

The Mountain Pine Beetle, Climate Change, and Scientists: Understanding Science's
Responses to Rapid Ecological Change in Western Canada

by

Heike Lettrari
Bachelor of Arts, University of Victoria, 2011

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of the Requirements for the Degree of

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Abstract

Today, climate change and rapid ecological change are impacting our ecosystems and landscapes in numerous, often surprising ways. These changes result in social, cultural, ecological, and economic shifts, as exemplified in the climate-exacerbated mountain pine beetle (MPB) outbreak in British Columbia. Recently, scientific communities have boosted calls for “usable science.” By interviewing leading MPB scientists, I ask, “How are scientists and their institutions responding to rapid ecological change?” Numerous factors shape MPB science—institutional support, funding, and values—and these factors enable and constrain effective relationships and ultimately, useful science, in response to the outbreak. Results suggest that while science and scientific institutions change slowly, and while relationships between MPB science and policy are characterized as tenuous, there are signs that crossing institutional boundaries (such as the TRIA Network) contributes to producing science that is more effective for responding to rapid ecological change.

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Dedication

I dedicate this thesis to my family, though especially to the strong women in my life: my grandmother, Sigrid Lettrari: the most steadfast, resolute and fierce support one could wish for; my mother, Gabriele Lettrari, whose work ethic, commitment, and selflessness continue to inspire me; and my sister, Heidi, whose intelligence, strategic acumen, and calm energizes me.

Chapter 1: Introduction

“The world is undergoing unprecedented changes in many of the factors that determine both its fundamental properties and their influence on society.”

— F. Stuart Chapin III & Gary P. Kofinas (2009): A Framework for Understanding Change

1.0 Introduction

Insects have always had a special place in history and culture. From long ago, biblical lore tells us that of the Ten Plagues of Moses experienced by the Jewish Pharaoh that held prisoner the people of Moses, four involved insects: flies, lice, and mosquitos that disgusted the Pharoan people, and locusts that devoured the all greenery in their landscape. Today, tens of thousands of people post to Facebook about the plight of the bees, struggling with colony collapse disorder. And recently, insects command their own section of the annual Wildlife Photograph of the Year Exhibit at the Royal BC Museum. In 2015, one of the most stunning photos there was “winter” with an explosion of mayflies in Spain—a swarm so thick they looked like the fluffiest of snowflakes fiercely sailing down as a snowstorm, shutting down local traffic with their abundance.

While the latest mountain pine beetle outbreak did not quite amount to the horrors of a biblical plague or shut down street traffic on a sunny summer day, the novel characteristics of the latest outbreak caught my attention, and reached me even in my tiny hometown of Kaslo in the summers of 2007 and 2008. I remember standing at the top of a ridge I had hiked, looking across Kootenay Lake to the Purcell Mountains from the balcony, surprised by the red patches of dying pines that I hadn't seen in our forests growing up—the fecundity of beetle reproduction given a warming landscape had resulted in beetle numbers sufficient to find even the spotty patches of lodgepole pine we had in our corner of BC's southern interior. Later, at Christmas, walking through the woods with my parents, we came across a sap-hole riddled tree trunk in the middle of the forest—what I would later learn was characteristic of mountain pine beetle attack.

In undertaking this study, it has struck me that the mountain pine beetle is a microcosm of some of the many different kinds of unforeseen climate impacts that begin as ecological surprises, yet also have economic, ethical, and social impacts that become apparent with closer examination.

The awareness that people are having a significant impact on the world is increasing, and ecosystems are likewise responding to both direct (pollution, ecosystem degradation, industrial and resource extraction) and indirect (climate change) anthropogenic perturbations in myriad ways. One study attempting to quantify anthropogenic impact estimated that more than 75% of the planet's terrestrial ice-free surfaces show direct anthropogenic impacts (Ellis & Ramankutty, 2008). While difficult to see when peering out a window or taking an afternoon walk, the effects of climate change and the potential for future climate change impacts are registering for people across the globe.

However, much of the recent conversation about climate change has been taking a negative slant: political leaders are not taking enough action; media reports continually warn of impending catastrophes of the future, including droughts, floods, rising sea levels, crop failures or reduced yields, and increasing frequencies of extreme weather events and storms. The stakes for not addressing climate change are high: some scientists argue that inaction will cost our global economies billions of dollars (*sensu* Stern, 2006).

How do scientists respond to these fast-paced changes? How flexible are their institutions in response to the pressures of past-paced environmental and ecological change, such as a climate-sensitive mountain pine beetle? Does an awareness of the real, social and economic impacts of climate change vis-à-vis the mountain pine beetle (lost jobs, mill closures) influence scientific efforts? Climate change impacts today add pressure to the question, "Whose responsibility is it, to adapt?" and "How are scientists adapting?" With this thesis I explore questions at the nexus of scientists, climate change, and the mountain pine beetle in Western Canada in this thesis.

1.1 Rapid Ecological and Environmental Change: Insects on the Move

Amid the stream of generally negative news about not enough action being taken to mitigate climate change, from one perspective, there seem to be some winners: a number of species have been nabbing headlines in recent news because of their *positive* responses to climate change. Notable species include the Raspberry or Tawny crazy ant (*Nylanderia fulva*) that has travelled north from its historic range in Central America, to Texas and the southern gulf states of the USA (Gotzek, Brady, Kallal, & LaPolla, 2012), and is displacing the formerly invasive fire ants (*Solenopsis invicta*), though negatively impacting native grassland ant and other insect species (LeBrun, Abbott, & Gilbert, 2013); *Aedes albopictus*, or the invasive Asian tiger mosquito, spreading their ranges northward in the United States (Urquhart, n.d.) and Japan (Mogi & Tuno, 2014), which for this mosquito means spreading the intensely painful joint disease, Chikungunya fever (Urquhart, n.d.); and the mountain pine beetle, which has been endemic to a large region across western North America, including British Columbia (BC), the USA, and Mexico (Safranyik & Wilson, 2006) for a long time, but which has spread far beyond its historic range in its most recent outbreak (Nealis & Peter, 2008), and has contributed to changing forest fire hazards (Jenkins, Hebertson, Page, & Jorgensen, 2008), forest disturbance and economic disruptions for wood-based economies, and the declining populations of whitebark pine (*Pinus albicaulis*) (Logan & Powell, 2001).

Indeed, recent work by the Intergovernmental Panel on Climate Change (IPCC) (2011) and others (Bentz et al., 2010; Carroll, 2012; Carroll, Taylor, Regniere, & Safranyik, 2003; Logan, Regniere, & Powell, 2003) indicate an expectation that in the coming decades, insect outbreaks and other disturbance events such as wildfire, drought, and extreme weather events in North America, will increase in frequency, and severity due to climate change. Closer to home, similar suggestions were made in a regional assessment of Canada's vulnerability to climate change, which projected the highest certainty for shifting disturbance regimes in BC (Walker & Sydneysmith, 2008).

Further, Hamann and Wang (2006) have shown that climate envelope models for BC project major biotic changes, including spatial shifts of optimal climate

conditions for montane and sub-boreal tree ecosystems. Recently, research has shown that using climate projections of future distributions of ecosystem climate niches in British Columbia show there is uncertainty and that management implications need to take changing climates into account (Wang, Campbell, O'Neill & Aitken, 2012). And more recently, the increased availability and quality of downscaled climate data compels thinking through the implementation of adaptation strategies (Wang, Hamann, Spittlehouse, & Carroll, 2016) for forest management, such as for reforestation programs (Mbogga, Hamann, & Wang, 2009) and assisted migration (Wang & Aitken, 2011). Already, the mountain pine beetle outbreak in British Columbia has been characterized as the most “ecologically and economically important of the insect herbivores” (Carroll, 2012), and killed a cumulative total of 710 million cubic meters of timber in just over a decade (MFLNRO, 2012). A careful eye is being kept on the mountain pine beetle because of its positive response to host tree stress and a lack of dependence on phenological synchrony, too (Carroll, 2012)—conditions that are further exacerbated by climate. And after a study that showed that the genetic variability of mountain pine beetles was retained after a mass-dispersal event, which is advantageous for adaptation (Gayathri Samarasekera et al., 2012), the researchers also concluded that other similar insect outbreaks and range expansions of pest and non-pest species was imminent. Clearly, we can expect more change in BC’s forests and the forests of western Canada in the future, not less.

Beetle outbreaks like the one seen from the mountain pine beetle are not new (Alfaro, Campbell, & Hawkes, 2010), but climate change is linked to causing some of the rapid ecological change that has driven numerous changes and novel characteristics in British Columbia’s current and ongoing mountain pine beetle epidemic (Carroll, 2012);(Sambaraju et al., 2012). Historical factors have contributed to conditions that have shaped the most recent outbreak, including nearly a century of wildfire suppression, large continuous stands of mature pine trees (abundant sources of fuel for the beetle), and particular forest management decisions that influenced the presence of particular mountain pine beetle friendly tree species (Nikiforuk, 2011; Carroll, 2012). Paired with regional climatic changes that resulted in warmer winters,

beetle populations were not regulated by cold temperatures as they have been in the past (Carroll, Taylor, Regniere, & Safranyik, 2003; Nikiforuk, 2011).

Over the last 15 years of the rise and fall of the most recent mountain pine beetle outbreak, scientists researching various aspects of the outbreak have mounted an immense research effort to expand knowledge about the mountain pine beetle. In 2003, scientists across institutions and borders, including federal scientists (Canadian Forestry Service), provincial scientists (Ministry of Forests), provincial and federal parks staff in BC, and scientists and researchers from the United States Forest Service met again for an international symposium that had not convened since the 1980s and early 1990s when the previous outbreak was occurring. Further, scientists and researchers commented in public (eg. York, 2014) and in academic articles on historical differences—novel characteristics—of the mountain pine beetle outbreak, which included identifying “novel habitat” that the beetle has spread to and changing the classification of the mountain pine beetle as a native species, to a “native-invasive” (Nealis & Peter, 2008). This significant flurry of research activity was initiated as part of the response to this event, ranging from trying to manage the risk of the mountain pine beetle entering the boreal forest (Nealis & Peter, 2008), to understanding the genetic differences of beetle populations and their outbreak patterns e.g. (Gayathri Samarasekera et al., 2012), to understanding the economic impacts of the outbreak, e.g. (Scott, 2007) and connecting the dots to the impact of climate change, e.g. (Carroll et al., 2003).

Because of significant differences between the most recent mountain pine beetle outbreak and historic outbreaks, and the multi-pronged scientific research contributing to understanding of the outbreak, the mountain pine beetle provides an excellent case study to focus on. It is important to investigate the scientific pattern of response to such a complex event: one of the clearest examples of climate change affecting western North America, and one of the clearest examples of rapid ecological change in the form of species range expansions, behavioural responses, and ecosystem boundary shifts. Scholars have been working to keep pace with understanding and defining these rapid shifts, observed in ecosystems that indicate state-changes that have not before been seen (‘no analog’ (Williams & Jackson, 2007) or ‘novel

ecosystems' (Hobbs, Higgs, & Harris, 2014)), or as discussed in *Novel Ecosystems* (2013), hybrid ecosystems that indicate some departures from historical ecosystems, and which may pose the trickiest to engage with.

I am also interested in the role of science and scientists responding to the outbreak. The mountain pine beetle is the common denominator between a broad variety of scientists spanning borders in Canada and the United States. On the one hand, ample research recognizes the ecological dimensions of the outbreak (including climate change), but a significant lack of research has examined this event for the social-ecological system that it is. In response, this thesis walks into a world that tries to understand the constructed nature of scientific knowledge production, asking what factors contribute to shaping scientific knowledge production processes, and how those impact the adaptability of science and scientists. Such an approach is timely and relevant: given anticipated future climate change, it is likely that surprise events like the recent climate-exacerbated mountain pine beetle outbreak will increase (Nelson, Adger, & Brown, 2007). For years the mountain pine beetle outbreak has been capturing headlines across the country and the globe, and continues to do so (though popular media attention has slowed as the outbreak has declined).

Therefore, this research expands and contributes to three main research areas. First, this project seeks to understand the significance of the mountain pine beetle for scientists, their knowledge production practices, and identify some of the major factors that shape scientists' abilities to undertake research and respond. Does rapid ecological change make a difference for scientific knowledge production? Does a climate-exacerbated outbreak sufficiently change the context of scientific knowledge production to catalyze efforts of scientists trying something new? Preliminary research indicated new cross- and multi-disciplinary collaboration through an organization like the Turning Risk into Action (TRIA) Network, which developed over the peak of the mountain pine beetle outbreak, and sees academic and government scientists working together—in other words, there has been a significant shift in the network of scientists researching the mountain pine beetle outbreak. At the same time, there are institutional shifts apparent among scientists: a shift of employment base for some government scientists to academic institutions. These shifts may be in part due to the

chilling effect of the Harper government (The Professional Institute of the Public Service of Canada, 2013).

Second, the impacts of climate change with regard to the mountain pine beetle outbreak represent indirect anthropogenically altered processes that are not without consequences. In some cases, this hyper-epidemic outbreak has resulted in changes to biotic and/or abiotic components of ecosystems to the extent that on the surface of things, they cannot be returned to a previous or historical state (Aplet & Cole, 2010; Marris, 2011). Understanding scientists' responses to inquiries about the practical and conceptual value of a concept that explores human-altered ecosystems is timely and contributes to ongoing discussions around the effectiveness of this emerging concept (eg. (Murcia et al., 2014); (Hobbs, 2013)), and perhaps leads to ideas about what options may be best in the context of mountain pine beetle response in the future.

And third, the mountain pine beetle also offers an opportunity to undertake an exploratory inquiry into the conceptual changes around identifying "novel habitat" for this insect species, which has a long and active history with the landscape of British Columbia, and whether there is any relationship between this signifier and emerging research around the novel ecosystems concept. Importantly, the concept recognizes the human influence on rapidly changing ecosystems, and their resulting consequences/implications (*sensu* (Hobbs et al., 2006)). I inquire about the practical and conceptual value of a concept that explores human-altered ecosystems is timely and contributes to ongoing discussions around the effectiveness of this emerging concept (eg. (Murcia et al., 2014); (Hobbs, 2013)), and perhaps lead to ideas about what option may be best in the context of mountain pine beetle response in the future. A pilot interview early in the research project yielded interesting comments by a scientist that warranted exploring the relationship between the outbreak and landscape shifts further. The concept of novel ecosystems (Hobbs, Higgs, & Harris, 2009; Seastedt, Hobbs, & Suding, 2008) has been emerging as an important idea with significant potential to change how we think about intervening in landscapes and undertaking resource and ecosystem management.

Given this context, I ask the following research questions:

1. How are scientists and their institutions responding to rapid ecological change in the context of the recent mountain pine beetle outbreak?
2. What are the dominant factors that shape mountain pine beetle science, and what do those factors tell us about the role of science in response to the outbreak?
3. Does the novel ecosystems concept aid scientists in adapting, and in understanding some of the implications of the mountain pine beetle outbreak, and best options for response?

This research presents the results of an exploratory research project, undertaken with qualitative research tools. In order to answer the questions posed above, I used a mixed-methods approach that combined an extensive literature review with 16 qualitative interviews with scientists across British Columbia and Alberta. A thesis summary follows below.

While I began as someone who hiked through mountain pine beetle attacked forests around my hometown, I hope that this project helps to make more explicit the important social, political, and ecological factors of response that influence scientists—the most trusted knowledge producers in our time—and their responses to a very quickly changing world. So while this project starts with a few million beetles in a warming landscape, with what primarily seems to be an ecological event, we follow what Robbins (2004) describes as the process of showing that “politics are inevitably ecological and that ecology is inherently political” (p. xvii). In this way, it becomes possible to define the role of mountain pine beetle science in responding to rapid ecological change today, and explores whether current institutional methods of response are working well enough.

1.2 Thesis Summary

This thesis comprises five chapters, beginning with this introduction. Chapter 2 presents background information ordered around understanding the rapid ecological change in the context of the mountain pine beetle, including some of the key management responses to date, and background information about the novel

ecosystems concept and its connection to the mountain pine beetle. This chapter concludes by pointing out explicit gaps in the literature that this thesis hopes to address. Chapter 3 presents the ideas that influenced this thesis, as well as the specific methods used for data collection and interpretation. Chapter 4 presents the findings of this thesis, and Chapter 5 provides an in depth discussion of several—but not all—of the themes that emerged strongly in the findings. A short Conclusion wraps up this thesis.

A List of Abbreviations can be found in Appendix 2, which also contains scans of the Ethics Approval documentation for this project, a copy of the interview questions posed to participants, a copy of the consent form template, and a full Table of Participants.

Chapter 2: Literature Review

“It has been a tough year for BC. Events bring to mind the riders of the apocalypse – pestilence, drought, fire, and floods.” (Wilson, 2002)

2.0 Introduction

In this chapter, I begin with a brief explanatory outline of why this study is necessary and how it will contribute to our understanding of the role of scientific experts and scientific knowledge in responding to an important socio-ecological event. I introduce the several relevant bodies of literature that help illustrate the context, motivation, and *why* of this project. I outline the case of the mountain pine beetle: the most recent outbreak and associated outbreak features that exemplify climate change exacerbation, followed by a discussion of the context of climate change and rapid ecological change today. I then shift to briefly examine some relevant science studies and science-policy literature, outlining how we can understand science today, explaining the importance and limitations of scientists’ roles as producers of scientific information, and how their understanding shapes what we know about the natural world. An overview of the novel ecosystems concept comes next, as well as connecting the concept to the case of the mountain pine beetle. I conclude by discussing the gaps in the literature that this study seeks to fill.

2.1 The mountain pine beetle: Rapid ecological change in Canada

Insects are among the most remarkable organisms on the planet. They were among the first animal species to colonize both terrestrial and aqueous ecosystems, and have played significant roles in shaping ecosystems across the globe, not least of which includes their varied co-evolutionary relationships with plants and other animals, including humans (Misof et al., 2014). More specifically, bark beetles and others in the Order Coleoptera, have been with us since the Permian Age, approximately 300-250 mya. Coleoptera is the largest order in animal kingdom, with over 350,000 species, and representing about 40% of known insects (ISU, 2014). The order includes beetles such as ladybird beetles, telephone-pole beetles, skiff beetles, false clown beetles, enigmatic

scarab beetles, earth-boring and sand-loving scarab beetles, long-lipped beetles, glowworm beetles, fireflies, tumbling flower beetles, ironclad beetles, jugular-horned beetles, blister beetles, and fire-coloured beetles, to give a sense of their diversity (ISU, 2014).

Bark beetles, woodborers and budworms and an extensive host of other insects have been known active players in North American forests from as far back as the late 1890s (Spalding, 1899). A variety of bark beetles (beetles that bore into bark bearing trees to reproduce) have long been endemic to Canadian forests (Safranyik & Wilson, 2006), including the spruce beetle (*Dendroctonus rufipennis*), Douglas-fir beetle (*Dendroctonus pseudotsugae*), balsam bark beetle (*Dryocoetes confusus*), and the mountain pine bark beetle (*Dendroctonus ponderosae*) (Westfall & Ebata, 2014). Of these beetles, none have had a greater impact on forests in western Canada than *Dendroctonus ponderosae* in the last fifteen years; the mountain pine beetle has widely become recognized as the most destructive influential forest disturbance agent (Westfall & Ebata, 2014). While historically, small scale, more localized outbreaks have cyclically occurred in British Columbia, notably in the 1930-40s, 1960s, and the 1970-80s (Alfaro, Axelson, & Hawkes, 2008; Alfaro et al., 2010; Nikiforuk, 2011), the latest outbreak, beginning in the late 1990s in central British Columbia, has seen a number of unique features that differentiate it from historical outbreaks. In order to understand those differences, however, we first need to understand a little bit about the biology of the beetle, as well as key historical outbreak characteristics.

As an invertebrate, all of its functions and life cycle are governed by the temperature of its environment, from movement to breeding (Safranyik & Wilson, 2006). As has much been remarked upon, it is a small insect, about the size of a kernel of short-grain rice, but is capable of enormously shifting and influencing (impacting) the life-cycle and forest ecosystems state (Nikiforuk, 2011). Already in the 1970s scientists knew a great deal about the basic biology and ecology of the beetle, including several factors that influence the success of beetle populations erupting into an outbreak. The main components of beetle interactions with their host trees are influenced by: “climatic effects, directly on the insect and indirectly through the tree; relations with the blue stain fungi and the tree; competition for food and space among

broods; predation, parasitism and disease interact to restrain the potential of populations to increase” (Safranyik, Shrimpton, & Whitney, 1974), pg. 14. A simple diagram from a 1974 publication depicts the main components that govern the mountain pine beetle’s biological interactions with its hosts, its predators, its symbionts, and its relationship with weather over a given year (Fig. 1 below).

