought, Great-Lakes – St. Lawrence water levels, frost and frost-free season, heating and cooling, and extreme weather events.	CCME (Canadian Council of Ministers for the Environment) http://www.ccme.ca/publications/list_publicatio ns.html#link3
From Impacts to Adaptation: Canada in a Changing Climate 2007	A vulnerability and adaptation study focused on human and managed systems, first conducted at an integrated national level, followed by regional assessments. Indicators for British Columbia include temperature, precipitation, extreme weather and related events, hydrology, sea level, and ecosystems. Indicators are assessed in several topic areas: water resource management, fisheries, forestry, agriculture, tourism and recreation, parks and protected areas, energy, critical infrastructure and health. Case studies are considered within the sectors and the specific indicators are dependent on the locality and driven by local variables.	Natural Resources Canada http://adaptation.nrcan.gc.ca/assess/2007/
Monitoring Framework or Program	Characteristics	Link
---	--	--
NatureCounts	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), British Columbia-Yukon Nocturnal Owl Survey, and the Canadian Migration Monitoring Network.	http://www.birdscanada.org/birdmon/
Canadian Environmental National assessment focused on health of Canadians. Indicators include air and freshwater quality indicators, as well as greenhouse gas emissions.		Government of Canada http://environmentandresources.gc.ca/
United States	·	
U.S. Climate Change Science Program (CCSP)	Integration of all federal research agencies studying climate change within the U.S. Comprehensive assessments and research are focused on the following topic areas: atmospheric composition, climate variability and change, the global water cycle, land-use and land-cover change, the global carbon cycle, ecosystems, decision- support resources, development and related research on human contributions and responses, observing and monitoring the climate system, communications, and finally international research and cooperation. The Synthesis and Assessment Products (SAPs) (e.g., Thresholds of Change in Ecosystems, or The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity) may provide guidance for the FFEI monitoring strategy.	U.S. Climate Change Science Program/ U.S. Global Change Research Program. http://www.climatescience.gov/
Forest Inventory and Analysis (FIA) Forest Health Monitoring (FHM) Program	This program tracks the annual status, changes and trends in national indicators of forest health. The monitoring program integrates ground and aerial data from several programs and surveys, (including from local management inventories, the Forest Inventory and Analysis program, additional FHM, urban forest health monitoring, intensive site monitoring), and strives to cover all forestland regardless of tenure. The indicators currently used in the FHM program include tree growth, regeneration, tree crown condition, tree damage, tree mortality, lichen	United States Department of Agriculture (USDA) Forest Service http://fhm.fs.fed.us

Monitoring Framework or Program	Characteristics	Link
	communities, ozone bioindicator plants, soil morphology and chemistry, downed woody debris, vegetation structure, and plant diversity.	
	Additional parameters being monitored for climate change include the status, health, distribution and range of Whitebark Pine; drought impacts on forest health in the Southeast US, Southern California, and Alaska birch stands; modelling fire spread, intensity, fuel load and tree deterioration across beetle-affected landscapes; and invasive species response and ecological implications after fire.	
Biological Assessment and Criteria Programs: Biological Indicators of Watershed Health	The US Environmental Protection Agency (EPA) uses biomonitoring to detect climate change effects for streams and small rivers, lakes and reservoirs, estuaries and near coastal, wetlands, and coral reefs. A recent report evaluated the effects of climate change on stream and river biological indicators: Climate Change Effects on Stream and River Biological Indicators: A Preliminary Analysis.	US Environmental Protection Agency http://cfpub.epa.gov/ncea/
The State of the Nation's Ecosystems 2008	Reports on 108 indicators spanning forests, grasslands and shrublands, coasts and oceans, freshwaters and urban and suburban ecosystems and landscapes.	The John Heinz Center III for Science, Economics and the Environment
	The State of the Nation's Ecosystems 2008: Focus on Climate Change is a fact sheet that analyzed several of the 108 indicators separately, specifically in relation to climate change. Other fact sheets cover wildlife, contaminants and nitrogen.	http://heinzctr.org/ecosystems/
National Ecological Observation Network (NEON)	Long-term continental research and monitoring network recently established to gather observations on environmental responses to land-use and climate change. Climate and canopy microclimate, air pollution and air quality, the carbon cycle, soil characteristics, water quality, soil and aquatic biochemistry, and patterns and changes in small mammals, insects, birds, fish, soil microbes, plants, and algae are all characteristics that will be studied at each site. Designed to provide GTOS and GSOS with terrestrial data.	National Science Foundation www.neoninc.org
Long Term Ecological Research Network (LTER)	A collaborative network of research sites spanning many ecosystems across the US. Monitoring core research areas over time and space that provide the basis for the	National Science Foundation