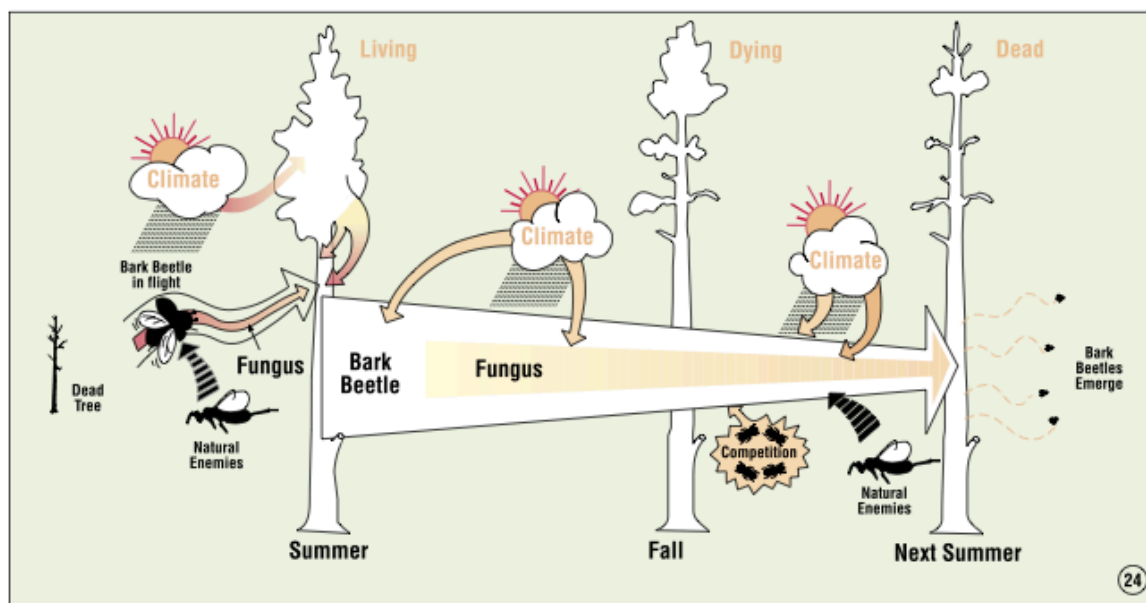


Figure 1: This diagram displays an average year of the main relationships between the mountain pine beetle, their host trees, the fungi that backpack with them, and the local weather and climate conditions that influence their yearly reproductive success. This relationship takes place year to year over the summer, fall, and summer again, and is sensitive to variations in local conditions. Beetles chew through the bark of their host trees, reproduce there, nest down for the winter, and the following year emerge to fly away to re-colonize trees new trees. In enough numbers, they kill their host trees. During flight is the main time they are susceptible to predation. From (Safranyik et al., 1974).

The mountain pine beetle has been present in Canada’s landscape for a long time, and yet with the onset of the most recent outbreak, few could have guessed that the beetle’s behaviours would depart so radically from its historic outbreak patterns.

2.2 Historical and contemporary outbreak patterns

A single beetle on its own is quite unremarkable, but the collective disturbance force of a population of erupting insects can significantly affect forests (Safranyik & Wilson, 2006). MPB have four distinct population dynamic phases: endemic, incipient-

epidemic, epidemic, and post-epidemic (Safranyik & Wilson, 2006). The longevity and severity of outbreaks are frequently influenced by host availability and climatic/weather conditions (Safranyik & Wilson, 2006).

During epidemic outbreaks, beetles and other insects attack the ‘old susceptible veterans’ (Nikiforuk, 2011): the largest, oldest, most decadent, or unhealthy trees in a given stand, essentially recycling them, and aiding in nutrient cycling and contributing to the regeneration of the forest stands (Hamish Kimmins, Seely, Welham, & Zhong, 2012). As gaps from beetle-downed trees open spaces in stands, the growth of younger trees and seedlings is stimulated (Nikiforuk). Not only does this lead to stands of trees that vary with age (Nikiforuk), but in the absence of forest-regenerating fires, the mountain pine beetle plays an important role in determining both stand and species structures of forests, notably in southern and central BC (Alfaro et al., 2008). Trees killed by *Dendroctonus ponderosae* also create favourable wildfire conditions that benefit lodgepole pines, whose cones are dependent on fire for opening up and releasing seeds, thereby allowing forest regeneration to begin (Raffa & Berryman, 1987).

Most studies usually point to invasive or non-native species as the best-studied examples of scenarios where biophysical and biogeographic barriers are crossed (Vitousek, Mooney, Lubchenco, & Melillo, 1997; Dukes & Mooney, 1999), however, in this case, with the historical context of the mountain pine beetle, landscape conditions, policies, and climate change, the mountain pine beetle as a *native* insect has done remarkably well in its climate exacerbated outbreak. It is notable that through the changes the mountain pine beetle exhibited in the most recent outbreak, it was labelled a “native-invasive” species—a term that had widespread support from federal scientists (Nealis & Peter, 2008). In the same research project undertaken to assess the risk of the mountain pine beetle both reaching the boreal forest and successfully reproducing in the boreal forest’s jack pine, scientists used the term “novel habitat” to describe the shift of the beetle into the boreal forest (Nealis & Peter, 2008).

With human systems driving much change in the landscape today, three historic factors of human agency influencing landscapes need to be identified in shaping the landscape conditions for the most recent beetle outbreak today: fire

suppression, forestry management, and climate change, which resulted in novel responses by the beetles that enabled their attacks to be more effective.

As a major industry in BC, logging has defined interactions with forested landscapes for about a hundred years. The BC provincial and Canadian federal government saw the dollar-signs the trees represented for their financial treasuries, supporting economic activities in the burgeoning forestry sector and increasing tax revenues, and invested millions of dollars into firefighting equipment, training, water bombers and helicopters to save the increasingly uniform, dense, and mature lodgepole forests (Nikiforuk, 2011). Fire suppression was long a priority of foresters well into the twentieth century, and has been observed to change forest composition, susceptibility to insect outbreaks, and changes in fire regimes (Alfaro et al., 2010; Raffa et al., 2008; Jenkins et al., 2008; Keane, 2002). Around the turn of the 19th century, only 17% of the lodgepole pines were mature growth (between 80 and 120 years) (Nikiforuk, 2011). Regular wildfires contributed to limiting about 25% of the pine forests at mature ages, which ensured resilience from large-scale beetle outbreaks (Nikiforuk). However, decades of fire suppression by provincial and federal foresters, including banning First Nations traditional burning activities starting in the 1930s, meant that the volume of mature lodgepole pine reached historic records of 53% mature forests by 1990 (Nikiforuk). And in (Shore, Brooks, & Stone, 2004), Taylor and Carroll found that because of successful and aggressive fire suppression management at the landscape levels, rates of burned areas dropped from about 100,000 hectares to less than 1000 over the past 50 years. Further, this decreased rate of disturbance meant that over 70% of lodgepole pines reached maturity (over 80 years of age), which amounted to an almost 3-fold increase in susceptible pine from 1910-1990 (Taylor and Carroll, in (Shore et al., 2004)).

The regional climate in British Columbia has also been changing due to indirect anthropogenic forcing: between 1885 and 1995, the minimum temperatures in the interior of B.C. increased between 1.3 and 1.7 degrees Celsius (Ministry of the Environment, 2012). Importantly, models from (Sambaraju et al., 2012) found that climate change could very much increase the risk of insect outbreaks first in higher elevations, and then extending on landscapes higher in latitudes.

The mountain pine beetle is one of a handful of native insects that have been identified to as likely thrive under climate change (Hamish Kimmins et al., 2012). Hotter summers result in temperature stressed and more vulnerable trees, and changes in precipitation regimes also contribute to drought stress (Wallis, Huber, & Lewis, 2011), while warmer winters enable MPB populations higher than the usual survival rates with colder winters (Nikiforuk, 2011). As scientists were also able to show in recent research, climate change shifted favourable habitat conditions for MPBs seven degrees northward in latitude over the past thirty years (Carroll et al., 2003). Favourable climatic conditions also shortened the normally two-year beetle lifecycle to one, which allowed the beetles to reproduce much more quickly (Parks Canada, 2007).

In conjunction with the direct human-influence factors that have shaped forests over the past century, dimensions of novel features seen in MPB forests that have been noted in the literature have included beetle population numbers at much higher and more dense concentrations than ever seen before, with clouds of dispersing beetles so large they were picked up on weather radar systems (Suzuki, 2013); beetles attacking smaller than usual hosts (trees of a diameter of 4 inches) (Suzuki, 2013); MPB using local updrafts and wind patterns to increase their range of travel significantly, including access to travel up and over the Rocky Mountains, eastward (Carroll et al., 2003); and moving from traditional hosts such as lodgepole pine (*Pinus contorta Dougl.*) to include ponderosa pine (*Pinus ponderosa*), white and Engelmann spruce (*Picea glauca* and *Picea Engelmannii*) and whitebark pine (*Pinus albicaulis*) (Pigott, 2012; Nikiforuk, 2011). Notably, the beetle also spread to places where no historical record of the MPB existed, such as into northern B.C., the Yukon, the Northwest Territories, and spreading east to northern Alberta's boreal forest and parts of Saskatchewan (Nealis & Cooke, 2014; Nealis & Peter, 2008)(see Figure 2 below). There, MPB was found successfully reproducing in the boreal forest with new and naive hosts, the jack pine (*Pinus banksiana*) (Nealis & Peter, 2008).

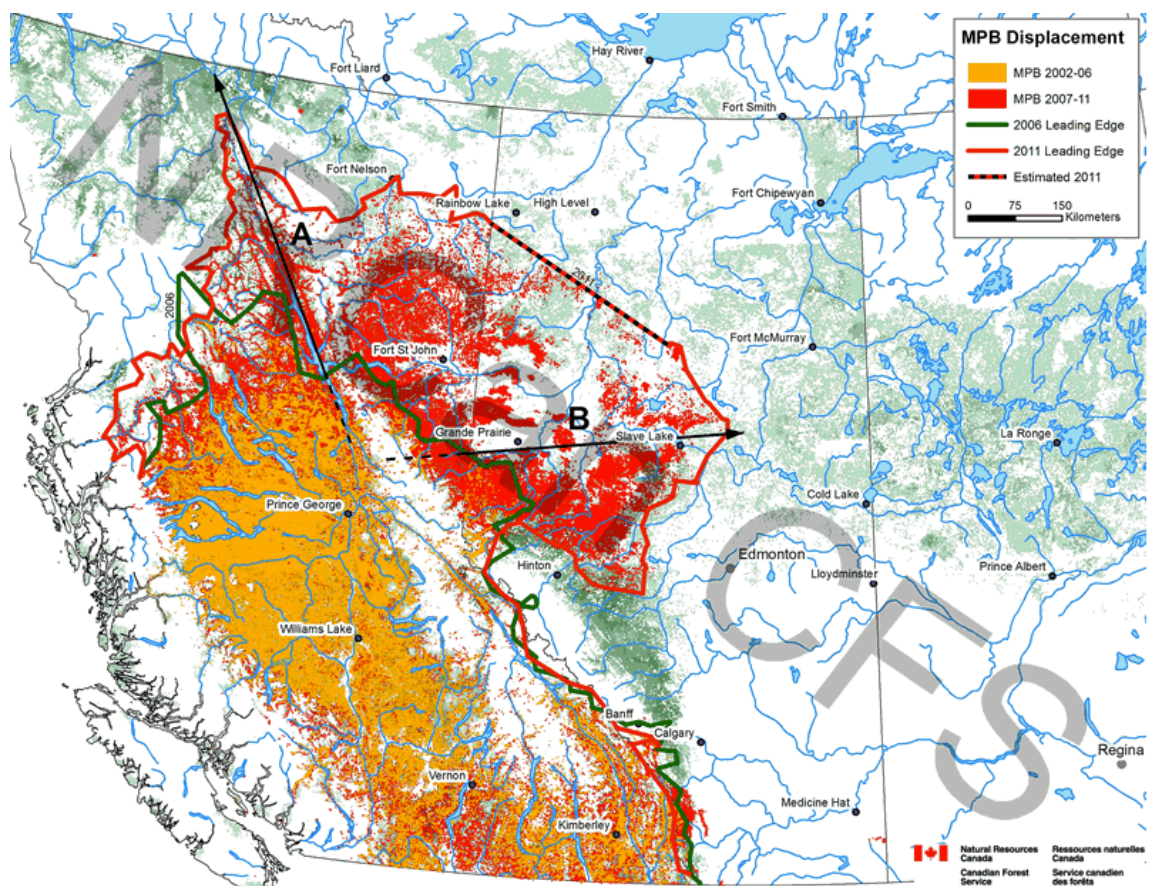


Figure 2: A recent map tracking the path of the mountain pine beetle's range expansion from British Columbia north and east, into the boreal forest. The two phases coincide with the two periods of research funding by the federal government (Source: NRCAN and the Canadian Forestry Service, 2014: <http://www.nrcan.gc.ca/forests/insects-diseases/13381>.)

In summary, the pine bark beetle epidemic that is currently still dwindling in western North America presents an example of a timely, challenging, complex, rapid ecological change in a human-altered world, and it is no wonder that this massive ecological event has attracted the attention of researchers, scientists, politicians, and resource managers, and the forest industry. One under-anticipated beetle outbreak has reverberated through ecological, social, and institutional spheres, challenging decision-making processes, scientific knowledge production, and ideas about how to intervene in increasingly complicated natures.

2.3 Mountain Pine Beetle Management Responses

Mountain pine beetle management has posed an interesting challenge for resource managers, in part due to the complicated and overlapping jurisdictions of the governing bodies; there are several different actors involved in generating responses to the outbreak. Generally, in Canada provinces manage their forests and natural resources, while the federal government has management responsibilities for pest outbreaks across the country. However, as Lindquist and Wellstead (2001) assert: governments no longer have the capacity or resources to handle issues on their own, and instead depend on cooperation with other non-governmental actors, such as forest companies. Wellstead et al. (2006) highlight the diverse forest policy community in British Columbia, where the Ministry of Forests, Lands, and Natural Resource Operations (FLNRO)(formerly the Ministry of Forests and Range) is the major actor, and is responsible for the main provincial forest policy. Other actors such as universities, environmental groups, consultants, labour organizations, communities, forest industry companies, First Nations, and specific federal government departments such as Environment and Climate Change Canada (formerly Environment Canada) and Natural Resources Canada, also participate in the forest policy community.

British Columbia is broken into eight geographic regions, within which are several smaller forest districts. For example, the Omineca region in central BC, one of the hardest hit by the mountain pine beetle outbreak, comprises the forest districts of Fort St. James, Mackenzie, Prince George, Vanderhoof, and Headwaters. However, that region is also broken into three larger Timber Supply Areas (TSAs): the Mackenzie, Prince George, and Robson Valley TSAs. In those TSAs, specific companies may hold a Tree Farm License (TFL), too; in the Prince George TSA, Dunkley Lumber Ltd. and Canadian Forest Products Ltd. hold such licenses. The Ministry of Forests, Land, and Natural Resource Operations maintains the map of current region, district, TSA and TFL boundaries (2014).

In 1999, the BC provincial government founded the Mountain Pine Beetle Emergency Task Force, which later led to the Mountain Pine Beetle Action Plan, and the Province committing more than \$100 million to support affected forestry

communities, as well as strategies to managing the outbreak. In a summary presentation for the Special Committee on Timber Supply, Susanna Laaksonen-Craig (2012) from the Ministry of Forests, Lands and Natural Resource Operations outlines the various funding and projects dedicated to addressing the outbreak over a timeline of 2001–2012. Provincial funding increased from \$16.5 million in 2000/2001 to \$36 million in 2001/2002; which later increased to another \$107 million for spread control alongside various direct forestry actions, such as increasing the annual allowable cut (AAC) in 9 TSAs and TFLs in 2004, and increases in another 9 between 2005-2007. British Columbia also received \$100 million from the federal government for their Mountain Pine Beetle Action Plan (Law, 2005). Laaksonen-Craig (2012) also highlights further federal funding applied for and received during that time: \$200 million. 2005-2007 was also a significant period for building partnerships: the report highlights that the “MPB was designated a cross-ministry priority.” Three Beetle Action Coalitions were formed: Caribou-Chilcotin, Omineca, and Southern Interior; and other initiatives were developed, such as the Future Forests for Tomorrow program, designed to find innovative ways to use beetle-kill wood, which received \$161 million. As the presentation summarized, an early response strategy for the Province of BC was at first to reactively and aggressively address the spread of the of the mountain pine beetle, and then this shifted to “making the best of the situation” and innovation, to try to effectively salvage some of the beetle kill wood (Petersen & Stuart, 2014). That strategy shifted in the mid and late 2000s, as the Province sought to find the best ways to make use of the many many dead trees in the landscape, which included having BC Hydro put out a call for bioenergy (energy produced from organic sources, such as dead trees), committing policy regarding “new bioenergy related tenure tools”, and further funding for the Forests for Tomorrow program (p. 7). Petersen et al. (2014) provide a detailed summary and explanation of the ecological *and* social factors that contributed to the mountain pine beetle response.

The federal government, whose jurisdiction covers pest management within Canada, provided two phases of mountain pine beetle research funding: \$40 million through The Mountain Pine Beetle Initiative (MPBI), which ran from 2002-2006 (Wilson, 2004), and the Mountain Pine Beetle Program, which ran from (2007-2010).

Both have now concluded, and according to a statement from Natural Resources Canada, all funding has been used up.

2.4 Context of Climate Change and Rapid Ecological Change Today

“One thing is clear: the future will not be like the past.” (Natural Resources Canada, 2014).

Rapid ecological change is in our future. Front and centre on Natural Resources Canada’s page on the mountain pine beetle, they recognize that climate change will affect Canada’s forests in myriad ways. “Some effects,” they write, “will be sudden and dramatic, and others will be gradual and subtle. Rapid climate change will affect tree growth rates, disturbance patterns and the distribution of tree species after disturbances. Impacts will be cumulative and interconnected...” One of the main examples they highlighted is the potential for drought to stress trees, making them more susceptible to attack by insects and disease (NRC, 2014).

Vitousek et al. (1997) assert that we live in a human dominated world (land transformation, changes in global biogeochemistry, and biotic additions and losses) with significant implications for the health of ecosystems. They point out that people have already transformed between 33% and 50% of the earth’s terrestrial surface; Ellis et al. (2010) put that number at more than 75% of the ice-free terrestrial zones across the globe. Further, global ecosystem changes are linked to climate change, highlighting that since the mid-1800s (the Industrial Revolution), people have put over 30% of the world’s carbon dioxide into the atmosphere (Vitousek et al., 1997).

Though numerous efforts to curb greenhouse gas emissions globally have been underway, thus far they have not been significant enough to mitigate climate change, and much much more will need to be done in order to avoid catastrophic climate change impacts (Peters et al., 2013). Because of the lack of international progress on climate change, many are now calling for the need to adapt to climate change, and adaptation has recently become accepted and institutionalized (Swart, Biesbroek, & Lourenço Capela, 2014), including in the context of adapting forest policy practices

(Spittlehouse & Stewart, 2003). While Canada is one of the top-ten carbon pollution emitters in the world, and climate change is a global problem that will require coordination, collaboration, and a will to work together from major emitters, lack of leadership from one country will not encourage leadership from others. Contributing to further climate change commits us to expect further—sometimes surprising and unexpected—climate change impacts, heightens the importance of mitigation, and furthers the need to adapt.

An important group of ecological events (or surprises) includes those tied to “thresholds” or “tipping points”, in which gradual or incremental changes catalyze sudden and potentially irreversible changes in ecosystem states (Lindsay & Zhang, 2005; Scheffer & Carpenter, 2003). Much attention, both nationally in Canada, and internationally has already been drawn to the mountain pine beetle (*Dendroctonus ponderosae*) as one of the most dramatic examples of such an outbreak, but others include outbreaks by the spruce beetle (*Dendroctonus rufipennis*) from Alaska down to the mid-western United States, and the pinyon ips beetle (*Ips confusus*) in the pinyon pine-juniper woodlands of mid-western North America (Raffa et al., 2008). Based on climate projections for warmer temperatures and precipitation changes, insect infestations and outbreaks are predicted to increase in severity, frequency, and see northward and altitudinal range changes in the future (Sambaraju et al., 2012). In particular, climate-driven rapid ecological change has also resulted in numerous changes and novel features in Western Canada’s current and ongoing mountain pine beetle epidemic (Carroll, 2012). Further, as climate change warming continues, we can expect that regions that were previously not susceptible to outbreaks, may begin to experience these kinds of events. And it is scientists from widespread groups and organizations who are keeping us abreast how these ecological events are changing, and what their implications are.

With this in mind, the next section introduces relevant literature from science studies.

2.5 Scientists and the Effectiveness of Science

A relatively recent and effective approach to understanding the dynamics of science is through ethnographic research. There have been a number of ethnographies investigating particular scientific communities: Hugh Gusterson's (1996) "Nuclear rites: A weapons laboratory at the end of the cold war," which engages with the top-secret culture among nuclear scientists at the Lawrence Livermore National Laboratory; Sharon Traweek's (1988) "Beamtimes and lifetimes: The world of high energy physicists;" and Bruno Latour and Steve Woolgar's (1986) "Laboratory life: The construction of scientific facts," which show how scientific facts are produced within specific contexts (or networks) that give them meaning. Each of these in-depth studies highlights the many ways in which scientists actively produce particular understandings of the world. While I did not conduct ethnographic work (no participant observation), these accounts influenced my appreciation for digging deeply into a scientific community bonded by their research. Many of these early studies seem to me to be the gateway for opening up questions about not only how science does what it does, but also how it goes about describing and translating the world, and asking "For whom is this useful?" and "How can this be done better?"

Science studies is about studying science: as a field, its methodology enables its users to be unified in what they study (science), and yet extremely diverse in approach (in terms of its methodologies, research questions, and institutional locations) (Biagioli, 1999). Further, science studies understands science as a set of scientists' practices, institutions, relationships, processes, and more (Biagioli, 1999). Therefore, based on Biagioli's recommendation, I try not only to understand what scientific understandings of the mountain pine beetle are, but rather, the dominant factors that influence the production of their scientific knowledge, how the crisis dimensions of the outbreak can tell us something about the processes that influence knowledge production, and whether the knowledge scientists produce is having its greatest possible impact in the context of the rapid changes of today.

I begin with a respectful acknowledgment that science has an important role to play in understanding, describing, and producing knowledge about our changing environments today, and that scientists have a very particular, institutionally

supported power in describing the world. Therefore, it is valuable to speak with them directly about their perspectives and understandings of that power. On the one hand, we have a society (and many scientists themselves) who support the idea of objective science. As Carl Sagan describes: the scientific method earns much of its success from the “built-in, error-correcting machinery at its very heart” (p. 27), which enables rigour and high quality scientific knowledge production. In fact, it is this commitment to peer-review and critical engagement and testing that differentiates science from pseudoscience (Shermer, 1997). The scientific method attempts to codify practices that ensure that if an individual scientist makes an error in their work, it is usually addressed, criticized, and/or corrected through the peer review process. If the scientific knowledge is somewhat incomplete, or only conceptual, then an improvement or expansion can be and frequently is suggested and undertaken in subsequent work by peers. In the case of conceptual work, empirical evidence or case studies are undertaken and can support or shift understandings of the concept, depending on how the evidence aligns. None of this is untrue, but assertions of “objective” science ignore the political dimensions of scientific knowledge production. For this project, I walk along the trail forged previously by science studies, science and technology studies, and sociology of science scholars such as Bruno Latour’s *Science in Action* (1988), who first set out to open Pandora’s box or the “black box of science”, which describes the process of articulating those aspects of scientific knowledge production that become common place or accepted, so much so that they are no longer questioned. They are “black-boxed.” His research helped bring an understanding of why it is so difficult to understand technical papers, and explores the “web” of what is involved for science to actually happen, including funding processes and the need to convince others of the value of science. Further, he outlines the processes of translation: how scientists need to translate their work and its value for others. Relatedly, John Law and John Hassard’s (1999) *Actor Network Theory and After* engages with Latour’s ideas of Actor Network Theory (ANT), an approach that offers researcher a way to articulate how to understand science in relation to other aspects of society. Law describes ANT as fundamentally preoccupied with semiotics, or how “entities take their form and acquire their attributes as a result of their relations with other entities” (p. 3). In his own

chapter of the same book, Latour further simplifies: “ANT was simply another way of being faithful to the insights of ethnomethodology: actors know what they do and we have to learn from them not only what they do, but how and why they do it” (p. 19). Two recent studies applied ANT to understanding climate change science’s role in the US Congress’s grasp of global warming (Besel, 2011) and in German coastal cities constructions of vulnerability and resilience (Christmann, Balgar, & Mahlkow, 2014). In his 2011 paper, Besel used ANT to illustrate how Michael Mann’s famous “hockey-stick” graph depicting climate change data was successfully defended by rallying the entire climate science actor-network in support of the legitimacy of the hockey-stick figure. In examining this case, Besel highlights a number of science communications lessons, including pulling together different nodes of climate science to defend the hockey stick graph (in essence, synecdoche of the larger body of climate science). In contrast, Christmann, Balgar, and Mahlkow (2014) use ANT and social constructivism to show how two similar German Baltic coastal cities differ significantly in their perceptions of vulnerability and resilience based not only on their physical-material characteristics (local geographic and climatological factors), but also cultural traditions and interpretive patterns in local society, as well as recent historical responses to local hazards. The authors show that one city can view climate change as an opportunity to evolve and adapt the local urban culture and design, whereas the other city viewed climate change as threatening to destroy their cultural identity and way of life. In other words, ANT can be used to show that context matters.

I borrow some aspects of ANT and other aspects of science studies to pry open how mountain pine beetle science happens—what scientists do—and how scientists build relationships with other scientists or policymakers where the beetle is the common denominator. On the other hand, I am interested by Haraway’s (1988) assertion that “[W]hat scientists believe or say they do and what they really do have a loose fit” (576). In her essay “Situated knowledges: The science question in feminism and the privilege of partial perspective” she criticizes the effectiveness of scientific ideologies of objectivity and the scientific method, stating that they “are particularly bad guides to how scientific knowledge is actually made” (p. 576). I think this is where there is great usefulness in speaking with scientists directly to gain insight into their

research activities, as well as asking about the institutional cultural factors that influence MPB scientific knowledge production.

Returning to other insect studies, recently, (Shaw, Robbins, & Jones, 2010) apply assemblage theory to understand relationships between managers, mosquitos, institutions, and the “sociocultural-environmental-technological-political contexts with the flights of the mosquito itself” (p. 373). Their research explored the spatial ontologies of mosquito management. My project bears some resemblance to this approach, focusing on the environmental/ecological impacts of the MPB outbreak, along with corresponding scientific knowledge production, funding, and institutional responses. I recognize that science is a very active process of translation (Robbins, 2004), meaning, a way of examining and engaging with the world, but also actively mediating how we get to know it. As such, its practitioners — scientists — actively undertake research, asking questions about the world, about nature, about a given observable thing; they not only translate observable nature into language and information that others can understand, but produce knowledge and translate it for others (media, policy analysts, public citizens) to understand. As such, science is not apolitical: scientists are not separate from the things they study, their funding sources, or the consequences of eruptive insect outbreaks.

Given that projections for climate change show that we will be in for more rapid ecological and environmental changes and surprises in the future, it is paramount to evaluate the effectiveness of existing science-policy relationships. While science studies authors such as Bruno Latour (1987) opened the “black box” of science years ago, other science studies researchers have also plumbed particle physics laboratories (Traweek, 1988), and others still have explored the development of new social relationships between fisherman and scientists due to a significant downturn in a scallop fishery (Callon, 1986) today.

While the science and technology studies research outlined above was relevant for shaping my earlier ideas, I also found great resonance as I got further into my research with more recent science policy literature. There, we see studies that engage differently with science policy relationships, arguing that science needs to have salience, be credible, and have legitimacy and in order to resonate with those

interacting with it from institutional relationships (such as governments) (Cash et al., 2002). Others, such as (Bidwell, Dietz, & Scavia, 2013) argue that in order to effectively respond to rapid change and climate change, network connections need to be established among scientists and decision-makers to effectively exchange information and encourage learning. Further, in answering numerous calls for “usable science,” (Dilling & Lemos, 2011) assert that the usability of science is “a function both of the context of potential use and of the process of scientific knowledge production itself” (p.680), and that in places where climate science has successfully been used and implemented, it is because an iterative process between science producer and science user took place (Lemos & Morehouse, 2005). Recently, other research has also criticized the imbalance between scientific knowledge production and its use (Cairney, 2016; Sarewitz & Pielke, 2007); and McNie, Parris, & Sarewitz (2016) openly ask how we can improve the public value of science. There has been a significant amount of natural science research undertaken over the last few decades, primarily in response to the episodic MPB outbreaks, but this research fits into efforts to improve the usability of science, assess its effectiveness, and ask, “If not this way, then what?” With this project I assert there needs to be a better understanding of the relationship between MPB science, its production and its use, in order to evaluate its effectiveness, and seek to contribute to the body of research engaged with climate change adaptation, and in general, responding to rapid change. Relatedly, this brings me to the concept of novel ecosystems.

2.6 Restoration and Novel Ecosystems

Ecological restoration is a seedling compared to the more well-established mature oak of conservation. It is often seen as a compliment to the fields of conservation and preservation, whose goals often align with preserving ‘pristine’ or ‘untouched’ nature. Conservation and preservation efforts typically aim to preserve a given species, or ecosystem that has a native plant assemblage found in few other places. Their goal is to maintain, preserve, protect, and support what is already there. The Nature Conservancy of Canada’s (NCC) website states their vision is to “[protect] areas of natural diversity for their intrinsic value and for the benefit of our children and those

after them” (2013). The field of restoration has been striving to solidify its identity over the past several decades, even as it has undergone much change.

There are many overlaps and relationships between conservation and restoration, and in some cases, they are intricately linked. For a relevant example: the NCC partnered with the municipality of Saanich, in British Columbia to undertake a collaborative project focused on restoring the Maber Flats wetland (MacKenzie, 2013). The project includes ecosystem engineering to improve the storm water retention, as well as enhance the ecological and recreation opportunities in the area. As the West Coast Program Manager for the NCC stated: “The restoration initiative is more than just a conservation project” (MacKenzie, 2013), which indicates how closely he sees the two entwined.

Restoration projects can range in size, scope, and scale, from restoring a riparian and river ecosystems post dam removal, as in the case of the Elwha and Glines Dam Removal Projects in Washington State, USA (Holtcamp, 2012); or in removing invasive species, such as Scotch broom (*Cytisus scoparius*), Himalayan blackberry (*Rubus armeniacus*), English ivy (*Hedera helix*), and Daphne (*Daphne laureola*), from the small (approx. 0.34 ha. park) Camas Park in Saanich, British Columbia (GOERT, n.d), to whole riparian forest ecosystem restoration in Sao Paulo, Brazil (Bank, 2014). The projects have enormous diversity and are being undertaken all across the globe (as the examples are meant to illustrate).

Restoration focuses on “assisting the recovery of an ecosystem that has been damaged, degraded, or destroyed ecosystems (Parks Canada, 2008, p. 8)” in as efficient, effective (Higgs, 1997) and “engaging” a way as possible; in this way, resources are well-used, specific goals and functions for the restored ecosystem can be set, and vitally important: people are brought together, invested in the process of restoration and the outcome of the project (Higgs, 2003). Perhaps one of restoration ecology’s strongest draws is that it advocates for engagement between people, place and nature, as opposed to movements in conservation that (especially historically) separate nature and people into neat categories. The history of conservation reveals a number of cases where even First Nations people were forced out of traditional territories to pave the way for parks to be established: parks wherein people can visit

temporarily, look at the nature there, and leave, thinking they were seeing a pristine, untouched thing, or, nature without a human influence.

Instead, restoration practitioners do not subscribe to narratives of pristine nature or wilderness. Cronon (1995) wrote a seminal essay titled “The trouble with wilderness: Or, getting back to the wrong nature”, arguing that there is nothing natural about the concept of wilderness, at all. “The more one knows of its particular history, the more one realizes that wilderness is not what it seems” (Cronon, 1995, p. 7). There has been an increasing recognition of just how much people have shaped ecosystems for millennia, and that these continued relationships have a longstanding history. It’s because of this philosophy that researchers and practitioners actively consider questions of *how* and *why* to intervene in damaged, destroyed, or degraded ecosystems, and what activities constitute *appropriate* intervention in nature. Perhaps the biggest question is “What is the best way to intervene in ecosystems?” Today, these questions continue to be vigorously debated, and in many ways, the novel ecosystems concept can be viewed as a branch in the tree of inquiry that extends mulling over that question. While the novel ecosystems concept is relatively new, it has quickly received much attention and has readily been employed by numerous ecologists, conservationists, restoration ecologists, and scientists. Last year the concept featured as the theme for the Ecological Society of America’s world conference.

Many of the authors who incorporate the novel ecosystems concept in their theoretical frameworks recognize the rapid changes in global ecosystems, and cite papers that link the increasing human impact on those systems. The first explicit attempts at defining the term novel ecosystems emerged in the seminal article by a group of restoration ecologists from across the globe, including Richard Hobbs (Australia), Salvatore Arico (France), Jill S. Baron (USA), Viki A. Cramer (Australia), Ariel Lugo (Puerto Rico) and Fernando Valladares (Spain) in their 2006 journal article: “Novel ecosystems: theoretical and management aspects of the new ecological world order.” This international attention to the concept has signalled its appeal to many who are noticing human-impacted and changing ecosystems in their local contexts, and are trying to figure out what to do. Previous uses of the term have been incidental (Pezzey, 1992; Parker et al., 1992; Ott, 1998). Similarly, F. Stuart

Chapin III and Anthony Starfield (1997) title their paper “Time lags and novel ecosystems in response to transient climatic change in arctic Alaska”, but none of these papers attempt to formally define the concept of novel ecosystems.

A second (now widely cited) article published in 2009 (Hobbs, Higgs, and Harris), explored some of the implications of the novel ecosystems concept, the most important of which asserts the need to revise, as needed, conservation and restoration approaches away from strictly place-based, traditional projects, and from historical plant assemblages (Hobbs et al., 2009). As the authors write: “Retaining the somewhat static view of ecosystems as particular assemblages in particular places will become increasingly unrealistic and is likely to shackle conservation and restoration efforts to ever more unrealistic expectations and objectives” (Hobbs, Higgs, & Harris, 2009, p. 604). In this way, proponents of the concept encourage opening the toolbox for managers of the future, who will increasingly be challenged by the restoration or conservation projects in front of them. This does not, of course, mean that there is no room for more traditional restoration or conservation approaches; rather, that considering other management and intervention options is necessary when traditional approaches are no longer Cinderella’s foot to fit the glass slipper of a given project. This prompt is the concept’s conceptual fire-rod: in times of fast-paced, sometimes unpredictable change, the concept asks those in ecosystem management, ecology, environmental studies, to consider options for action widely, rather than to reach for technical manuals or the bookshelf of tried and true options. They may no longer be the best way to engage or intervene.

The novel ecosystems definition continues to evolve and become refined, as seen in recent publications, the latest of which includes a chapter dedicated to a discussion of the concept in a book that also explores other aspects, applications, and uses of the concept: *Novel Ecosystems: Intervening in the New Ecological World Order*, edited by Richard Hobbs, Eric Higgs, and Carol Hall (2013). As presented in the book, the definition reads: “A novel ecosystem is a system of abiotic, biotic, and social components (and their interactions) that, by virtue of human influence, differ from those that prevailed historically, having a tendency to self-organize and manifest novel qualities without intensive human management. Novel ecosystems are distinguished

from hybrid ecosystems by practical limitations (a combination of ecological, environmental, and social/financial thresholds) on the recovery of historical qualities” (Hobbs, Higgs, & Hall, 2013, p. 58). By extension, hybrid ecosystems are those that may have a combination of novel characteristics and historical characteristics, but still retain the potential to be restored, or remain manageable. Figure 3 (below) presents the conceptual relationships between novel, hybrid, and historical ecosystems.

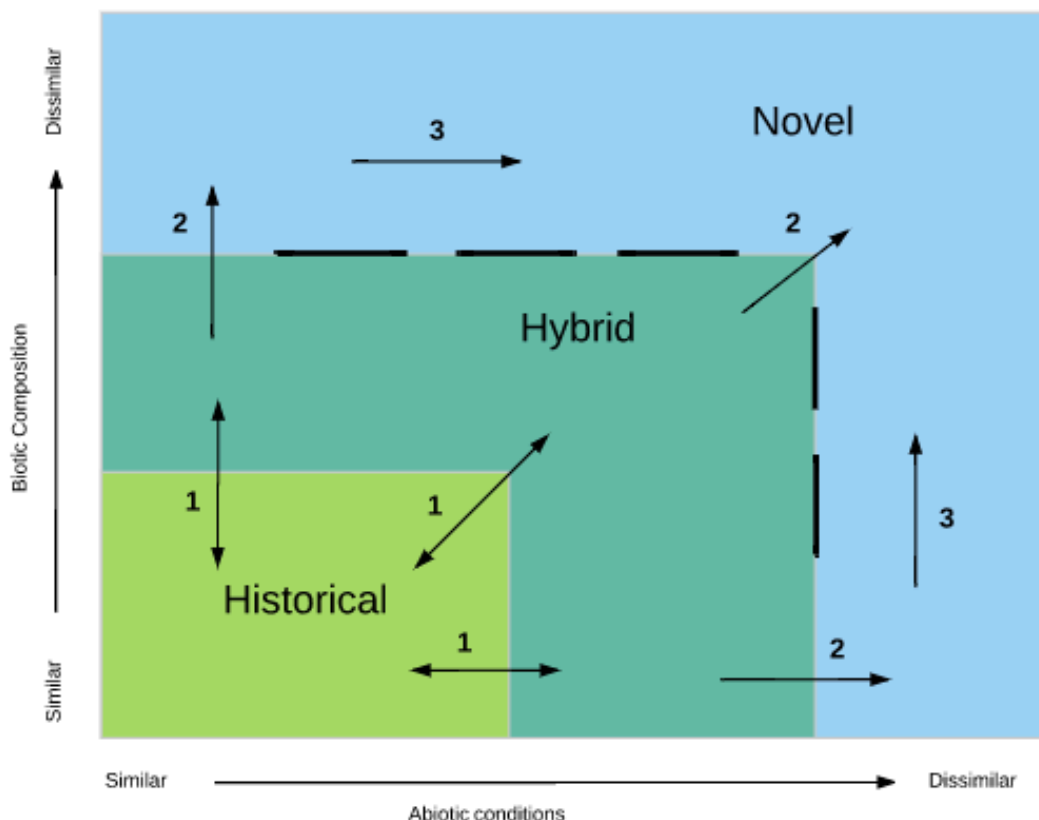


Figure 3: Conceptual relationships between historical, hybrid, and novel ecosystems, given different levels of biotic and abiotic change, adapted from (Hobbs et al., 2013). Historical ecosystems remain within their historical range of variability. Hybrid ecosystems are biotically and/or abiotically dissimilar from historical ecosystems, but are able to return to historical states (1). Novel ecosystems are biotically and/or abiotically dissimilar from historical states and have crossed irreversible thresholds such that they can no longer be returned to historical states (2) (restoration thresholds noted in black bars). It is also possible that further shifts may occur within novel ecosystems (3).

Higgs, Hobbs, and Hall (2013) also describe what novel ecosystems are not: “(1) a system that would have occupied space in the past (i.e. part of a historical range of variability); (2) managed intensively for specific production or built over; or (3) managed with the purpose of reproducing the historical ecosystem (i.e. classic restoration)” (p. 59).

Hobbs et al., 2013 also described the conceptual relationship between historical, hybrid, and novel ecosystems, showing that it is useful to ask two key questions (Figure 4, below): 1) Is the target ecosystems altered because of anthropogenic forcing? 2) Are the changes reversible? I discuss the relevance of these questions and scientists’ engagement with the novel ecosystems concept in Chapter 5.

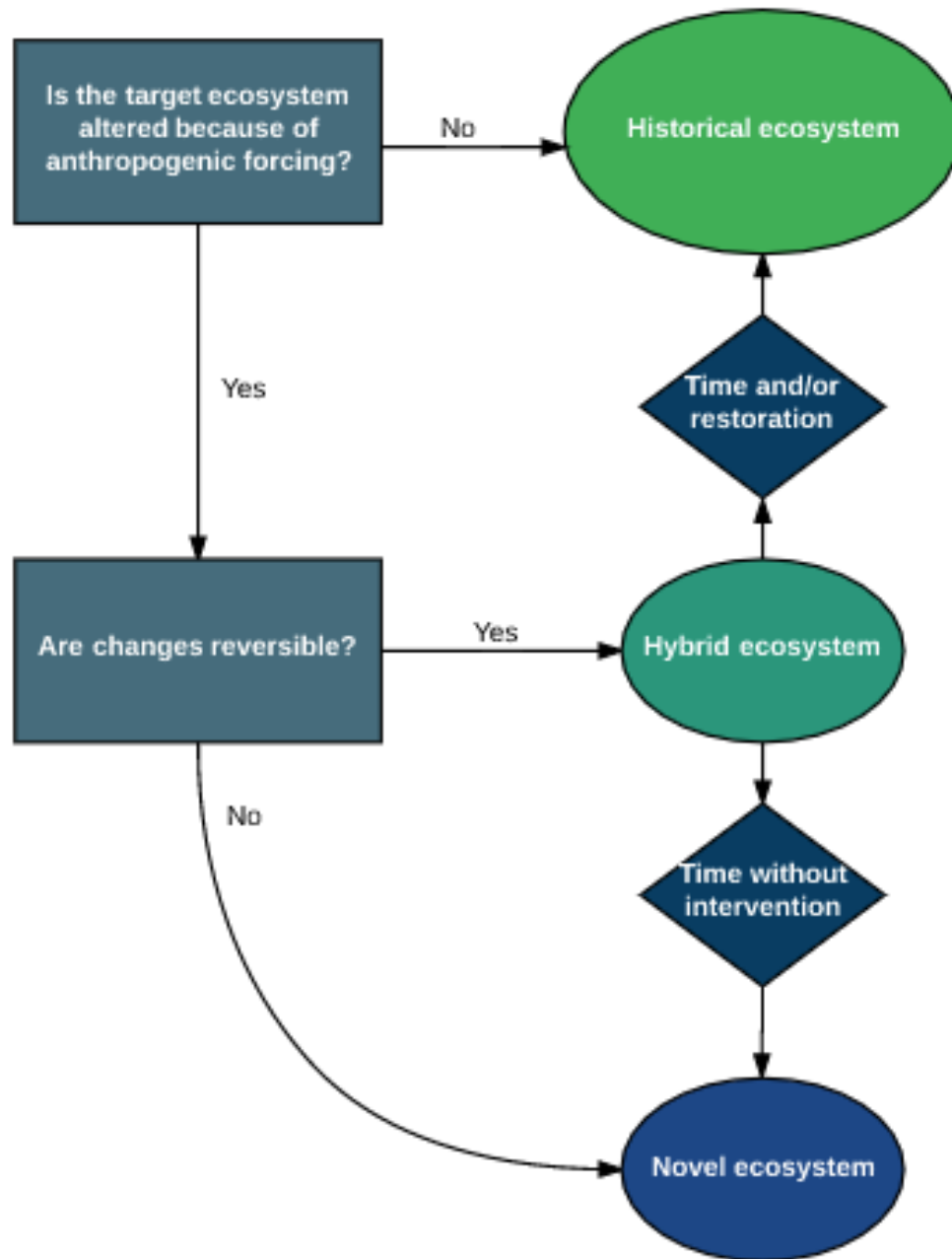


Figure 4: A simplified view of the definition that illustrates the conceptual relationships between historical, hybrid, and novel ecosystems, from (Hobbs et al., 2013). This diagram also shows how time and/or restoration can be used to transition a hybrid ecosystem back into a historical ecosystem, and how time without intervention can also result in a novel ecosystem.