Monitoring Framework or Program	Characteristics	Link
	LTERN. Core areas include primary production, population studies, movement of organic and inorganic matter, and disturbance patterns. The Global Change Research sector of LTER provides information on programs within the network that are researching climate change.	www.lternet.edu http://www.lternet.edu/global_change/
DRAFT National Report on Sustainable Forests 2010	Reports on a monitoring framework with Criteria and Indicators (C&I) based on the Montreal Process (similar to CCFM National C&I). The report generally assesses sustainable forest management in the US but attempts to integrate climate change discussion into the analysis. The report also designates a section to specifically, however briefly, reflect on the relationships of several C&I to climate change. Further analysis, including a distinct report with a climate change focus, is mentioned as an option that may be considered in the future.	United States Department of Agriculture (USDA) Forest Service http://www.fs.fed.us/research/sustain/2010Sustai nabilityReport/
Global		
ICP (International Co- operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests)	European monitoring network originally designed to monitor for effects of air pollution on forests, but is now being adapted to monitor for both pollution and climate conditions. It is one of the largest bio-monitoring projects in the world, with two levels of monitoring which span several countries. Current monitoring indicators include local air quality and meteorology, atmospheric deposition, litterfall (biomass and chemistry), soil and soil chemistry (e.g., soil solution chemistry, dissolved organic carbon, plant available sulphur), foliar biomass and chemistry (i.e., foliar chemistry indicates nutritional status of tree) crown density and DBH (annually), phenology, ground vegetation composition (cover and species comp) and community structure (tree recruitment), deadwood (abundance and condition), biodiversity indices (e.g., bryophytes under coniferous tree species (i.e., lower plant groups) and higher plant groups), and above-ground carbon stock change.	http://www.icp-forests.org/
Global Climate Observing	Internationally coordinated network of long-term surveillance systems designed to provide global, comprehensive, and continuous observational data regarding the	http://www.wmo.int/pages/prog/gcos/index.php

Monitoring Framework or Program	Characteristics	Link
Systems (GCOS)	state and variability of the entire global climate system. It plays a major role in ensuring that observation systems meet international requirements and can further provide much needed information for decision-making.	
Global Terrestrial Observing System (GTOS)	International observation network developed to increase scientific understanding of climate change impacts on terrestrial ecosystems and ecological processes. GTOS Essential Climate Variables (ECV) for terrestrial monitoring include: albedo, biomass, fire disturbance, fraction of absorbed photosynthetically active radiation (FAPAR), glaciers and ice caps, groundwater, lake levels, land cover (including vegetation type), leaf area index (LAI), permafrost and seasonally-frozen ground, river discharge, snow cover, and water use.	Food and Agriculture Organization (FAO) of the United Nations www.fao.org/gtos
International Long-term Ecological Research Network (ILTER)	Global network of LTER sites and researchers. The network focuses on long-term, ecological and socio-economic, site based research and encompasses numerous ecosystems around the globe, including 26 in the US.	http://www.ilternet.edu/
UNESCO Global Change Monitoring Programme	The UNESCO Man and Biosphere program was originally created as a Biosphere Reserve program and spans 94 countries. It is now being adapted to monitor global climate change in all of the major mountain regions in the world and will be the basis for the Global Change Monitoring Program.	United Nations Educational Scientific and Cultural Organization
British Trust for Ornithology: Climate Change Research	The BTO uses long-term datasets such as the Common Bird Census (CBritish Columbia), National Ringing Scheme, and the Nest Record Scheme to monitor potential impacts of climate change on bird population sizes, ranges, and breeding events such as arrival on grounds, timing, survival and success. Other relevant research included testing a suite of indicators for bats, marine and terrestrial mammals, fish, turtles, and birds. Indicators used often span several species, rather than just one. Examples of indicators include the change in relative abundance of trans-Sarahan migrants, change in reproductive output of shorebirds, abundance of bats at underground hibernation sites	http://www.bto.org/research/climatechange.htm