Given the recent inception of the concept, its revision and development is to be anticipated. Indeed, as of June 2014, another definition *has* already emerged: ecologist Nathaniel B. Morse and seven colleagues proposed a revision to the concept, citing reasons that the above-mentioned definition is not broadly applicable; therefore, they shift the definition to: “[A] unique assemblage of biota and environmental conditions that is the direct result of intentional or unintentional alteration by humans, i.e. Human agency, sufficient to cross an ecological threshold that facilitates a new ecosystem trajectory and inhibits its return to a previous trajectory regardless of additional human intervention. The resulting ecosystem must also be self-sustaining in terms of species composition, structure, biogeochemistry, and ecosystem services. A defining characteristic of a novel ecosystem is a change in species composition relative to ecosystems present in the same biome prior to crossing a threshold.” One weakness of this definition seems to be its emphasis on the *direct* human impacts to ecosystems, as the shift does not adequately address the significance of indirect pressures like those of climate change. But even this proposed revision of the concept accepts the core theoretical assertions that novel ecosystems exist, and they warrant further the discussion of the concept’s definition. A few other early uses of terms such as “no-analog” and “emerging” show complimentary terminology, describing future or past ecosystems in which species assemblages had not been seen before, though these writings also emphasized that the species composition comprise species that had previously existed, meaning they were ecological in nature, as opposed to evolutionary (Williams & Jackson, 2007; Milton, 2003).

Mascaro et al. (2013) summarize a few key foundational components of the concept: 1. Gleason’s (1926) idea of ecosystems as linked individual species, as opposed to a unified organism, whereby the assemblage of species found in an ecosystem will shift given the right conditions for life. 2. Biotic and abiotic characteristics of an ecosystem are tethered, such that changes in one will affect changes in the other. 3. Humans’ agency as the origination of ecosystem change that can be directional and permanent. Each of these plays out in a different way in the case of the mountain pine beetle, as will be discussed below. Most important for the mountain pine beetle case study, are the chapters devoted to fauna and pathogens.

2.7 Critiques of the Novel Ecosystems Concept

Critiques and opposition to the concept of novel ecosystems have remained marginal to the academic literature. In *Novel Ecosystems*, Patricia L. Kennedy details criticism of how her methods, approaches, and views towards the methods used in intervening in ecosystems (*viz.* incorporating non-native species for grassland bird habitats) because they have changed to be more innovative over recent years. “Moving over to the dark side,” was one the accusations she received.

The first peer-reviewed published paper (Murcia et al., 2014) regarding the novel ecosystems concept, argued for the whole-sale abandonment of using the term “novel ecosystems.” However, there seems to be a mix-up in terms of recognizing that semantic discussions or debates around the concepts can happen apart from the very real conundrum and existence of novel ecosystems (Hobbs et al., 2014). Murcia et al. rely on a number of flurried and misdirected criticisms of the concept, including an uncharitable interpretation about the goals and aims of the proponents of the concept, and interpreting falsely the motivations of the authors, and relying on the straw man argument/red herring that the use and value of the activities of restoration ecology would be undermined. None of the writing from proponents of the novel ecosystems concept has encouraged the abandonment of ecological restoration; instead, descriptions of how the concept should be applied or incorporated are frequently complimentary to existing paradigms/approaches/conceptualizations of how ecological restoration functions, as is evidenced by much of the conceptual work done by the authors in *Novel Ecosystems*: indeed, historical ecosystems are always shown beside what the authors call hybrid ecosystems, or those that are biotically or abiotically dissimilar from historical ecosystems, but still able to be returned to their historical state (Hobbs et al., 2013). Instead of undermining ecological restoration, the novel ecosystems framework becomes useful during the process of evaluating what kind of ecosystem there is. If an assessment is made that a given ecosystem has undergone so much change from its historical state that traditional management techniques are no longer suitable/would be ineffective, the proponents of the novel ecosystems concept assert that the question of *how* intervention in this ecosystem is considered would look

very different. Thus conceptual diagrams that depict the novel ecosystems concept employ historical, hybrid, and novel categorizations (*sensu* (Hobbs et al., 2009)).

Some of the criticism from (Murcia et al., 2014) amounts to objections rooted in different opinions about how we should discuss the kinds of landscape and ecosystem changes being observed.

In trying to understand the criticisms, Richard Hobbs, long-time Editor-in-Chief of the journal *Restoration Ecology*, penned an article aimed at explaining the emotional responses to adapting to a rapidly changing world (Hobbs, 2013). Hobbs wondered whether the “polarized debates in conservation and restoration, for instance in relation to non-native species and novel ecosystems, result in part from people operating from different places in the grief spectrum (p. 144),” which makes them more or less receptive to new ideas and considering different perspectives, depending on their internal state. Undoubtedly, many who are paying attention to news regarding the environment have difficult issues to grapple with, many of which revolve around loss, including the loss of some ideas that had seemed stable in the past, such as how we classify various ecosystems.

Further, restoration practitioners, and indeed, conservationists, can be very principled, and in the face of rapid ecological change, and a variety of ecological losses (from species loss, to industrial development and pollution, and local losses to paying attention to global issues in conservation and restoration), it is possible that many folks cling to those principles, because they are known, and familiar. This may help explain why some scientists and ecologists are frequently in varying states of the grief process, which Hobbs asserts has contributed to the discordant conversations.

Restoration offers hope as an alternative to the doom and gloom; many of the successes of restoration projects show encouraging possibilities for ways to intervene and work with ecosystems, and options for positive actions to take place, both within physical landscapes and along emotional, cultural, social dimensions (Higgs, 2003). Hobbs, however, advocates for not letting restoration be an empty hope; instead, he argues that: “hope needs to be grounded in a realistic assessment of what is possible in a rapidly changing world (p. 145).” The novel ecosystems concept remains very attached to practical realities and respects those realities in light of budget and

resource constraints that have always existed. While it is clear that the novel ecosystems concept is still undergoing some revisions—an ironing out of the details—the rapid uptake of the concept shows that the concept is resonating with a wide variety of researchers.

2.8 Connection to the Mountain Pine Beetle Case Study: Fauna and Novel Ecosystems

Historically, much of the field of ecological restoration dealt with plant-based ecosystems: this being a product of the field being dominated by plant ecologists (Majer, 2009). In a review paper analyzing trends in studies focused on animals in restoration, Majer asserts that restoration practitioners are now beginning to take “a more mature approach than simply monitoring vegetation development” (p.317). Before the 1970s, very few studies took animals into account for restoration efforts, but in the mid-70s, this attention started to increase, with a more rapid uptick after 2000. Further, his review indicates important trends in animal-related restoration project, showing that practitioners still display biases towards studying the charismatic megafauna, which comprise less than 1% of all animal species, but in the smaller numbers focusing on invertebrate populations, beetles were fifth-highest in their coverage, though this is still a small number of papers: nine between 1993-2007.

Given this context, it is not surprising that in their chapter “Fauna and Novel Ecosystems,” Kennedy *et al.* (2013) begin by recognizing the paucity of examples of animals in restoration. It was and perhaps still is common in restoration to reason the way Dukes and Mooney (1999) justify their focus in their paper on restoration with plants: invasive animal species, they argue, will have their responses to climate change (increased CO₂) mediated by plants. In contrast, however, Kennedy *et al.* assert a need to directly include and focus on fauna in restoration because it is not enough to assume that faunal dynamics are given enough coverage, attention, or representation in linked changes occurring in other abiotic or floral assemblages. Further, of the five features of novel ecosystems most important to fauna that the chapter identifies, three can be singled out as most relevant to the mountain pine beetle: 1. Ecosystems contain non-native vegetation and/or animals; 2. Contain native species mixes not historically

present due to rapid recent range expansions; 3. Have altered abundances or interactions partially or wholly mediated by anthropogenic activities. For the first, one of the most interesting occurrences during the mountain pine beetle outbreak is that the beetle spread its geographic range to extend from its historical region to a completely new region, *viz.* the boreal forest (Cooke & Nealis, 2004; Nealis & Peter, 2008). The mountain pine beetle, a native insect to British Columbia, and certainly North America, suddenly garnered the name “native-invasive” due to its epidemic infestation characteristics and the rapid expansion of the geographic range of the insect (Nealis & Peter, 2008). Post 2005(ish), the beetle was found in relationship with a different native species, the jack pine, which as far as the historical spatial and geographic record shows (based on a dendrochronological (tree ring) analysis (Alfaro et al., 2010)), has never before been the case, and the mountain pine beetle is suddenly named as a native and alien invasive species.

This first point also speaks to the second in the chapter, where novel ecosystems with fauna contain native species not historically present due to rapid recent range expansions; the rapid range expansion in the most recent MPB outbreak led to a flurry of research asking very basic questions about the relationship between the jack pine’s (naive) response to their new attacker, the mountain pine beetle (Cudmore, Björklund, Carroll, & Lindgren, 2010), and trying to understand the genetics of the beetle to better understand the outbreak from a different perspective (Gayathri Samarasekera et al., 2012).

For the third feature, much has been written about how historical forestry management and fire suppression directly influenced the susceptibility of forests to insect eruptions (Alfaro et al., 2010), on top of the indirect anthropogenic influences that have resulted in a warming of regional climates to which the beetle has positively responded (Kurz et al., 2008); (Carroll et al., 2003). There are several ways in which the mountain pine beetle’s on-the-ground interactions through a rapidly expanded range and interactions with new hosts present complicated questions for management, and spaces to open conversation about the role of science in addressing these novel issues. Applying the novel ecosystems concept to the case of the mountain pine beetle may be useful for understanding and exploring response and intervention options,

further highlighting the need to update forest policies and ecosystems intervention options before the next outbreak. In grappling with the conceptual shifts for changing ecosystems, there is a significant role for science in helping to establish what these options for new paths in forest and pest management may look like.

2.9 Gaps in the Literature

What is currently missing in the literature is a deeper look at scientific knowledge production in the context of rapid ecological change in the case of the mountain pine beetle. Currently, few scholars have examined the processes of rendering the natural world of the beetle visible; the messy language and conceptual delineations scientists make in order to describe what they see; the factors (generally) that influence scientific knowledge production; and the resulting pathways that science takes to communicate knowledge within scientific communities and outside of them. I ask: does focusing on the case of MPB tell us something important about the way that our social systems of scientific knowledge production are shaped, and how science and policy engage with such an important issue? By interviewing the scientists that help to produce MPB knowledge, I think it is possible to gain a more thorough understanding of the role of research in the context of an outbreak event/rapid ecological change, relationships between science, policy- and decision-makers, and what such events have to tell us about the way our social systems respond to ecological events. Furthermore, it's not clear at this point *how* the science engaged with policy and management decisions that were made regarding the outbreak (briefly outlined above in the case study), and how the science can inform new approaches. Prying into this relationship from the scientists' perspectives may also give us some insight into the limits of science's role in a very complicated policy field, and how recent mountain pine beetle science interacts with policy and management responses that were undertaken to address the outbreak.

My intention is broadly to examine the role that the scientific community researching the mountain pine beetle has had in responding to this outbreak. I agree with Petersen and Stuart's (2014) overall characterization that there are numerous understudied relationships between important actors involved in the MPB outbreak, and that explanations of the outbreak are too simple. As has been shown in this

literature review above, there is ample quantitative research outlining the dimensions of the outbreak, mapping out the extent and movement of the beetle into climate-suitable habitat. Indeed, there exist relatively disciplinary-defined (hard sciences) approaches to understanding primarily the ecological, entomological, and climate-related explanations of the outbreak, but little work that examines qualitative aspects of researching and engaging with the mountain pine beetle.

Recent research also examines short-term forest policy approaches to addressing the outbreak (Lindquist & Wellstead, 2001; Nelson, 2007), and some research has examined the outbreak's impacts on forestry dependent communities across British Columbia (Parkins & MacKendrick, 2007), and public perception of the outbreak (McFarlane, Stumpf-Allen, & Watson, 2006). Further, some research has identified that climate change can result in policy opportunities to shift away from traditional management response paradigms in BC (Wellstead, Davidson, & Stedman, 2006) towards longer-term policies that enable addressing climate change, while another paper examines argues for carefully examining policy options to enhance resilient forests post-outbreak (Burton, 2010). These studies provide only partial views of the social and ecological aspects of the outbreak. On the other hand, Petersen and Stuart's (2014) work is necessarily broad in view as they seek to identify relationships between all the major actors involved in the outbreak. My work takes a similar approach to theirs (discussed further in Chapter 3), but examines specifically the experiences and perspectives of MPB scientists, and their role in scientific knowledge production in the context of the outbreak.

Reviewing the literature of the mountain pine beetle also shows scientists adopting language to describe differences between historical and contemporary MPB change. Indeed, the significant geographic range expansion of this insect, and its impact on forested ecosystems in Western North America (as outlined above) have drawn much attention not only from within Canada, but also abroad. It is the perfect time to engage with scientists who are clearly identifying a difference between previous outbreaks, and who are adopting new terminology to identify these differences: the peak of the outbreak in British Columbia has passed, and research funding is dwindling; scientists are well-positioned to reflect on their roles in developing our

understandings of the mountain pine beetle outbreak. And further, to investigate whether there is any relationship between this new use of language and the concept of novel ecosystems that has been emerging in the literature.

In the next chapter, I describe the methodology, qualitative case study approach and specific research methods used to gather data for this study.

Chapter 3: Methodology and Methods

“Scientific research plays a crucial role in our ability to knowledgeably engage with the natural world. In many ways, scientists act as interpreters for nature, and for the species, waterways, and ecosystems that cannot speak for themselves.”

— Carol Linnet, *Academic Matters*, May 2013

3.0 Introduction

This thesis is an exploratory, qualitative research project, meant to contribute insights into understanding scientific knowledge production in the context of rapid ecological change, since it is likely that this kind of change will occur more frequently as the effects of climate change manifest across the globe. In this chapter, I begin with a discussion of my approach, and then I describe the methods used to explore my research questions. I outline my methodological approach, followed by the qualitative design (case study) that drove my research project, and continue with a description of specific methods I used, the places I went, and the people with whom I spoke. In this section I include a brief discussion of the ethics agreements with participants. Then I describe the processes I used for understanding my data. I close this chapter with a brief discussion of the challenges I encountered, as well as the scope and limitations of this project.

3.1 Methodological Approach

Two different fields have primarily influenced my approach: science and technology studies, and science policy literature. This section reiterates some of the prominent works and pieces that have shaped my thinking around both project design, and results interpretation and presentation. Chapter 2 has already presented several science studies works that influenced my project, as well as recent research into science-policy connections and relationships.

Rapid ecological change is altering the nature we know: one that surprises our social and economic systems with longstanding and costly impacts. Scientists generally produce reliable understandings of the world, and it is important to assess whether that science, often undertaken at significant cost, is effective, and able to engage with policy and decision-makers. In shedding light on the factors (barriers, constraints, enablers) that influence the ways in which they produce those understandings—we may realize there are other options for increasing the effectiveness of science, and better produce science that links into government and management priorities. Considering that very little social science has turned to examine MPB science, I follow the lead of other social scientists like (Dilling & Lemos, 2011) and (McNie et al., 2016) to do my best to examine the scientific and institutional responses to a climate-exacerbated beetle outbreak in Western Canada.

3.2 Scientists and mountain pine beetle research: Understanding the lenses that show us the beetle world

Scientists are frequently on the frontlines of understanding changes in our natural environments. They are featured in the media as experts who illustrate observed changes and explain their implications. In the Canadian setting, the mountain pine beetle outbreak is one such case. Dr. Allan Carroll is an example of a scientist who was interviewed as an authority on the mountain pine beetle on a prominent scientific television show (*The Nature of Things*) by another well-known Canadian environmental scientist, David Suzuki, who confidently narrated the current understanding of the mountain pine beetle outbreak (2014). In the same video, Dr. Carroll reassured viewers of such information as the fact that the beetle wouldn't destroy the boreal forest, and he calmly explained the processes of succession and forest ecology after an insect outbreak, while also discussing some of the changes we may anticipate in MPB-affected forested landscape. Our understanding of changes to mountain pine beetle outbreaks are mediated through scientists like such as Allan Carroll. Further, we rely on these scientific experts for their sense-making skills of the natural world, among other things. As the federal government asserts on their "Impacts to climate change" page, scientists have already linked a number of forest

changes to climate change, and that scientists at the Canadian Forestry Service "are studying many aspects of the impacts of climate change on Canada's forests to provide a basis for future forest policy and management" (2014). In other words, scientists play a crucial role in making sense of the natural world for us.

This project presents a richly voiced account from scientists across organizations and institutions with firsthand experience understanding (and translating) this massive disturbance event. Frequently, groups of scientists are brought together by discipline, training, culture, and experience, and sometimes, as in this case, by event and purpose. As Neuman (1997) writes, "Science is given life through the operation of the scientific community, which sustains the assumptions, attitudes, and techniques of science" (p. 7). The scientific community is a group of interacting professionals, and a set of norms, beliefs, and attitudes united by a commitment to scientific research (Neuman, 1997). Preliminary research in the published academic and grey literature showed that the scientific community engaged with the mountain pine beetle came from a widely varied scientific community: scientists in the federal government, in the BC provincial government, and from various academic institutions. Each had been working to understand the many dimensions of the mountain pine beetle outbreak, some of which include mapping and tracking the beetle, understanding its genomics, understanding its relationships with its host (the trees) and its role as host for fungi that synergistically contribute to the success of its attack to trees, understanding some of the social and economic dimensions of response to the outbreak, and understanding the impact to Canada's forest carbon budget. For this project, I identified four main research hubs from which several scientists are actively engaged with producing knowledge about the mountain pine beetle in light of the recent outbreak. While their research disciplines cover an array of disciplines and fields, the common denominator for these scientists is the mountain pine beetle: a small insect that has caught international headlines and has made climate change impacts real for Canadian landscapes.

Before describing the various areas in which these scientists published, it is important to describe a bit more generally ideas that influenced my understandings of

the scientific lens, and then how I applied that to my case study as regards the mountain pine beetle.

Prying into this relationship from the scientists' perspectives may also give us some insight into the limits of science in a very complicated policy field, and how the recent science interacts with management solutions that were undertaken to address the outbreak.

3.3 The Exploratory Qualitative Case Study

Creswell (1994) and Yin (2003) describe that one of the four most common qualitative research design studies is the case study, where a researcher can explore a single entity, organization, event, or phenomenon ("the case"), and collect detailed information by using a variety of data collection methods. This study sought to understand the case of scientific knowledge production in the context of the climate-exacerbated mountain pine beetle outbreak that began in the late 1990s in central British Columbia, which included the spread of MPB out of its historical range to affect neighbouring provinces and territories, and interactions with new (naive) hosts in novel territory. I engaged with the network of scientists I could identify as part of this case, described in more detail below.

3.4 The Data Collection

The methods I used to collect data were three distinct but complimentary methods: a historical, context-setting literature review; qualitative, semi-structured, in-depth individual interviews; and the maintenance of personal reflections via a research journal that I kept alongside the interviews and data analysis process.

The literature review helped me to build the historical context of scientists undertaking mountain pine beetle research, understand what the historical and current scientific understandings of the mountain pine beetle outbreak were, and identify scientists who were potentially suitable to interview for this project. I examined a broad suite of resources, from government policy documents and presentations to educational information regarding the mountain pine beetle, from forest industry statistics to pest management plans, from government reports and risk assessments to

academic journal articles, and from media reports to educational videos produced by interested NGOs. It was important for me to gain as thorough as possible an understanding of the research context into which I was stepping. Understanding the context of the outbreak in Western Canada was important for preparing me for the interviews, and as was suggested in the literature, enabled me build rapport quickly with my interviewees (Phillips, 1998; Harvey, 2011; Mikecz, 2012).

3.5 Which scientists? What community(-ies)?

This short section describes the network and community of scientists into which I tapped, to establish a widely-sampled selection of views from scientists undertaking MPB-related research. In order to understand how scientists build knowledge of the mountain pine beetle and its effects, I identified five active hubs of research from the already established academic and literature, both academic and other publications, frequently grey literature, including major reports from the government. An example of such a report is the “Risk assessment of the threat of mountain pine beetle to Canada’s boreal and eastern pine forests,” published in 2008 by the Canadian Forest Service (CFS). The Canadian Forest Service, particularly the Pacific and Northern Forestry Centres seemed to have the richest concentration of scientists involved in the research of mountain pine beetle. The CFS is the primary source for scientific and technological support for forest pest matters for all levels of jurisdiction in Canada, and frequently engages in research collaborations and partnerships with other agencies.

Three other hubs of mountain pine beetle research were taking place at the universities of Northern British Columbia and of British Columbia, as well as the University of Alberta in conjunction with the Turning Risk into Action for the Mountain Pine Beetle Epidemic (TRIA), a project that focuses specifically on mountain pine beetle genomics and economics and includes researchers from both inside and outside of those three academic institutions. TRIA began as a two-year NSERC funded project, but garnered further support and funding from GenomeBC and GenomeAlberta. Participants were recruited from all hubs except the Northern

Forestry Centre (NFC); I was not able to recruit any participants from that institution. Instead, a BC provincial scientist contributed his perspectives.

It is clear from publications and other comments by participants that there is ongoing involvement from NFC scientists in MPB research, as well as some relationships that span institutional boundaries. A significant part of identifying and recruiting participants relied on referrals or suggestions for potential participants from already interviewed scientists, and it became clear from some of the suggestions that the research network spanned the country.

It was clear from both the collaborations in articles in the literature and recommendations by my participants for further interviewees, that even though the outbreak happened in western Canada, this did not limit research interest and participation to scientists who only in British Columbia and Alberta. Rather, there was already a lot of national collaboration and work underway between federal scientists in the Canadian Forestry Service. Even further to that, however, as evidenced by publications and a perusal of the records at the Pacific Forestry Centre show that collaborations have also regularly taken place with researchers south of the 49th Parallel in the US Forest Service. This became most clear when looking at the changing locations of reasonably regular mountain pine beetle symposia which took place in the US and Canada: 1985 (Smithers, Canada), 1988 (Kalispell, USA), 1992 (Kailua-Kona, USA), and in 2003 (Kelowna, Canada) (from the BC FLNRO Library, 2014).

And, in some cases, borders are fluid between nations as well; for example one scientist that I contacted but who did not participate in my study is Dr. Brian Aukema, a Canadian scientist who had for a time been a researcher with the Canadian Forestry Service, but as of September, 2010, relocated to the Department of Entomology at the University of Minnesota. He maintains research affiliations with the University of Northern British Columbia, and TRIA. A quick glance at his publications record shows direct links to several Canadian university research groups. Cross institutional collaboration seems long to have been a component of research on the mountain pine beetle, which is well-suited to research an insect whose range (now) extends from the southern Yukon and Northwest Territories down to Mexico.

3.6 Participants and Recruitment

In order to identify factors that influence how scientists produce MPB knowledge, I tapped into the network of researchers conducting work related to this insect perturbation. Alongside from the five previously located hubs of research (discussed above) where groups of scientists were publishing some of the latest scientific information on the mountain pine beetle, I also took guide from scientists mentioned in the news or other popular media regarding the mountain pine beetle. For example, Dr. Allan Carroll was the expert scientist interviewed for a segment of "The Nature of Things", produced by another prominent and well-regarded Canadian scientist and communicator: David Suzuki. Dr. Christopher Keeling was also featured in presentations and publications such as *The Globe and Mail*, and the *Huffington Post*, and the University of Victoria's annual Forest Biology Symposium, announcing that scientists had decoded the genome of the beetle, or more specifically the transcriptome: the expressed portions of the genome for which specific functions in the beetle are known, such as processes of cold tolerance, olfaction, and pheromone biosynthesis (Keeling et al., 2012). Dr. Keeling is associated with TRIA (Turning Risk Into Action for the Mountain Pine Beetle Epidemic), a network of researchers that emerged during the height of the latest outbreak to tackle a number of research areas regarding the beetle. The most prominent was the genetic approach (Bohmann, 2012). The richness of the group of scientists researching the mountain pine beetle and related aspects enabled me to recruit a diverse set of views, perspectives, and opinions in my data set.

My search through the literature led me to send out initial invitations to participants based on their work, and finding other participants proceeded from there. The interviewees are experts in their fields: scientists who have actively been publishing and contributing to the public and academic research on the mountain pine beetle outbreak, and who were (and are) shaping the scientific knowledge production around understandings of the mountain pine beetle. Each was well-suited to provide answers and contribute perspectives to my research questions (Rice, 2010).

Once I had identified a core group of scientists (purposeful sampling) from a diverse set of literature and media sources, and had begun undertaking the individual interviews, I followed up with snowball sampling (where already-interviewed participants recommended other scientists to include in my study) to find and select other knowledgeable research participants, as they would be able to offer rich and insightful data based on their experiences and knowledge (Kemper, Stringfield, & Teddlie, 2003; DiCicco-Bloom & Crabtree, 2006; Newing, 2011). This method was particularly key when I realized that I had not been able to recruit provincial scientists, and later one referral panned out.

As the interviews targeted experts in their fields, the interviews were semi-structured to allow maximal exploration of key ideas—a collaborative building of shared information during the interview (Graham, 2005; Rice 2010). In total I sent twenty-five invitations to researchers in these three main groups: federal scientists, academic BC scientists, and academic AB scientists, and ended up with sixteen participants. Broken down by group, I sent thirteen invitations to federal scientists, with six accepting my invitation to participate; one invitation was sent to a provincial scientist who accepted; and eleven invitations were sent to scientists primarily in academia or very closely related to it (such as TRIA), of which nine were accepted.

I am pleased with the group of participants that I went forward with for this project, as I had set my initial goal for of recruiting between fifteen and twenty-five participants. More importantly, however, it became clear with successive interviews that data saturation had been reached.

3.7 Semi-Structured, In-Depth, Individual Expert Interviews

I reviewed the literature on several different aspects of the research process included best practices for interview experts, such as recommendations for gaining access and establishing trust (Harvey, 2010), presentation of the interviewer, length of the interview, broaching awkward topics and questions, maintaining interest, flexibility of scheduling (Harvey, 2011), and formats such as conducting interviews over the phone (Holt, 2010) or face-to-face. In order to gain the depth and nuance of perspectives,

and explore the ideas that I was interested in, I opted to arrange semi-structured, in-depth, individual expert interviews with my participants.

As part of the interview process, I had decided to send all participants a draft of the interview questions in advance, with the exception of the questions regarding the novel ecosystems concept. Given the newness of the concept, I did not want participants to receive the questions, see that they did not know anything about the concept, and look it up ahead of time. I wanted candid reactions to those questions; participants who may have been inclined to look up the concept in advance, which would have skewed their answers. While I looked for advice in the literature about whether to send interview questions in advance or not, there were no comments to be found on the topic. I decided to (by some mix of advice from colleagues, supervisor, and instinct) to send the questions ahead as a gesture of good will. While most participants read the questions in advance, others did not due to busy schedules.

3.8 Data Collection

The majority of interviews were collected in the summer and fall of 2013, with the final interview with Les Safranyik done in the spring of 2014. I sent the interview questions to participants ahead of time; most were able to view the questions in advance, though some did not. I audio-recorded the interviews using a Zoom H2N Handy Recorder (portable). As soon as was possible post-interview, I transcribed the interviews verbatim as accurately as possible. I edited out ahs and ums and other micro-text that did not contribute to the content and substance of what participants were saying. I used ExpressScribe to process the audio files. After finishing transcribing an interview, I listened to the audio data at the same time as reading the transcript I had produced, to verify accuracy. I also highlighted small sections of text where I had not understood what was being said (i.e. One participant referred to a paper “Kurz and Apps”, and I didn’t understand the names during the interview; this was clarified in the follow-up email).

As soon as I had finalized the transcripts, I prepared follow-up clarification questions to participants. As a courtesy, I sent the transcripts of the recorded

interviews to the participants at the same time, for verification of accuracy (Graham, 2005), as well as to offer participants a chance to eliminate any misinterpretations of the data collected as possible (Ostrander, 1993). I always outlined a timeline for sending the transcripts and the follow up questions, but if a researcher did not respond to the first or second email prompt, I did not pursue further follow-up, and proceeded with the notion that the participant felt comfortable with their transcript. Follow-up question non-response occurred with roughly one third of the participants.

The data was collected from four primary locations. For the federal scientists located in Victoria, BC, I visited the Pacific Forestry Centre (PFC) to meet all of them in their offices to interview them in person. I was greeted by an enormous sculpture of a mountain pine beetle in the lobby of the PFC (see Figure 5 below). The PFC is one of five research centres of the Canadian Forestry Service, which has a number of research priorities, including fire management, forest inventory and monitoring, forest entomology and pathology, and climate change (Natural Resources Canada, 2015).



Figure 5: Image of large sculpture of the mountain pine beetle in the lobby of the Pacific Forestry Centre in Victoria, British Columbia, Canada.

Over two research trips to Edmonton and Prince George, I likewise interviewed those scientists at their offices or other spaces in which they felt comfortable at their universities. For a couple interviews, this meant a couch or lounge area in the university hall way, replete with summer science camp kids running and yelling excitedly down the hallways halfway through the interview; in another case it meant settling down across at the desk of a researcher who cleared some desk space for the recorder on the cluttered surface. Later, one researcher shushed their 10 year-old son and friend who'd dropped by for their lunches, and asked them to wait outside a little bit longer while we wrapped up our interview.

I also undertook several telephone interviews with scientists in Vancouver and in Terrace. The telephone interviews were something that I wanted to experience to gain a sense of how they might differ from face-to-face interviews, so it felt appropriate to mix the contact participants in the in-person interviews. It also made sense practically, as in the one case it would have been very difficult to get up to the remote Northern BC community in which this researcher was living and studying. Overall, while I found that the interviews were on average shorter than the in-person interviews I conducted, the interviews felt as complete and successful as face-to-face interviews, which no doubt Amanda Holt (2010) would be happy to read, considering her advocacy of the telephone as a suitable choice for an interview format. And regardless of format, undertaking the interviews and research trips was undoubtedly one of the best parts of the research process.

In total, I conducted 16 eighteen individual interviews with scientists in British Columbia and Alberta from a variety of institutions and organizations that were prominently engaged with producing research about the mountain pine beetle and its associated outbreak. After fifteen individual interviews had been completed, preliminary analysis determined if saturation has been reached (Newing, 2011), and I determined that with the broad themes and overlapping content between participants, the number of interviews I still had scheduled then (1 more) did not need to be adjusted. I ended up including one more interview with Mr. Les Safranyik because it was too good to pass up: Safranyik is the longest-standing researchers on the mountain

pine beetle in British Columbia who is still alive, and had retired approximately a year and a half prior to my study. I was extremely fortunate to connect with him and have him participate in my study despite being retired. He keeps an open door for his old colleagues and other researchers (like me!) who have questions about the mountain pine beetle.

And lastly, one academic scientist had been away gathering field research when I first contacted him in the summer and later I assessed my group of participants and was satisfied that I had recruited several of that scientists' direct colleagues already, and further, I felt that I had reached saturation of data at that point, so I did not pursue that potential participant any further.

3.9 Finding Participants, Consent, and Ethics

My participants were identified first through a search of the literature to see which scientists were publishing high profile and important information about the mountain pine beetle, whether those were academic articles or government reports. My search for participants began with those metrics, and continued with a search through recent conference proceedings and newspapers articles so that I could understand who was publishing relevant research, and whose research was achieving prominence in the public and governmental spheres. Early on in the data collection phase I had planned for my interviews to begin with a small pilot series (2-4) that allowed me to evaluate my questions and the flow of conversation with the federal researchers I'd identified from my recruitment phase, and make necessary adjustments from there. However, due to early recruitment challenges, my interview schedule changed quite a bit from the initial planning stages.

Early challenges with recruitment changed my interview schedule significantly: I had intended to interview the group of scientists closest to home—the group of the federal researchers who were, by-and-large, physically located in Victoria, BC, the city where I was currently living. However, very slow response rates or non-responses to invitations and absences due to field research or vacation made impossible the schedule I had wanted to keep. I had already started to set up interviews for other groups of

participants in cities I would be travelling to later in the summer. By the time I was packing my bags to head out on my research trips to Edmonton and Prince George, I had only one local interview completed, aside from the informal meetings I was able to have prior to the formal interview. So instead of having a good chance to trial my questions locally in Victoria, I took them on the road. After I'd finished the first set of interviews in Prince George, I reflected on and reviewed my research questions, and felt comfortable moving forward.

My project successfully received Ethics Approval by the university (see Appendix 1). I offered all participants a range of options for managing their confidentiality in exchange for their participation:

1. Full confidentiality where no personally identifying information except the institution would be used to identify participants, and, if requested by a participant, a pseudonym would be used, and in some cases was used in order to further decrease the likelihood of identification;

2. Partial confidentiality, where direct quotes could be highlighted and used from the transcripts, but the participant's name would not be disclosed, though identifying their institutional affiliation would be allowed; or

3. Consent to disclose identifying information, where their name, their institution, and direct quotes could be used. See Appendix 1 for a template of the Consent Form. The List of Participants in Appendix 1 also shows participants and their level of comfort with disclosure.

3.10 Interview Analysis

For this project, I employed the qualitative data analysis program NVivo 8 (QSR International) to assist with analysis of the transcripts I produced from the interviews I undertook. NVivo was helpful in identifying common themes, patterns, connections, and contradictions in the data (Bazeley, 2007; Saldana, 2011), as I was able to code the content of the transcripts, and sort and sift and connect and combine themes that emerged, thereby coming to an understanding of my data. Being a relatively heavy-weight program, I used far fewer aspects of the functionality of the program than it offered, and in many ways my process of data analysis was reasonably simple, though

this by no means has resulted in a simple story of from the data. I used five distinct rounds of visiting the data to make sense of it, though I also repeatedly revisited, re-read, stewed on, and reflected on the interviews from the moments the first one was finished. The qualitative research process, and arguably the entire research process as a whole, is very iterative, and mine was no exception. NVivo provided a structure to thoroughly and objectively ensure that I handled all my data in the same way, thus providing a structure that increased the validity of my data.

For a detailed description of the analysis that I undertook of my data, I used five different linked stages to comb through and understand the data collected in the interviews, which is described in Appendix 1. The findings reported in this thesis are a subsection of all of the data; as is to be expected, qualitative data is rich and detailed, and some of it was not as relevant to my research questions as those that made the cut.

All through this process I was also maintaining a journal (discussed below) that allow me to reflect on the process of my analysis, writing out thoughts, asking questions of my data, and otherwise trying to keep tracking some of the ideas of the pieces that spoke to me the most, that struck me as most important.

3.11 Maintaining a Journal

In order to keep track of my personal perspectives, reactions to the interview process and respondents and ongoing analysis and reflection on responses, I concurrently maintained a research journal (Rubin & Rubin, 2005; Hilperts, 2010) to help me keep tabs on introspective and reflexive reactions, insights, and/or observations I may have during the process. In particular, after I conducted each interview, I sat down and reflected on the most interesting or distinctive comments I heard during the interviews, made notes on whether there was repetition or a similar vein of thought that someone else had mentioned in their interview, and made note of what was most striking about each interview. These initial notes assisted me during the iterative, reflective process of coming to understand and interpret the interviews, pulling out key lessons or insights, strong themes or surprises, and managing or debriefing my internal and emotional states after the interviews (Blake, 2005; Rubin & Rubin, 2005; Charles, 2010). And I

added more notes on the overall process of making sense of my data after I had collected it.

During the course of the research project, the journal entries shifted from the earlier interview-specific response journaling, to speculative, keeping-track-of-insights, ah ha! moments, and general thoughts about the research process, including sources to follow up on, further reading, and questions that emerged. Practically speaking, journaling the journal also served as a mnemonic tool; I am endowed with a terrible short-term memory and found that keeping a journal was a useful prosthetic for my memory, and keeping track of notes and impressions of each the interview, the scientist/participant, the experience, other contextual impressions that the recording device did not pick up from the interviews themselves, as well as thoughts, impressions, and insights along the way. Certainly the journal notes that I made right after the interviews are proving useful, when memory has shed all the crisp details that were fresh post-interview, but that now no longer have a home in my mind.

3.12 Contextual Recruitment and Interview Challenges

A factor that has influenced this thesis project since even before I began identifying different scientists to interview, is the political antagonism between elected federal government officials, primarily under former Prime Minister Harper and the then-Conservative government's vision of the role of science and evidence in society. With that in mind, what follows here is a general discussion of the institutions from which I sampled scientist participants for this research project.

On top of any recognition that I would be sampling from a group of experts, much was my trepidation when I began to contact scientists for my project; I was aware of the current circumstances of science and science communication being conducted in Canada, especially at the federal governmental levels: much research by various scholars and journalists has brought attention and awareness to what has been characterized as the “muzzling” of scientists. Since 2007, the Harper government had been taking action in several different ways to prohibit and limit researchers from discussing and sharing their work; these actions were widely criticized in the media.

Linnet (2013) provides a detailed account of examples that illustrate the Harper government's attempts to control science, including rules that governed how Environment Canada's scientists interacted with the media, eliminating the position of National Science Advisor, and sending scientists to events with media relations chaperones to ensure that scientists did not communicate information that was not approved. One of the most prominent media events to bring attention to what has been classed as a "systematic attack on science" (Linnet, 2013) was PhD student Katherine Gibbs from the University of Ottawa, who organized a rally on Parliament Hill to mourn the "death of evidence": a response to the systematic cuts to science funding that the federal government under Prime Minister Stephen Harper have undertaken, including targeted cuts to specific departments, such as Environment Canada, Fisheries and Oceans Canada, Library and Archives Canada, the National Research Council Canada, Statistics Canada and the Natural Sciences and Engineering Research Council of Canada (Davison, 2012a). Davison (2012b) also reported specifically on a few scientists who were barred from sharing their scientific work with the public, including Drs. Kristie Miller, Scott Dallimore, David Tarasick, a group of scientists from Environment Canada and Health Canada; their work ranges from climate science, fish stocks, radiation, and research into the ozone layer. A very recent example also includes federal scientist Dr. Max Bothwell, whose media request regarding his research on the pervasive algae, *Didymo*, or "rock snot," as it is fondly called, elicited 16 different public servants to get involved in addressing the request, which was ultimately not approved (Moore, 2014). The federal government's internal processes of granting approval to scientists took weeks, sometimes causing interview deadlines to be missed, and timely responses to become impossible. I was aware of this "big chill" (The Professional Institute of the Public Service of Canada, 2013) and wondered whether it would play a role in my project.

While I do not have conclusive causal meta-data that I can share on about my experience of trying to contact researchers, there are a few interesting observations that I made during the process of recruiting participants. There was a marked difference in the response time of federal scientists and university scientists. (I interviewed only one provincial scientist that I engaged with is too small a sample

size). However, my interview schedule and plan needed to change substantially as I did not have the requisite number of pilot interviews completed with my initial interviews—which I had hoped would come from the federal scientists that were present in Victoria, where I was studying. It took in some cases weeks and follow-up emails to hear back from each of the federal scientists, and because of the long response times, I had to adjust my planned schedule of interviews, travelling to Prince George and Edmonton before solidifying the majority of interviews with scientists in Victoria. In comparison, when I contacted university professors, it was unusual to have a response that took more than a same-day or next-day time. In the end I had far fewer federal scientists participate than university scientists, given the number of invitations I sent to each group (See Section 3.4, Participants and Recruitment). Fewer than 50% of the federal scientists accepted their invitations, whereas approximately 80% of academic scientists accepted their invitations.

3.13 Scope and Limitations

Perhaps one of the biggest challenges of this project was identifying and *limiting* the scope of the project. The mountain pine beetle outbreak lasted years, affected an enormous geographic space, and involved thousands of people: scientists, policy and decision-makers, forestry workers, environmentalists, media and journalists, students, and citizens, and more. A long, iterative process had to take place in order to both make sense of the data that I had, including how best to select and interpret my data, because what I had collected turned out to be more broad than what I initially thought I would hear. I interviewed a group of scientists whose common denominator was a really interesting and fascinating insect that had been making a splash in the media and capturing people's attention across the globe because of its climate exacerbated outbreak patterns.