Monitoring Framework or Program	Characteristics	Link
Environmental Monitoring at the Center for Ecology and Hydrology	A network of greater than 180 monitoring sites in Great Britain covering a broad range of ecosystems. Monitoring and research topic areas include animal taxa, soils, vegetation, water, air chemistry, and meteorology.	Center for Ecology & Hydrology. http://www.ceh.ac.uk/science/EnvironmentalMo nitoring.html
Environmental Change Network (ECN)	Long-term monitoring program designed to detect, monitor and interpret environmental change in the United Kingdom. Indicators include 34 climate change indicators and additional biodiversity and water quality indicators affected by climate change.	United Kingdom http://www.ecn.ac.uk/environmental_indicators. htm http://www.ecn.ac.uk/ICCUK/
Climate Change and Freshwater	The project aims to define indicators and investigates the effects of climate change on European rivers, lakes and wetlands in both cold and temperate eco-regions. It first gives an overview of current indicators being used for monitoring frameworks, and then suggests indicators for climate change impacts. It goes on to assess how individual species are affected by climate change, and then finishes by describing case studies of how specific indicators are being used.	http://www.climate-and-freshwater.info/

Appendix B – Workshop activities

### Workshop Activity 1:

For this activity you are asked to consider the question: What are the critical factors that should be considered in developing the indicators for the monitoring framework? Table 4 details some of the 'characteristics of a good indicator' that have been identified as potentially suitable. In this activity you are requested to rank these characteristics based on what you think are the most important attributes for developing indicators under this particular framework and include any additional characteristics that you think are important that are not included in the table.

Please note that for this exercise you are not asked to detail the formally recognized 'characteristics of a good indicator'. Your subjective opinion of what you think is important for this particular monitoring framework based on your experience with British Columbia's forests and rangelands it what's important - there is no right or wrong answer!

## Workshop Activity 1: Developing the critical selection criteria for choosing indicators

Characteristic:	Your ranking: 1: highly important 2: moderately important 3: not important	Your comments:
Cost of monitoring		
Use existing data sources and collections		
Trend data is available for monitoring		
Measurement is repeatable over time		
Easily measurable		
Relevant to current policy arrangements		

Understandable	
Flexible	

Workshop Activity 2:

For this activity you are asked to prioritize information needs by considering the question: What do you consider to be the most important forest and rangeland species and ecological processes that require ongoing monitoring in light of climate change? The document provided to you has briefly described a number of topic areas which could be used. For this workshop activity you are asked to:

- Identify any further areas that are needed
- Identify the ways in which the particular topic areas are likely to need further work or revision before implementation
- Identify additional data sources that may be able to support analysis of the topic area
- Prioritize those areas that are the most important for monitoring

Again, in considering the topic areas please note that your subjective opinion on what you think is important for this particular monitoring framework based on your experience with British Columbia's forests and rangelands is sought.

<b>XX</b> <i>T</i> = <b>11</b>		- <b>^</b> -	D.:: .: _:	- · · · · ·			f 11		f
workshoi	$\mathbf{n} = \mathbf{A} \mathbf{C} \mathbf{U} \mathbf{V} \mathbf{U}$		Prior11171r	ισ ιητοι	manon	needs	tor the	monitoring	tramework
1 OINDIO		y <u>~</u> .	I IIUIUUU		manon	nocus.	IOI UIC	monitoring	in unite work
		/						0	

		Your ranking: 1: Highly important 2: Moderately important 3: Not important	Your comments:
1	Biodiversity		
1.1	Change in the distribution and composition of forest and rangeland ecosystems		
1.2	Area of forest and range by protected area categories		
1.3	Levels of ecosystem fragmentation		
1.4	Trends in population and range information for species from a range of taxa and habitats		
1.5	Forest and range associated species at risk of losing their genetic diversity and forest management and conservation efforts for those populations and species.		
2	Forest and range health		
2.1	Scale and severity of insects and pathogens adversely affecting forest and rangeland health		
2.2	Scale and severity of wind-throw damage affecting forests		
2.3	Extent to which fire frequency, severity and seasonality has deviated from the historic range		
	Scale and severity of unseasonable or unexpected weather conditions		
3	Water		
3.1	Extent to which precipitation rates and timing within selected forest		

		Your ranking: 1: Highly important 2: Moderately important 3: Not important	Your comments:
	and rangeland catchments has deviated from the historic range		
3.2	Extent to which snowpack in forest and rangeland catchments has deviated from historic amounts		
3.3	Extent to which streamflow rates and timing in selected forest and rangeland catchments has deviated from the historic range		
3.4	Extent to which temperatures in selected forest and rangeland streams and lakes have deviated from the historic range		
3.5	Changes in glacial mass balance		
4	Soils and geomorphological proce	sses	
4.1	Scale and density of rapid mass movements and erosion events		
4.2	Temperature of soil at selected forest and range sites		

Appendix C - Forest and range managers' survey

#### **1. SURVEY INFORMATION**

As one of B.C.'s forest and range management experts, your input is needed to help us to develop a better understanding of key monitoring and reporting information needs in relation to climate change adaptation.

Observational evidence has been given from all continents and most oceans showing that many natural systems are now being affected by regional climate changes, particularly temperature increases. All reported temperature trends show that B.C. too has warmed in recent decades. Models and emissions scenarios for B.C. forecast that these temperature increases will continue and are likely to be compounded by various changes in the province's precipitation regime. Extreme weather events are also predicted to become more commonplace along with increases in the frequency and intensity of windstorms, forest fires and landslides. Even if the most optimistic predictions are taken, these changes are likely to affect the ecological processes in B.C.'s forests and rangelands significantly.

Given that many of the decisions that resource managers make will be influenced by the ecosystem changes caused by the changing climate, it is valuable to monitor these changes to help inform those decisions. The Future Forest Ecosystems Initiative in collaboration with the Forest and Range Evaluation Program (FREP) and the University of British Columbia has, through a process of literature review and expert input, developed a preliminary framework of indicators for monitoring forest and rangeland species and ecological processes in light of climate change. The report resulting from this initial work (along with the references associated with the text above) can be found at: http://www.for.gov.bc.ca/HFP/frep/site\_files/reports/FREP\_Report\_20\_web.pdf

In 2010 we are building on this work by further developing the indicators. To assist in making the monitoring framework most valuable, it is vital for us to better understand decision makers' key information needs and reporting requirements.

In completing the survey please be assured that any personal information you provide will remain confidential and data will only be reported in a form that will make it impossible to determine individual identities.

If you have any questions relating to the survey or would like further information about this climate change monitoring project please direct inquiries to: Email: margie.eddington@ubc.ca Telephone: 250-733-9881

If you would like more information about FREP and it's other forest and range monitoring initiatives please visit our website at: http://www.for.gov.bc.ca/hfp/frep. Or direct inquiries to: Email: peter.bradford@gov.bc.ca Telephone: 250-356-2134

I encourage you to take the time to participate in this important survey.

Jim Snetsinger Chief Forester Ministry of Forests and Range British Columbia, Canada

### 2. YOUR CLIMATE CHANGE ADAPTATION INFORMATION NEEDS

\*

1. What type of decisions do you make that could be influenced by changes to ecosystems caused by rapid climate change?

2. The following topic areas have been identified as important for monitoring in B.C.'s forests and rangelands for climate change adaptation. Using the scale provided please rate their importance with regard to your own climate change information needs.

	Extremely Important	Very Important	Important	Not Very Important
Ecosystem productivity	0	$\bigcirc$	0	0
Ecosystem distribution	0	$\circ$	0	0
Ecosystem composition	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$
Ecosystem connectivity	$\circ$	$\bigcirc$	0	$\bigcirc$
Species population levels	$\bigcirc$	$\odot$	0	$\bigcirc$
Species ranges	$\circ$	$\circ$	0	0
Species phenology (i.e. timing of life events)	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$
Genetic diversity	$\bigcirc$	$\bigcirc$	0	$\circ$
Insect incursions	$\bigcirc$	0	0	0
Pathogen incursions	$\circ$	$\bigcirc$	0	$\bigcirc$
Wind throw damage	$\bigcirc$	$\bigcirc$	0	$\bigcirc$
Fire season length	$\bigcirc$	$\bigcirc$	0	$\bigcirc$
Fire season severity	0	0	0	0
Precipitation form	$\bigcirc$	$\circ$	0	$\bigcirc$
Precipitation rate	$\bigcirc$	$\bigcirc$	0	$\bigcirc$
Precipitation timing	$\bigcirc$	$\circ$	0	0
Snowpack extent and depth	$\bigcirc$	0	0	0
Streamflow rate	$\bigcirc$	$\circ$	0	0
Streamflow timing	$\bigcirc$	0	0	$\bigcirc$
Water temperature	0	0	0	0
Water quality	0	0	0	0
Mass movement and erosion events	$\bigcirc$	$\circ$	0	0
Unseasonable or unexpected weather	$\bigcirc$	0	0	0
Extent of glaciers	0	0	0	0
	_		-	-