Scientists played an important role in producing information that underpinned some decisions that federal and provincial governments made in addressing the outbreak, but by and large, they are only half of the rather complicated process of

turning that knowledge into real decisions. Resource managers, policy- and decision-makers and other public officials are the other half, and I did not interview anyone from that diverse group. And further, science extension and communication folks are also an important part of making scientific information understandable by a wider audience (essentially, translating that knowledge). An example is the organization FORREX, the Forest Research Extension Partnership, which was based out of Kamloops, and part of the Ministry of Forests and Range (now Ministry of Forests, Lands, and Natural Resource Operations), but whose website has not been functional for some time. The last publication I was able to find from FORREX was from 2012. This extension research group produced a number of interesting papers cited in this thesis, and it would have been useful to interview some of the scientists that produced that research. However, it's possible that this is part of the provincial funding cutbacks that AP4 described in his interview (discussed below), which is why it was difficult to find those folks or their research now.

Chapter 4: Findings

“I was pretty excited when the outbreak came [laughs]. I could get to see a whole bunch of live beetles doing their things on the tree, so, that was a lot of fun, to be able to go out and you know, look at a pine tree, look where the beetle entered into the tree, and the pitch tubes, whether or not the tree was able to resist, whether the beetle was colonizing the tree, and then we would take the bark squares off and look and I actually got to see a lot of things that moved, you see, because I’ve been studying trees for so long that it was pretty exciting to study things that actually dispersed or actually moved, and went from tree to tree, things that dispersed at a time scale that was much shorter than tree reproduction” (AP5, 2013).

“...[T]he fact that [the beetles] have recently spread over the Rockies and seem to be in the jack pine is something completely novel, we think, we don’t think it’s ever been there before, at least, in any recently recorded history, even going back quite a ways. So, we’re seeing things that are amazing and new and that’s, so on the one hand, as an entomologist and a biologist and just an everyday citizen, you look at it and you go, Wow, that’s an amazing thing that’s going on here...” (DH, 2013).

4.0 Introduction

This chapter covers the major themes and findings of my research project. This chapter delivers the findings from 16 semi-structured interviews conducted between the summer of 2013 and the spring of 2014. There are five major categories of findings, each of which comprises research themes, delivering themes that range from the attitudes and outlooks of scientists, institutional cultural components and influences, the impacts of funding on scientific knowledge production, scientists’ connections to and reflections on the novel ecosystems concept, the research network of people engaged in mountain pine beetle research, and scientists’ engagement with MPB

management and policy. The categories clump together somewhat related themes, and are meant to help organize the themes in the chapter. There were so many findings, that it was organizationally useful and expedient for me to organize the themes this way.

This chapter delivers the findings from 16 semi-structured interviews conducted between the summer of 2013 and the spring of 2014. Throughout I use the text of this chapter, a combination of (sparingly used) block quotes from participants were used to present different aspects of their voices and characters, and to enable their voices and characters give them an active presence in the text. The block quotes are sparingly used. Attribution is otherwise noted in the format: (PARTICIPANT NAME, INTERVIEW YEAR), or PARTICIPANT NAME (INTERVIEW YEAR). Please see Appendix 1 for the full list of participants and their acronyms.

4.1 Category 1: Scientists' Cultures: Studying the Mountain Pine Beetle Within an Outbreak Context

This category reports eight key themes that scientists discussed about their research experiences during this the most recent and the preceding mountain pine beetle outbreaks. The themes discussed include their general research experiences, their relationship with the mountain pine beetle, their self-perceptions about the value and motivation of their research, their responsiveness to external factors that shape research (though the impact of funding is handled in a series of themes in Category 3), their general agreement on the history of factors that influenced the MPB outbreak, their perspectives on research opportunities in the outbreak, the disconnection between research and ideas in the preceding outbreak and this recent one, and the products of their scientific knowledge endeavours. Researchers whose careers spanned the current and previous outbreak in the 1980s contributed more comments to the long-term research experiences (eg. AC, LS, PB and KL) than did researchers who more recently began their research careers, and for whom this was their first experience undertaking research in an outbreak context (eg. DH, BM, and AP2).

4.1.1 Research Experiences

As many of the scientists asserted, the mountain pine beetle has long been a part of forests in British Columbia and in the western and central United States, and its presence in forests has long been monitored and tracked. Researching a beetle that has cyclical outbreaks that can span decades, and that are separated by decades, has a variety of distinctive factors that influence the character of that research. Several scientists were quick to point out that funding for research on such an insect tends to mirror the patterns of the outbreaks: when the beetle is in its outbreak phase (or epidemic phase), and is attacking healthy, mature trees, and since these trees are frequently of economic value and interest, research funding is consequently made available to address this perceived threat. When the beetle is in its endemic population phase, such that the beetles exist in forests at very small population densities and can consistently only attack weakened and sick trees, funding disappears (KL, 2013; SL, 2014). This frustrates research efforts that try to ask questions in non-outbreak contexts, as funding is difficult to obtain and precludes scientists from undertaking long term studies, as PB (2013), KL (2013) and LS (2014) pointed out. Funding will be discussed in more detail below in Category 3 below. The disappearance of funding during endemic population phases makes it difficult to carry on important research and prevents scientists from answering even the most basic questions about the beetle, such as the mechanisms that trigger the beetle to change population phases, from endemic to incipient-epidemic to epidemic, (LS, 2014) or hyper-epidemic. LS (2014) pointed out that despite all the research and knowledge that has been undertaken on MPB in the last several decades, the answer to one of the most basic question of what triggers the beetle to change its population cycles (especially into and out of epidemic status), as well as the associated thresholds, remains unanswered. AP4 also pointed out that it's very difficult to study *Dendroctonus* in a laboratory.

AP4 (2013) described a particularly harrowing incident of the beetle attacking experimental tree plots that this scientist was responsible for. AP4 had predicted that the beetles wouldn't attack the experimental pine plots he had been working with, but one day AP4 was in one of the plots monitoring the trees, when "swarms of beetles started to drop in on the trees from the sky." AP4 leapt into action, and scrambled to

slap together resources and people to capture data on rates of the attacks, which he succeeded in doing. At one point, he described, this involved setting sticky traps to catch the beetles, attempting to establish a way to capture the beetles so they could measure differences between attack rates in the various tree plots, and several weeks later, when the beetles left, AP4 thought the project successful, especially given the painfully fast timeline of the experiment. The success of that research project, as AP4 emphasized, hinged on the fact that beetle attacks cannot be simulated in a laboratory; the beetles' outbreak dynamics in the landscape cannot be reproduced. AP4 was particularly pleased with the fast response and project that the small team put together, even if it was slapdash. However, he also realized shortly after the attack had finished that they had missed one key component of measuring tree data—details on the physical properties of the bark of the trees—that could have better informed the mountain pine beetle's (a *bark* beetle's) preference for attacking certain trees over others in the plot. On reflection, AP4 thought that that omission likely wouldn't have happened if they'd had more time and a better budget to more thoughtfully design the study.

The outbreak began in the late 1990s, and was familiar to researchers who had seen the previous outbreak in the 1980s. As AP5 (2013) asserted in a pilot interview for this project, scientists (especially colleagues in the CFS) knew that another outbreak was imminent. The only real surprise, she asserted, was the unknown factor that the changes in climate would have made. As the outbreak continued to escalate (between 2002-2006), several researchers became newly interested in the mountain pine beetle (eg. DH, 2013), including a number who had not previously undertaken research on either this species (eg. AP2, 2013), or beetles (eg. AP3, 2013) before. As SL (2013) stated, some researchers were very opportunistic about the funding that was made available, but he did not see this as necessarily negative.

Overall, however, scientists were very clear that the main products of their activities were scientific data, typically in the form of academic journal articles. Many of the scientists described their work, whether it was learning about the pheromone biochemistry (CK, 2013) or modelling the climatically suitable habitat for the beetle (AC, 2013), or understanding the beetle's effect on the transition of a whitebark pine

ecosystem (AP5, 2013) or gathering a group of scientific experts to undertake a risk analysis on the mountain pine beetle in the boreal region, which was published as a government report (VN, 2013). Aside from a few media interviews, scientists focused on contributing to the academic literature and state of knowledge about MPB.

4.1.2 Scientists and MPBs: Behaviours, Expectations, and Beetle Transit

Studying the mountain pine beetle outbreak did not revolve only around the beetle, and interviews with scientists included a mix of those who studied the beetle and its behaviour directly (SL, 2013; BM, 2013; DH, 2013; AC, 2013; AP5, 2013), the host trees (JC, 2013), and the fungi that the beetles carry with them (JK, 2013; RH, 2013). As JC (2013) pointed out, trees do not move quickly: their reproduction by seed spread is relatively slow compared to the movements of the beetle, and RH (2013) stated, the fungi are passive passengers that the beetles carry with them in their abdomens, though they play an important role in helping to colonize a host tree. However, the attention in any outbreak is primarily on the beetle and its movements, because it is the agent of the outbreak. A frequently asked questions that scientists contend with is “How many trees is the beetle killing?” which reveals how many interests in managing and controlling the beetle revolve around managing and controlling the economic impact of the outbreak. The beetle is the organism that moves relatively quickly on a landscape. As AC (2013) stated about the beetle’s behaviour: “Outbreaks are normal. Outbreaks are required. Outbreaks tend to recycle the system...” This general “no-surprises-there” attitude was shared by other participants (AP5, 2013; PB, 2013; LS, 2014).

So how do scientists think about the beetle? Descriptions and conceptions of the beetle ranged from the most basic physical “a small black beetle” (EC, 2013), to the metaphorical “a slow-moving fire on the landscape” (LS, 2014; VN, 2013) that engaged with the beetle’s movement through the landscape, and its regenerative function in a forest ecosystem landscape: as the beetle kills the old lodgepole and other pine species, younger trees or saplings are able to colonize on the sunshine and fill the newly opened canopies. As a sidenote, VN (2013) jokingly stated that he would love to one day write a paper about how the mountain pine beetle *actually* kills trees.

Apparently that process is not yet fully understood. Returning to the earlier discussion point, AP5 (2013) pointed out that the relatively quick opening of the canopy allows forest ecosystems to potentially experience quite rapid shifts of species composition — this was something she noticed at several of her research sites at higher latitudes in BC, where at the time of my interview with her, her preliminary findings suggested to her a novel ecosystem in the making. This is discussed more in Category 5 below.

Scientists' descriptions frequently *only* situated the beetle in relation to its outbreak patterns, highlighting especially those that departed from historical expectations of behaviour. A few different metaphors were used by different researchers, too, such as the outbreak being a “perfect storm” (AC, 2013; DH, 2013; AP2, 2013; JC, 2013), where a number of conditions coincided in the favour of the beetle, including historical forest management practices and forest fire suppression, and warmer average winter temperatures due to a warmed climate. JC (2013) thought that it was also significant that BC Parks management responses after the USA's Yellowstone National Park fire in 1988 mirrored those of the US Forest Service, which had turned heel from the 1960s fire suppression-at-all-costs approach, to one being friendlier towards letting smaller more frequent fires burn out in parks naturally and thereby reducing the number of enormous and devastating fires. She asserted that this attitude likely led to some early decisions on the BC government's part to take a hands-off approach to managing the beetle outbreak. Another different metaphor, still, was DH's (2013) perspective that the highest density of mature, landscape-scale lodgepole pine in history presented a veritable “buffet” for the beetle to eat as it spread and multiplied across the landscape (DH, 2013).

LS (2014), one of the longest engaged mountain pine beetle researchers, emphasized the importance of previous research and some of the longer-term threads on this topic. He pointed to two key articles that shaped his views about how to understand the beetle, including the 1975 article by federal research scientists Shrimpton and Whitney, in which they first described the relationship between the lodgepole pine, the mountain pine beetle, and its associated blue-stain fungi. His emphasized that anyone building an understanding of the beetle and its various population states cannot divorce the beetle from its natural setting, or its relationships

with the host and attendant species. Overall, scientists described the mountain pine beetle in different and creative ways, reflective of the differences in approach, engagement, and understanding with the beetle.

4.1.3 Research Value and Motivations

Scientists expressed several motivations for undertaking their research, including the normative desire to undertake research for the benefit of society (CK, 2013; DH, 2013; JC, 2013), to develop a better understanding of the beetle (CK, 2013), and to understand the mechanisms of resistance to attack in trees that may be useful for future attacks by bark beetles, not even specific to the mountain pine beetle (AP4, 2013). Many expressed general motivations such as wanting to produce knowledge that extended what science currently knows about a particular organism, or the way that trees respond to insect attack; some expressed the hope that the knowledge they produce will help to plan better responses to such outbreaks in the future. Others asserted that more knowledge may aid in building understandings about the mediating role that the fungi MPB carry in their stomachs play for the beetle (eg. RH, 2013; JK, 2013), or how other forest insects may respond to climatic and other shifting environmental factors (eg. AC, 2013). For example, CK (2013) expressed “[W]hat we’ve been doing and continue to do in the mountain pine beetle provides some insight into what might happen in these other organisms,so mountain pine beetle’s quite unique because it has such a large range from Mexico all the way not to the Northwest Territories, and so it provides a good model for understanding these climatic changes and the influence on their behaviour and outbreak status.” He and several other scientists (AC, 2013; SL, 2013; AP3, 2013; DH, 2013; AP4, 2013) flagged that the mountain pine beetle is one of several forest insect species in Canada that have the potential for destructive outbreaks, including the emerald ash borer (*Agrilus planipennis*), the spruce budworm (*Choristoneura* sp.), and the spruce bark beetle (*Ips typographus*).

The majority of scientists (DH, 2013; KL, 2013; AP3, 2013; CK, 2013; AC, 2013, AP1, 2013, JC, 2013) asserted a generalized awareness that their work can beneficially contribute to society at large, and to understand nature better, whether the

knowledge produced helps to shape policy, or forest management practices, or has implications for forestry workers' jobs. AP2 (2013) expressed the desire to have his work actually matter to somebody, emphasizing that it should have an applied angle. Not all scientists thought this way, and instead, several made an argument for the value of basic research—research that doesn't necessarily have immediate application (DH, 2013). A short discussion of the tension scientists reported between government-directed applied and basic research is presented in Category 3 below.

The research motivations and expressed values of the scientists held across the sciences. While the majority of the science undertaken by participants was firmly rooted in the hard sciences, VN (2013) focused on social science based risk assessment. He expressed that it was valuable for all those involved in the MPB Risk Assessment actually to go through such an exercise, where participants took part in an extensive workshop that gathered the most up-to-date information on the beetle, its movement through the landscape to date, to develop a model that produced projections of the risk of the spread of the beetle into Alberta, north of the 60th parallel, and further east into jack pine territory. He expressed great value in bringing together colleagues to work together on such a collaborative assessment project, and thinks it helped influence lasting collegial relationships among the varied participants.

4.1.4 Research Responses to External Factors

The scientists interviewed for this study described or mentioned the importance of being able to adapt to complex scientific problems and the external factors that influence research responses. Participants were divided between four main groups of research leverage points: the lodgepole pine and jack pine (tree) components, the fungi components, the beetle and climate change components. Whether turning their research skills and learned tools to a new problem (RH, 2013; AP1, 2013; AP2, 2013; AP3, 2013; AP4, 2013), forging new relationships (JC, 2013; AC, 2013; KL, 2013) or persisting in finding avenues to fund their research (SL, 2013; AP3, 2013; DH, 2013)(discussed in Category 3 below), these scientists covered much of the relevant research undertaken. All of the scientists reflected on their roles in undertaking research on one aspect of the outbreak or another. In engaging with the rapid

ecological changes characteristic of the outbreak, the realities of recognizing climate change meant incorporating ideas of change into the scientists' perspectives, such that almost all of them now ask questions explicitly within the context of climate change. AC (2013), for example, stated "More and more and more, all the people that I work with, and myself included, realize that climate change is changing the rules. Any question being asked in the absence of climate change is not a good question."

Several participants described capitalizing on the research opportunity that the outbreak represented (described in Section 4.1.6 below). Several studied different insect species such as the warren root collar weevil (*Hylobius warreni*) and ticks (*Ixodes scapularis*) before changing gears to also study *Dendroctonus ponderosae* (SL, 2013; DH, 2013; AP2, 2013). They viewed their research toolkits and training as flexible enough to change species, and adapt the kinds of research questions they were asking. One scientist had studied other animal species in a completely different genera (AP3, 2013). Some others had no prior experience with animal or insect species, and took advantage of the funding opportunities to take on projects that were completely new for them. For them, they saw the outbreak as an opportunity to apply their skills to a different challenge. A few researchers studied different aspects of the outbreak: where before, CK (2013) had studied trees' responses to the beetles, during the outbreak he studied the beetle itself, and the beetle's pheromone biochemistry, for example, which he was very excited about. He expressed that this is what he was *really* interested in researching.

Overall, both in attitude and perspective, scientists expressed a willingness to be resourceful and put together the funding (in some cases, through much perseverance) to undertake the research that they thought was most necessary.

4.1.5 Consensus on the Historical Factors of the Outbreak

Scientists, regardless of institutional affiliation, when asked to identify the factors that influenced the shape of the most recent mountain pine beetle outbreak, converged on identifying roughly the same complex interacting factors that contributed to the characteristics of the most recent outbreak. Scientists also frequently referred to their own and colleagues' research papers that contributed to these findings.

The main factors that scientists identified included CK (2013), KL (2013), LS (2014) (RH, 2013), VN (2013), AP1 (2013, and JC (2013) commenting on historical fire suppression over the last century, which resulted in landscapes of dense, lodgepole pines (primary hosts for the beetle), though AP5 (2013) raised a question about the certainty of fire suppression, except for its role in specifically parks and park management. She, PB, and AP1 also pointed to large-scale fires that occurred in the late 1800s, and early half of the 20th Century, which resulted BC's forested landscape resulting in the establishment of large-scale lodgepole pine forests. Climate change, which enabled faster summer reproduction, lower over-wintering mortality, and a significant range expansion geographically, and higher in altitude and latitude, was also discussed by several participants (CK, 2013; AC, 2013; JK, 2013; KL, 2013; PB, 2013, RH, 2013, VN, 2013).

JC (2013) also identified forest management, including cut block in both size, and number, and forest regeneration practices that led to predominantly even-aged stands. PB (2013) and VN (2013) agreed about the relatively uniform age-class of trees being a significant factor. Relatedly, she also commented on the BC Parks management philosophy at the outset of the outbreak, which was influenced by the management of the Yellowstone fire, where US park managers took the attitude "Let nature take its course." This, she stated, was the philosophy that the government of BC adopted, and that the beetle should be left to do its thing in Tweedsmuir Provincial Park, one of the early outbreak epicentres, though she was sure to remind me of research that had shown that the beetle emerged from thousands of epicentres across the province, and not simply in one provincial park. JK (2013) also identified forest management in western North America more generally. SL also identified specific differences in tree populations: in northern and British Columbia, at the leading edge of where trees historically had not been attacked by beetles because colder climates kept them further south in latitude, the trees were not able to defend themselves as effectively from beetle attack, which enable beetle populations to reproduce more effectively. VN, JC, and LS also identified microclimatic differences that explained by the outbreak did *not* take off in the "pine basket" (JC, 2013) between Hinton and Canmore.

KL (2013), the only scientist in the participant group who identified a direct connection and past and ongoing collaboration with industry, spoke to some specific policy changes (eg. appurtenancy rules, which govern where loggers for specific mills and from certain communities can log their trees from) that BC's provincial government set regarding harvesting of wood post-outbreak, that did not end up contributing to an effective management response. She also pointed out that the US housing market crash (which had direct consequences for forestry communities in Canada because there was lower demand for certain types of wood products) coincided with the peak outbreak, when harvesting of beetle kill wood was high, and the Canadian dollar was high, which negatively affected lumber exports, so these factors strained some of the economic and social dimensions of Canada's experience of the outbreak. AP5 similarly highlighted key fires in the 1920s and 1930s in the Chilcotin area that, paired with a 'hands off' management attitude by Parks Canada in that area, resulted in record pure lodgepole pine stands in that area.

4.1.6 Climate Change

Scientists' views on the impact of climate change were varied. AC (2013) and DH (2013) identified climate change as decreasing the capacity for predicting the future in the context of forestry and beetle outbreaks. AC also asserted that climate change adds a layer of uniform stress on ecological systems. AC was also primarily the scientists behind the research that showed the connection of climate change to range expansion to areas that were more habitat suitable for it (in warmer winter climates). Similarly, several scientists, such as AP3 (2013), CK (2013), DH (2013), AP5 (2013) SL (2013) and JK (2013) identified that climate change has resulted in fewer colder winters to kill off beetle populations, which alters the over-wintering survivorship of the beetles. Further, CK, KL and AP5 discussed the importance of phenological timing and that climate change may now disrupt species' interactions that had previously been in sync. They expressed some concern that it's possible that beetles and other defoliator insects may be more effective in their attacks if trees cannot kick their defences in at the right timing. DH mirrored this reasoning with a different example of whitebark pine in Montana: previously, these trees had established in high altitude,

cold climates, but with a warmer climate, the trees' defence physiology may be impacted, and they may be much more susceptible to beetle attack that way.