2. Ave there any other tenis eress that you think are important for menitoring for slimet	-
change adaptation that are not listed above? If so, please detail them below and rate them with regard to their relative importance using the above scale (i.e., Extremely Important to Important).	e
×	
4. Given the topic areas you identified as most important for monitoring, what key information needs do you have (or perceive you will have) in adapting B.C.'s forests as rangelands to climate change?	nd
· · · · · · · · · · · · · · · · · · ·	
5. Do you have any insight as to what we should specifically monitor in order to respond to your key information needs?	
×	
*	
In relation to the responses you have given above, the timeframe(s) you are most	
interested in is:	
<10 years	
10-20 years	
20-50 years	
50- 100 years	
Please explain your choice(s) in a few words:	
× 7	

7. In relation to the responses you have given above, are there any specific geographic			
regions/transition areas that are of most importance?			
○ No			
○ Yes			
If yes, please detail those areas and explain your choice in a few words:			
×			
×.			

### 3. YOUR CLIMATE CHANGE ADAPTATION REPORTING NEEDS

1. Do you think there is enough data collected to understand how to manage forests and rangelands to adapt to climate change? If no, what are the important data gaps?

2. Do you think B.C. manage forests and suggestions do you	is doing the co frangelands for have?	rrect type of analys climate change ad	sis on data alread aptation purpose	y collected to s? If no, what
3. Please rate how f	requently you u	★ ▼ se the information	sources below to	make decisions
in your work area:				
	Frequently Used	Sometimes Used	Rarely Used	Never Used
Webinars/ e-lectures	0	<u> </u>	0	0
Consultants	0	0	0	0
Technical articles	0	0	0	0
Professional association(s)	0	0	0	0
Face-to-face extension activities	0	0	0	0
Government reports and briefings	0	0	0	0
Internet	$\bigcirc$	0	0	0
Journal articles and other academic literature	$\circ$	$\circ$	$\circ$	0
Newspapers/Magazines	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$
Seminars	$\bigcirc$	$\circ$	$\bigcirc$	$\bigcirc$
Corporate Databases (RESULTS, SPAR, FTA (etc))	0	0	0	0

4. At which coole(c) do you work?	
4. At which scale(s) do you work?	
International	
Federal	
Provincial	
Regional	
District/Field-office	
Municipal	
Other (please specify)	

5. If you selected that you work at the district scale, in which forest district(s) do you
work?
100 Mile House
Arrow Boundary
Campbell River
Cascades
Central Cariboo
Chilcotin
Chilliwack
Columbia
Fort Nelson
Fort St. James
Haida Gwaii
Headwaters
Kalum (including North Coast)
Kamloops
Kootenay Lake
Mackenzie
Nadina
North Island - Central Coast
Okanagan Shuswap
Peace
Prince George
Quesnel
Rocky Mountain
Skeena Stikine
South Island
Squamish
Sunshine Coast
Vanderhoof
Other (please specify)



### 5. THANK YOU

We greatly appreciate the time and effort you have taken to complete this survey.

The information you have provided will help us to better refine and target B.C.'s climate change adaptation monitoring and reporting efforts.

Thank you!

Appendix D – Process for monitoring ecosystem distribution

and composition

# Box 1 – Process applied for testing the approach for monitoring ecosystem distribution and composition

The VRI data (veg\_comp\_lyr\_R1\_poly) was downloaded in August 2010 from British Columbia 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\_British ColumbiaAlbers\_CSRS.shp).

### 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.

### 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 British Columbia\_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 BEC\_full field to create polygons outlining the BEC variants occurring within the six plots.

### 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 me 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.

### 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.