Both LS (2014) and KL (2013) identified that there were key differences in studies they had done or were aware of, that pointed out that northern populations (genetically distinct) of MPB were historically climate limited, while this was not the case with southern populations. As KL described: "We learned that you can't apply knowledge necessarily from what we learned in the south, in the beetle's range there, to what we know in the North. There is a difference in what the beetle is doing in the North, because it's under different kinds of impacts from environmental factors" (such as climate change). And, as AP3 (2013) pointed out, it was the northern populations that exhibited the aggressive range expansion, not southern populations.

AP3 was also excited to work on modelling genetic data in North America to examine whether other factors were involved in determining the outbreak, or whether climate change isn't simply expressed as *temperature* change. Instead, climate change may have notable impacts on water and moisture in a given ecosystem. AP3 also expressed hope that climate change will be a larger lesson to those who expect things to stay the same, and will prompt planning for environmental change.

AP2's comments differed slightly from his colleagues. While acknowledging that global climate change was negative, and would have negative consequences for some countries (eg. desertification), he made a general point about the importance of researching how Canada may benefit from climate change, which he understood was a deeply unpopular stance among his colleagues. He made a general comment about his perspective on the ineffectiveness of the Rio Summit, and that perhaps more effort should be put into helping countries adapt to the impacts of climate change. In the meantime, Canada can research some of the positive effects of global climate change.

Citing some of his historical research examining the international contribution of CO₂ emissions due to forest disturbances such as fire and MPB outbreaks in Canada, AP1 (2013) commented that he was keyed into large-scale disturbance regimes occurring in Canada. On top of his research into the significant emissions contributions that the recent outbreak resulted in, AP1 echoed comments by other scientists about the behavioural differences a warmed climate had resulted in for the

mountain pine beetle: the increased rate of fecundity during summer, the increased over-wintering survivorship, and the significant range expansion towards eastern Canada. Overall, he identified that it has become increasingly clear that climate change shapes “the very foundation of concepts and forests, forestry, and in science more broadly,” and accordingly, research questions are changing. Scientists such as AC (2013), KL (2013), and AP3 made similar comments.

4.1.7 Research Opportunity in the Outbreak

Several scientists commented on the opportunity for research that the mountain pine beetle outbreak represented. Some sought to pursue the research style they were interested in (CK, 2013), to ask research questions they’d never asked before (AC, 2013; JK, 2013), or to try a new process (VN, 2013). The theme of opportunity surfaced repeatedly. For some the opportunity was in new collaborations that could be made across institutions, such as with the TRIA Network (JC, 2013; AC, 2013; KL, 2013, DH, 2013; AP3, 2013), while for others the opportunity was to study a beetle in the wild that is very difficult, or near impossible, to study in a laboratory (AP4, 2013; AP5, 2013).

For CK (2013), it was a chance to pursue a particular style of research: “I saw this as a really good opportunity to get my foot in the door into the research style I’d like to pursue in the future, because this is sort of what I had always intended to work on...” PB (2013) also saw the outbreak as an “opportunity to ... extend and apply my own research interests in a practical manner.”

SL (2013) and VN (2013) both emphasized that the outbreak represented an opportunity to undertake research that otherwise wouldn’t have happened. As SL (2013) stated: “[The outbreak’s] certainly given us opportunities to do research that we couldn’t have done otherwise.” VN (2013) also stressed that the high profile of the outbreak in the media resulted in influence at political levels, such that the risk assessment he was a major part of, could take place. In his words: “I think the magnitude of the problem, and the novelty of it, and the high profile of it at the political level enabled some things that otherwise wouldn’t have happened, which hopefully are good changes. And this application of risk management, a formal risk

assessment, and taking [federal government] scientists through that formal exercise, is one example of it.” The value of undertaking the exercise of the risk assessment with federal government scientists produced the projections of risk the beetles movement through the boreal forests represented, and, as he emphasized, helped to build relationships that lasted beyond the risk assessment exercise.

DH (2013), who took on a Canada Research Council Chair in Forest Entomology and Chemical Ecology stated: “... I knew I would be working on something like that—mountain pine beetle obviously presented a major opportunity to learn something new about an interesting creature that had, you know, some very amazing biological attributes, but also hopefully to be able to provide some ... input into management decisions and policy-making decisions...” As mentioned earlier, DH was not the only scientist to assert the motivations for his research as being conducted to influence management and policy.

4.1.8 Research that fell to the wayside

Three scientists who had conducted research in the 1980s asserted that there were few links between past research from the outbreak in the 1980s and research conducted with the current outbreak (KL, 2013; PB, 2013; SL, 2013). PB seemed to view that kind of work as central to what the role of government is. Establishing a longitudinal view of research is difficult, especially without institutional or research support to do so.

KL and SL (2013) expressed frustration about the lack of continuity between information produced during different outbreaks. KL cited research ideas from forest companies in the 1980s that would have delivered information about the shelf life of beetle-killed trees and the length of time that trees could still be harvested after death. She undertook that research during the mid-2000s herself, because she saw it as extremely important and timely, given the millions of hectares of dead trees in this outbreak, and the economic value of those trees. However, she expressed frustration that while people were talking about that research in the 1980s outbreak, no one actually undertook that research, or thought ahead that knowing that information

would be useful for future outbreaks, such as this one. Her criticism spoke to a more general point about the lack of long-term data management and response strategy:

“That [the previous outbreak] would have been a really good time to start establishing some permanent sample plots, for example, and being able to monitor those over time, so that we’d have better data available when the next big one hit, and then, as far as I know, nothing was done. And so it’s frustrating that... it takes a crisis to cause some change, but we still don’t seem to get there and, I know that dollars are scarce, and they have to be invested in areas of greatest need, and all that kind of stuff, but we just don’t seem to have any kind of a long term strategy, that in the end may actually be economically beneficial. So that was a bit of a frustration.”

SL similarly expressed: “Even in the cycles that we had, where you had 10 to 20 years between an outbreak, the industrial knowledge essentially got wiped out between each cycle, because the people that were really keen and interested and learned things, they would invariably move up in the food chain, within industry, move to other positions, and they would no longer be where they could apply that knowledge.” The failure to have a long-term maintenance, transferral, and application of mountain pine beetle research is a point that several scientists made (KL, 2013; PB, 2013; SL, 2013).

4.2 Category 2: Scientists’ Institutional Settings

This theme presents comments scientists made specific to their institutional cultures and settings, and their influence on scientific knowledge production. This theme discusses both positive factors that scientists mentioned, as well as areas of challenge and concern. This category tries to focus on some of the instances where it was clear that working in different organizations (universities vs. federal government research centres) made a difference for their work. What also became evident with the interviews is that there have been some institutional changes for scientists during the MPB outbreak. For example, a scientist who may have worked for years for the federal government was let go or left, and joined an academic institution instead.

4.2.1 Academic and Government Scientist Institutional Cultures

As several academic scientists expressed, the reality for many of them, especially those with early careers in the making, is that they are assessed by the standards of their institutional cultures for their work, which is mostly in publications, ability to garner funding (which also enables further research and publications), and in some cases, their mentorship and research extension through graduate students (AC, 2013; SL, 2013; DH, 2013). In contrast, as a senior government scientist, AP1 (2013), described, the opportunity to have the freedom of taking on any project that they wanted, which led them to look at carbon budget implications regarding the mountain pine beetle outbreak, or in another case, one senior scientist who led a group of others through a risk assessment exercise (VN, 2013). So there are some institutional differences among the scientists, though not significant ones, as the more senior, tenured professors have similar freedoms for undertaking research as long as they are able to obtain or maintain funding for their projects.

Added to assertions for the need to publish, was the acknowledgement by several of the senior scientists that they have a drawer full of unwritten papers from previous research over the years. Time was a limiting factor for all the potential papers and write-ups that they could start tomorrow. Two of the more senior scientists, nearing retirement, daydreamed about having an assistant to help write up all the papers that they have not had the time to complete, especially before they retire; it would be shame to leave all the work unshared, but they stated they were unable to get to it on their own under present circumstances (AP1, 2013; VN, 2013).

Several academic scientists (AC, 2013; DH, 2013) mentioned their appreciation in being able to extend the reach of their research (the number and area of their research questions) through the graduate students whom they supervise. The graduate students, under their supervision, are able to explore ideas and then co-publish that research with the scientist in question, which facilitates more scientific knowledge production than the scientist would otherwise be able to do on their own.

Similarly, two federal research scientists (VN, 2013; AP1, 2013) mentioned that they no longer conduct primary, field-based, empirical research any more, as they are the most senior level of five levels that one can reach in the federal public research

service. Instead, they supervise, collaborate, and direct the more junior researchers under them, which enabled them to synthesize research, undertake cross-case examinations, and overall focus on doing research that is different in nature than their previous field or empirical work.

One aspect of institutional culture that academic scientists also mentioned was the ability (and work expectation) to attend conferences where they presented on their research, and had the opportunity to meet with other colleagues, discuss research more informally, and hear about other research in progress and that is at the edge of scientific knowledge; because of the lag time between research produced and research published, the conferences offer a beneficial intermediary step in accessing emerging research. This kind of institutionally supported professional networking is separate from the TRIA Network and other new relationships that have been emergent during the mountain pine beetle outbreak.

4.2.2 Cultural and Institutional Challenges: Scientists vs. Politics

Scientists made numerous comments identifying troublesome characteristics about the context of government scientists working in Canada currently. A significant number of the participants made reference to the growing climate of the federal government controlling science and its scientists in Canada, whether through funding, or by limiting what scientists were able to say or report from their research, and with whom that information was shared. One government scientist outlined a series of cuts that had happened to their division of government, such that the group of colleagues they had to work with were reduced by a third, and overall, this scientist described the climate as very discouraging, frustrating, and disheartening. It was mainly when we discussed this participant's research, that the scientist became animated anew. Their research was important and motivating for them, still.

In particular, when discussing the scientific motivations for undertaking their research, it was clear that the majority of the scientists were driven by a desire to contribute positively to society and its betterment, as was discussed in Theme 4.1.3 above. Another of the most senior government scientists in my participant group also

reflected that they had never before seeing this much centralized government control over what scientists were able to say or report out, and added that in their view, this was unnecessary.

Boundaries between the groups of scientists were not set in stone; several of my participants had previously worked for the federal government, but no longer did. As in the case of one scientist, cuts to funding meant that their research position and unit in the federal government no longer existed; it was high profile enough that the media reported on specifically this scientist's cessation of employment.

Non-government scientists made reference to the chilled research climate, and several funding cutbacks that had influenced some of their own decisions to leave positions in the public service. Two scientists made only limited reference to their previous positions on the federal payroll, and one scientist was very outspoken about the pattern of funding cuts that eliminated their research unit, and they discussed not only their transition into an academic position at an academic institution in British Columbia, but how another scientist (a colleague) had relocated their research laboratory to a different country because the federal government "shut down the CFS node....[and the colleague] essentially got tired of government bureaucracy... It was our loss. Brilliant guy."

In another case, an academic scientist strongly warned me to understand that government scientists are being co-opted by the federal government, by either being muzzled directly, or told not to speak about their research to the media or others. Because of this, those government scientists really need to watch what they say. They need to be very guarded, this participant asserted, because if they say the wrong thing they risk losing their jobs. This participant mentioned a government scientist that I had actively tried to recruit for this project, but was not able to. This participant reflected that it was not a good thing that the federal government was not open to hearing someone point out that the emperor has no clothes on, which he saw as one of the core things that scientists are supposed to do. He asserted that there was an open policy for government scientists to conduct research in support of policy, as opposed to research that informs policy, a change, which this scientist stressed, is a subtle, but very important one.

One participant mentioned developing a working relationship with federal government scientists in order to maintain at least some form of knowledge exchange of the research and the work that was being undertaken in government, in case the government scientists were not able to report on their research findings publicly. This participant also mentioned that the findings of the research could then be reported, even if no credit was given to the federal government scientists that were left off the reporting to avoid trouble or complication from their organization. There is benefit to bridging organizational boundaries anyways, as the scientist acknowledged, but to have the comment explicitly made that such alliances were forged out of necessity is troubling.

Prior to the beginning of one interview, one scientist needed to clarify my intent for undertaking the project, and wanted to ensure that there was no underlying political motivation for my research. As this scientist stated: "I'm less interested in sharing my views for those kinds of veins... not because I don't think that they're not important, but what happens is that you put your views out there and if they are in a political context, they can be misconstrued. And one of my goals in leading [this scientific enterprise] is to maintain objectivity as much as possible." This scientist elaborated, "...I support science, I support management... but I don't support a political viewpoint. I don't...advocate, because that might be portrayed as advocating on behalf of a larger group, and don't think that's my position." As one of several reflections on the perceived role of scientists that appeared throughout the interviews, this comment reveals another aspect of tension between politics and science.

4.3 Category 3: Scientific Research Funding

This category presents scientist's assertions about the importance of funding regarding the mountain pine beetle outbreak, with special focus on the enabling and disabling roles that funding played for their research. There were a variety of ways in which funding was discussed as either an enabling factor for undertaking research, or the lack of obtaining funding by researchers stifled their ability to undertake work they thought was important.

4.3.1 Funding—Mediating and Enabling

Scientists were quite united about their assertions that funding influences their ability to undertake research. Sometimes, funding means affording lab tests such as those that produced the genomic information that enabled scientists to put together the transcriptome of the beetle; other times it is to enable an academic scientist to fund graduate students or research assistants that help with their work. Sometimes the funding goes towards field equipment and field supplies that enable on-the-ground data gathering. In any case, the importance of funding was discussed by almost all scientists. As many of the scientists discussed, it is also one matter to obtain funding, and another to not receive any. Scientist's comments about the disabling role of funding are covered in the next theme.

There did seem to be some variation among institutional influence of funding for scientists. The academic scientists spent much more time discussing the influence of funding on their work than did the governmental scientists, who are salaried public servants and have differently defined research budgets. None of the governmental scientists from the PFC or provincial government spoke of the positive factors of receiving funding.

In contrast, it was an academic scientist who discussed the benefit of actively lobbying provincial politicians for funding during the ramping of the outbreak. AC (2013) anecdotally discussed appealing directly to several of BC's Members of the Legislative Assembly (MLAs), describing the importance of opening up funding to undertake research on the mountain pine beetle at the onset of the outbreak; he also recalled his thrill about influencing the discussion: how exciting it was to hear the politicians repeat his words—it indicated that they understood the problem MPB posed, and why it was important to make funding available. He credits this direct action with opening up some of the monies that he and other scientists received. His was some of the first and earliest work making the climate change attribution connections in 2003. He retooled to be able to work with climate models to deliver projections around the changing habitat suitability of the landscape for the mountain pine beetle.

Few other scientists highlighted the chicken-and-egg nature of lobbying for more resources, as opposed to submitting for the grants when the funding was made available. It was, however, much more common for scientists to characterize that the outbreak was an opportunity to tap into funding made available by numerous governments (provincial and federal) and organizations so that they could ask pressing research questions, some of which were practically motivated, some of which were altruistically motivated, and some of which were curiosity driven. The Mountain Pine Beetle Initiative (MPBI) was identified as one of the major sources of funding for several scientists. MPBI was set up by the federal government in 2002 with a \$40 million budget. Its aim was to structure and fund research deemed necessary to address and help respond to the outbreak, and reduce the risk of future outbreaks, and comprised three main components: the Mountain Pine Beetle Epidemic Risk Reduction and Value Capture Research and Development component; the Federal Forestlands Rehabilitations Program; and the Private Forestlands Rehabilitation Program (Wilson, 2002).

It seems that research funds were awarded when applications could demonstrate accord with wider political concerns and the timeliness of these ahistorical outbreak features. Indeed, the *timing* of the research undertaken, or of a particular scientist's entry into the MPB research greatly influenced their geographic focus. Many of the scientists I interviewed began research well into the outbreak (2005 onwards), as the realization about the seriousness and scale of the outbreak became widely apparent, including in political circles and in the media. With the significant range expansion of the beetle, it is clear that the focus and attention of researchers followed the expanding frontier of MPB, into Alberta, across the Rocky Mountains, and into the boreal forest, as described in Section 4.9.3 below. Funding monies were made available with the expanding progression of the beetle on the landscape, and the majority of scientists focused on the beetle's new frontier.

For several of the scientists interviewed for this project, such as those undertaking research with the TRIA network, the success of pursuing research funds could not have been predicted beforehand — as JC (2013) highlighted, no one could have foreseen the provincial government approaching researchers to get involved and to try

to find new perspectives on how to understand the mountain pine beetle. JC (2013) made the only explicit comments in reference to being approached by the Province of Alberta to work together to address the beetle, but did not elaborate further. She indicated emerging partnerships initiated by and with government, and at the time of the interview mentioned that by the time any of this research project's findings would be reported, the announcements of funding would be public. Since then, the TRIA Network has announced a \$3 million award to further the research the Network began in 2007 (Robertson, 2014; Huber, Murray & Kellett, 2014). The TRIA Network has since established itself as the leading research consortium on the mountain pine beetle, with partnerships between industry, government, academic research institutions, and non-governmental organizations (Robertson, 2014). As reiterated in the media statement from the January 2014 announcement, JC indicates that the research is meant both to counter the spread of the beetle to new areas during the continuing progression of the current outbreak, and address the next outbreak that emerges (Robertson, 2014). The TRIA Network ties together researchers from different backgrounds, institutions, focuses, etc., engaging with the main components of the outbreak (the beetle, the trees, the fungi, climate, and related economic dimensions) to propel research. Notably, TRIA connects researchers in Alberta and British Columbia, with JC and another scientist, the University of British Columbia's Dr. Joerg Bohlmann, at the head of the organization. Dr. Bohlmann was invited to participate in this study, but due to timing and schedule conflicts, was not able to accept the invitation.

Over the current outbreak, TRIA successfully secured three rounds of major funding from Genome Alberta, Genome BC, and Genome Canada, and then NSERC, the most recent funding of which is currently supporting their third research phase. This has, as JC asserted, enabled TRIA to become a national research network. DH (2013) expressed both excitement and gratitude about the funding, in that it not only meant that TRIA's research questions could be pursued, but the funding facilitated the expansion of a research network and has produced significant information to date. Correspondingly, a visit to the TRIA website (tria-net.srv.ualberta.ca) shows at least 70+ publications since its inception in 2007, ranging from the discovery of a single

nucleotide polymorphism (SNP) which is responsible for certain types of genetic variations, in a fungi symbiotically associated with the mountain pine beetle, to characterizing the physical and genetic structures of lodgepole and jack pine hybrid zones in Alberta. DH also explained that he was able to expand the number of colleagues that he worked with; he went from collaborating with a small group to a much bigger group, and this was a positive because he knew the boundaries of his own expertise. By collaborating with more people, he could fill in the holes of his own capabilities and find those with work skills very complementary to his own.

TRIA brings together scientists from a variety of institutions. Media statements can now be found about the funding that TRIA was awarded (Eg. <https://uofa.ualberta.ca/science/science-news/2014/january/pinebeetle>). DH (2013) also spoke of the research capacity that opened up and was enabled with the continuation to receive funding for this strategic network. It is apparent that when I conducted my interviews, TRIA was growing in importance, and examining the researchers involved in the Network through their affiliations and collaborative publications, indicates that this organization was central to moving MPB research forward.

From the comments of many of the academic researchers, it is clear that the award of funding increased their capacity to do research, whether that meant supplies, or people power. AC (2013) and AP3 (2013) described being able to be in academic positions with funding that enabled the kind of research they thought was necessary and important, and that opened up access to graduate students, who extend their own research capabilities (AC, 2013; AP3 2013; PB 2013). While it is clear that there is some institutional difference in the influence of the positive role of funding for research among this study's participants, generally speaking, it was clear that money was needed to run tests, supply field crews, sequence genomes, and facilitate relationship-building.

4.3.2 Funding—Mediating and Disabling

Scientists across all institutions except the federal government mentioned the negative impact of funding on their work, though particularly academic scientists. As

professionals, they are rewarded for undertaking research that is timely, prescient, and that pushed the boundaries of knowledge; academic scientists apply for and receive funding that can be demonstrably *current* and interesting. Approximately one quarter of my participants undertook research during the previous outbreak (1980s), in part due to where they are in their careers as researchers and in part due to their senior experience, but there was less direct engagement with questions about long-term research regarding the mountain pine beetle than I had first thought. Of the participants that have the longer term engagement, they commented on the noticeable absence and decrease in research (both monies available for and actual production of) between the end of the 1980s outbreak, and the beginning of this most recent outbreak in the late 1990s. Two scientists (KL, 2013; PB, 2013) attributed this in no small part of this to what they characterized as the crisis-response attitude towards funding research by government. Further, KL (2013) was very critical of what she perceived to be a lack of a long-term strategic plan for research funding in Canada. Instead, she sees that various levels of government run through cycles of responding to crisis after crisis, regularly saying that funding needs to change, and forest practices need to change, but after the excitement of an outbreak dies down, then “we kind of go back to doing things like we’ve always done them, and you forget about the need to diversity our economies so that we’re not so heavily dependent on pine to make 2x4s” (KL 2013). KL expressed hope on behalf of herself and other colleagues, that the scale and intensity of this outbreak would change government and resource management’s responses, but that it does not seem like that will help. Her comment addressed both the crisis-like response as well as the institutional legacy of approach to such a problem, and the shift in management she would like to see in the future. Several other scientists made similar comments, criticizing the fact that it has become much more difficult to plan longer-term research projects due to funding constraints (PB, 2013; DH, 2013). A few of the scientists characterized this shift in funding as one that disables basic research, and requires research to have a more applied focus. For example, after discussing the funding his own projects on the mountain pine beetle has received, DH (2013) expressed concern about the trend for funding’s influence on the type of research that can be undertaken:

“I think there is a spot for applied, very applied research, but I sometimes worry when a lot of the government funding agencies are pushing this applied agenda to what I sometimes worry, is to the detriment of basic research, so the basic research ends up being sort of off the side of your desk, type of stuff, or, basic research within the larger construct of applied research as well. Again, not to say that applied research is bad, in fact I think we need a lot of it, I mean any, any medicine that you or I take, you know, is the result of applied research, obviously, but that, that applied research only happened on the foundation of basic research prior to that, if you’re taking I don’t know, let’s just say because it’s summertime here and I sometimes take an antihistamine, but [...] the only way to know what to produce that little pill and have done the research to produce it, is to know how the body is reacting to pollen, and that’s very basic research to allergens in general, so, if we’re not also promoting this foundation of basic research, we’re never going to, we’re going to run out of, I think basic research is like the fuel for applied research. And so that’s where I would, I guess, funding these days worries me a little bit, that it tends towards more applied things, and to the neglect of basic questions.”

DH was far from alone in identifying a worrying trend to place more restrictions and boundaries on funding, and funnelling applications into pre-determined themes for awards and grants. AP2 (2013) asserted that his general philosophy was that it was very important to invest in a lot of basic research because it is basic research that has a high likelihood of being applied when you set out to apply your research. He warned that setting out to apply research from the beginning meant that oftentimes researchers constrain their thinking too much.

Several scientists described not being able to undertake a given project because of a lack of funding (PB, 2013; SL, 2013; AP3, 2013), especially during the earlier years of the outbreak when it was still ramping up, and when it was unclear how sizeable the outbreak would be. As SL (2013) describes, at the time he and colleagues were working on beetle population dynamics, their movement and dispersal rates. They had been trying to get funding for about five or six years, including under the Mountain Pine Beetle Initiative, and had not been successful. As he states: “[M]y suspicion is that there’s politics involved because what we were looking at was to see

whether we could show where the beetles that went over the Rockies, where they came from, and that's probably politically sensitive because then it's black on white that yeah, they are British Columbia beetles that came over to Alberta and the other thing is that probably because a lot of the framework of the Mountain Pine Beetle Initiative was supplied and was directed by industry, and because we were doing molecular genetics, they just weren't interested. I get the sense that they just thought that was just bunch of crap." In contrast to SL's statement, DH (2013) also described struggling to put together research applications for a graduate student's work on a different tree insect that also negatively impacted lodgepole pine, because "no one's interested in it."

Overall, few scientists had the longitudinal research histories with the beetle that I had at first been searching for. Of the 16 participants that I recruited, only four researchers had undertaken research during the previous outbreak. Part of this is generational (some researchers are close to retiring, and others are closer to the beginnings of seriously establishing their research careers), but part of this is also institutionally influenced (LS, 2014; EC, 2013; AC, 2013; KL, 2013). Given the progression of the outbreak, however, there are very real temporal consequences linked to the progression of the outbreak. As outlined above, the *time* during which researchers joined in the research effort, paired with their institutional support for doing so, was crucial: post-peak of the outbreak, when I was undertaking my interviews for this thesis in the fall of 2013 and spring of 2014, one of the academic researchers had already had to change their research focus based on the lack of funding and tenure-track position despite their prolific research output during the outbreak. In his own words (CK, 2013):

"On a personal level, I came back to Canada from my first post-doc hoping that within a couple more years I would get a faculty position, and when we started talking about writing a proposal for the TRIA Project, I think, in 2006, I saw this as a really good opportunity to get my foot in the door into the research style I'd like to pursue in the future, because this is sort of what I had always intended to work on: pheromone biochemistry at the genomic level, like in bark beetles, and so I was hoping that in the process of the TRIA Project, I would be able

to obtain a faculty position where I could continue working on this, and, and the resources that was available in the TRIA Project would allow me to get a really good head start in my career, but unfortunately I have not yet got a faculty position and now the project is over, so, it's a little bit, 'Kay, what am I gonna do next?'"

PB (2013) also commented on the lack of continuity of funding and subsequent struggle to undertake long-term research projects. Generally, he asserted that funding cycles are very important for the length that academic scientists can undertake projects for. He discussed using some of his personal salary to fund a long-term (20+ year) monitoring of forest stand development post-beetle outbreak (from the 80s outbreak) because he sees the value of the long-term comparative lens that one can only get from such a study. He thought it was important enough to put his personal funds towards such a study, because he was unable to garner funding for the study from federal research grants. It is extremely rare for scientists to obtain funding for projects that take a longer-term view. As SL (2013) pointed out, this is particularly detrimental in the case of mountain pine beetle research, when some of the most valuable knowledge could potentially be figured out during the quieter phases of the outbreak, such as what factors contribute to the beetle changing population phases (though most importantly, as LS (2014) asked: What triggers beetles into epidemic outbreak phases?)? The answers to this question can likely only be discovered through empirical field monitoring and trials with beetles in the wild, and not, as LS (2014) and AP2 (2013) pointed out, in a laboratory setting.

As a general comment, JC (2013) also had this to contribute, regarding the general challenges of funding, being a scientist, and having to respond to various pressures: "We've been told make ourselves relevant as scientists. Make ourselves relevant; you have to do something useful. And that's been a challenge. It's been a real challenge to meet the peer pressure of this is what scientists expect scientists to do, meet the pressures of funding agencies; this is what they expect us to do and, potential partners—this is what they want to receive, and oftentimes they're incongruent expectations." She did, however, explain further that new tools, technologies, increases in computational capacities, new mathematical and statistical methods, and advances in genomics make it possible to address some of these variable pressures, and expressed

some optimism about how these advances enable her to undertake broader scale collaborative work as a scientist.

4.3.3 Tenuous Connections

A few scientists identified their relationship with policy- and decision-makers more generally alongside the connection to funding. AC (2013) described how he lobbied politicians directly with the evidence of the startling negative economic impacts of the outbreak in British Columbia, to illustrate the need to make available more funding to research various dimensions of the outbreak. For a while, his actions and efforts seemed to make a difference, and he expressed excitement about the fact that various politicians were talking about the outbreak using the same words that he'd spoken to them with. AC (2013) was one of few scientists that explicitly mentioned a direct interaction with policy folks (aside from JC (2013), who described being solicited by the provincial government of Alberta to collaborate on the MPB issue, as discussed earlier); however, DH (2013) also pointed out that there was an unprecedented coordination of funding and support among several western Canadian provinces such that the provincial government of Saskatchewan contributed money to the Alberta provincial government to pre-emptively aid the mountain pine beetle response; according to some of the most severe projections at the time, the beetle was anticipated to spread east across the boreal, which would have negatively affected Saskatchewan's timber supplies. The Canadian Press (2011; 2012) announced that Province of Saskatchewan was spending almost \$1 million on various efforts regarding the mountain pine beetle, including stopping its spread eastward in Alberta, detection and monitoring, and removal of trees. As reported, the Saskatchewan Environment Minister Ken Cheveldayoff pointed out that jack pine comprises 40% of the province's harvested softwood timber, and the province's forest industry accounts for more than 2600 direct jobs and \$400 million in sales. DH (2013) acknowledged that while Saskatchewan's forest industry is smaller than British Columbia, and that overall the impact would be lesser than what it was in BC, the negative impact would likely still be significant.

SL (2013) expressed disappointment about the federal government having cut funding and shut down the Canadian Forest Service node that had existed at UNBC.

After having mentioned the loss of one bright colleague who moved his laboratory to the USA after being at UNBC for less than 4 years, and that UNBC *would* have one of the “strongest research teams on bark beetles in Canada, if not North America,” he smiled sadly and stated that the funding for forestry-related projects has dried up, apart from the Mountain Pine Beetle Initiative funding (which is now finished). He also mentioned that he thought the 2008 financial crisis caused financial difficulties for governments all over the place, and since then there has been little funding, with the exception of very targeted programs like the Province of BC’s Future Forests Initiative. While he sees advantages to such a program, he characterized it as putting the cart before the horse, because it sets out specific criteria and then the collaborators for those projects need to come together, which they wouldn’t have otherwise done. He did not think it was the best way to build productive interdisciplinary relationships. Instead, he imagines them taking place more organically, with people already interested in similar things, and not being directed to do so. He himself no longer conducts mountain pine beetle related research, and has gone on to do work with a different focus.

The BC provincial scientist (AP4, 2014) also expressed a great deal of sadness, frustration, and hopelessness about having seen their research team reduced by a third; he expressed that it was more than having their research capacity diminished: the loss of skill, training, and expertise was significant, and the overall message that this sent for the value of the research team had a very negative impact on the psychological toll of this participant. They expressed quite a bit of cynicism. They also commented on the wider negative cultural impact of working in such an environment, where fewer staff were supposed to achieve the same amount of work as before, and the impossibility of the task set for them. This point was also discussed further in Theme 4.3.2 above.

PB (2013) also had a few words to say on what he thought the governments and their economic priorities: “From the [federal] government level where again we should be taking this long-term sustainability perspective, instead we have governments that are saying, you know, our economic agenda is to grow jobs and prosperity and not talking about quality of life or the conservation of biodiversity or the sustainability of jobs 10 years out. So, I’m very pessimistic about the current role of

science in policy-making. There needs to be more, and it needs to be more objective rather than just accepting that which coincides with the preconceived notion of, you know, what needs to be done. I mean for heaven's sake, in Ottawa we have ministers who don't believe in evolution, so you know, the role of science around that cabinet table is almost laughable." Here, PB was referring to Gary Goodyear, the Minister of State for Science and Technology under the Conservative government from 2008-2013, who was not re-elected in the October 2015 federal election.

None of the federal government researchers spoke about limiting factors when it came to funding.

4.3.4 Other Specific Funding Challenges

A general sentiment about the ineffectiveness of the "apply-for-a-grant, receive grant, spend grant, rinse-repeat" system of funding academic research was voiced by several participants (DH, 2013; PB, 2013; JC, 2013; KL, 2013; JK, 2013). Importantly, these scientists also identified this as an institutional cultural issue, and an idea that they had encountered and discussed with numerous colleagues. However, it bears mentioning that academic scientists saw this cycle as an ineffective use of their time, especially since time and lacking time was identified as another factor that posed a challenge to conducting their work. DH (2013) exclaimed, "You don't know how much time it takes to write one of these NSERC Discovery Grants—a ton of time!" Relatedly, JC (2013) specifically identified the challenge of not being able to carry funds over after the agreement for their disbursement passed.

One scientist (PB, 2013) proposed the solution of offering a minimum stipend to all scientists employed at research institutions as a base level of research funding, with higher amounts of funding to be applied for, and undergoing the rigour of peer-review for more ambitious projects. PB argued that there is much utility in low-budget, low-risk projects, and having funding available to set up longer-term monitoring projects that otherwise could not be accomplished under short-term budget funding periods. As a slightly different suggestion, DH (2013) also proposed (though this is not his own idea) that granting agencies look at an academic institution's number of active researchers, and rely on the university's own promotion and tenure system to award

funding, according to professorial rank. As long as researchers are doing good research, they should be awarded funding in accordance with those efforts. In whichever way funding cycles or systems would be revised, enabling funds to facilitate long-term research was a revision proposed by several academic scientists, including PB (2013), KL (2013), and DH (2013). JK (2013) also remarked that the capacity (especially funding) to undertake longer-term funding is very important.

4.4 Category 4: Ecological Novelty and Novel Ecosystems

This theme presents scientists' views as they pertain to novel ecosystems, and ecological novelty (generally) as they arose throughout the interviews. Starting with immediate responses to the novel ecosystems concept during the interviews, this theme reports on other tangible responses to the novel characteristics of the MPB outbreak, uses of language like novel habitat the geographic sites of research addressing the landscape scale of the outbreak, and perspectives of the future trajectory of the mountain pine beetle.

4.4.1 The Novel Ecosystems Concept: Engagement and Definition(s)

Seven scientists (AP2, 2013; AP5, 2013; VN, 2013; PB, 2013; JK, 2013; RH, 2013; SL, 2013) had some familiarity with what they discussed as novel ecosystems. Both AP2 and AP5 referenced paleoecological and pleistocene ecology ideas that classed novel ecosystems as novel based on the species assemblages found there. Both asserted that taking a long-term view of landscapes mean observing that there have always been historical fluctuations of species' geographies and locations. AP2 was particularly enthusiastic about the concept, and stated that it was part of the reason he enjoyed the Prairies so much: there are many different ecosystem types, and intermingling and mixing species assemblages there. Further into the discussion it emerged that AP2 had not engaged with the recent academic papers that had worked to expand the concept and provide contemporary examples and context. He very much understood, however, that some people would object to the concept. He asserted that many people are

invested in stasis, and that they do not like being challenged to change or adapt with time, especially if they have invested in certain skills, or a particular sort of self-identity, so this does not position them well to deal with concepts of continual change or novelty. AP5 was not sure if coining the term novel ecosystem was something that has recently been pushed forward because of climate change or not.

AP5 (2013) believed that at her research sites in British Columbia she was seeing an ecosystem shift from a tree-dominated to shrub-dominated ecosystem, triggered by the mountain pine beetle killing a specific tree species, and viewed that shift as generative of a novel ecosystem. AP5, DN (2013), and PB (2013) expressed an expectation that there would likely be a rising incidence of these kinds of ecosystem shifts in the future. Further, PB (2013) asserted that most ecologists, himself included, did not believe in the idea of a very prescribed or easily defined species' assemblages comprising a specific, replicable ecosystem. His expectations for ecosystems are that species sort themselves more or less independently, interacting with each other, and that there will of course, be new assemblages.

JK (2013) also had a fairly high familiarity with the novel ecosystems concept and recent literature, even citing the "no analogue" alternate term for the concept in the context of reclamation and restoration work she had been doing in areas after oil sands mining. At the time of the interview she was still actively building an idea of how to think through naming something a novel ecosystem or not because of implications she saw with such a name. She wanted to ensure that in naming something a novel ecosystem, it still fit under some existing policy or regulation, and that interest in engaging with the relevant policy or regulation would remain. Her main concern—one shared by VN (2013)—is that calling something a novel ecosystem would give people grounds not to attempt to restore a particular site. This is where she was worried that it would lead to a misuse of the term, and she did not want people to have an excuse to either not do any reclamation or restoration, and/or to go ahead and do damage, and call it a novel ecosystem.

Discussing novel ecosystems with VN prompted a series of thoughtful questions for him. Still speaking in general terms, he asserted that one of the characteristics of human civilization is its propensity to create novel ecosystems.

Further, he asserted that it is overdue that we pay more attention to them, that we analyze what ecosystem services we both do and do not want, and how we evaluate them. He questioned the stability of novel ecosystems, and how they would be measured or how researchers would identify functional relationships that either threaten or enhance a system's stability. He questioned whether it was a good thing to try to hold ecosystems in stasis for as long as possible, referencing the forest succession initiator of fire: "Who would've think that putting out fires in lodgepole pine, fifty years later, would be a bad, bad, bad thing to do?" Today, he pointed out, people live in lodgepole pine forests; if historically there was little reason to put out a fire, now there certainly is.

Engaging in conversation about the novel ecosystems concept with SL (2013) elicited numerous thoughts about ecosystems in general. SL, like several other scientists (AP2, 2013; VN, 2013), is a proponent of understanding that ecosystems are constantly evolving and changing. Today, he asserted, the mechanisms for change are shifting, where anthropogenic forcing is sometimes the main cause. He identified climate change as a driver for ecosystem change. He discussed that taking a historical gaze at ecosystems was immensely useful: look at a photo now and one from 150 years ago, for example, of US prairie ecosystems and removing large grazing animals such as the buffalo, and those ecosystems are hardly recognizable. For an example closer to home, he pointed to the moose in the Chilcotin region. Apparently, 150 years ago, there were very, very few moose there, and instead there were caribou. Now the opposite is true, and with moose populations currently declining, there is great debate in the community about what to do, though he thinks the issue is mostly political: hunters want to have moose. Discussing another example with an invasive and species in the southeastern United States, he asserted that generally, if people wait long enough, an ecosystem tends to settle down. The invasive red fire ant is starting to do so even as it displaces a lot of other ant species. Because of his general views on ecosystem change and animals' ranges and populations shifting, he stated that he struggles to think of something as a novel ecosystem. When it comes to management, he seemed less certain of its ability to make a difference, saying: "...the more we try to manipulate things, the more we just create new problems." For SL, it was important to

point out that *people* are concerned with the historical. Nature doesn't have anything to do with historical. Personally, he does not like to use the idea of historical range of variation for plants or animals because we implicitly make value statements about what time frame we think is important. These are anthropocentric in perspective, and really only helpful to humans, rather than the ecosystems or species themselves.

RH's (2013) comments in answer to the novel ecosystems questions differed from his colleagues. While stating that he was familiar with the novel ecosystems concept, he expressed excitement about a georeferencing project with TRIA where researchers were creating maps for organizing both genetic and location data for the trees, beetles, and "fungal helpers," to see if that illuminated any insights into predicting the beetles' attacks. RH and colleagues, he described, are using the georeferenced genetic material to see whether it was possible to identify certain genotypes of trees that were more susceptible, or whether the differences in the fungal genotypes made a difference for the effectiveness of the beetle's attacks. So while he described a novel approach to researching the beetle, he did not more clearly expand on the connection to the novel ecosystems concept.

4.4.2 Other "Novel" Terms: Novel Habitats, Novel Hosts, Novel Interactions, Novel Species, Novel Systems

Scientists noted numerous differences in this MPB outbreak from those historically, and the widespread use of the adjective "novel" brings this to the fore. The language that scientists are using to identify these changes is still settling out. The scientists I interviewed used varying terms to identify characteristics of the outbreak and related interactions that differed from those historically: LS (2014), AC (2013), and JC (2013) referred to "novel habitat" throughout the interviews. In another example, JC (2013) walked me through her thinking about novel ecosystems with the beetle: "What we mean by 'novel habitats' are the habitats in which the mountain pine beetle now resides, that had not been documented as being attacked previous to this current outbreak. So for example, north-central Alberta, there's never been a record of mountain pine beetle in that area prior to this outbreak, so we consider that a novel habitat. The Kananaskis, there is a prior record, so that's not a novel habitat. The

boreal forest, that's a novel habitat. We think. At least in contemporary history, we would consider that a novel habitat." Similarly, AC defined the beetle and novel habitat thusly: "Novel habitats are those areas that the pine forest that we have no evidence for prior mountain pine beetle activity in." Noting the difference in the range of the beetle was the primary reason to identify novel habitat for it. CK (2013) referred to a "novel system" when describing the beetle in the boreal forests. DH (2013) referred to the MPB as a "novel species" for the jack pine trees. Further, AC also referred to "novel interactions" and that the jack pine trees in the boreal forest are "novel hosts" for the beetle, and that the beetle moving into the boreal is "novel habitat."

At closer examination, some scientists seemed to be quite flexible and perhaps somewhat imprecise with their definitions when it came to characterizing the novel elements they had identified. Discussing specifically the novel ecosystems concept as it appears in the recent literature, AC, for example, responded: "Yeah, no, we're not quite talking about it that way. Novel only means so far as presence or absence of mountain pine beetle is concerned. So they might actually lead to a novel collection of species, when mountain pine beetle's done with them, and there you would have a definition in keeping with [the novel ecosystems concept], but in this particular case, I'm only referring to the range expansion issue by the movement in areas where it hasn't been before... I see that as novel interactions on the part of the beetle with the trees that are there, and so I call it novel hosts, or novel, I guess novel habitat might be a more appropriate term that I've used." This comment in particular raises the question: What *is* the difference between a novel ecosystem and novel habitat?

As mentioned above, a few scientists (SL, 2013; AP2, 2013; PB, 2013) shrugged off the importance of the concept. For example, AP4 (2013) stated that the concept is simply a construct that ecologists put together to help them discuss something that is not real. This scientist remarked that he probably just laughed when he heard someone say novel ecosystem in the past, because he believes they do not really exist. These comments led to a more general discussion of ecosystems, in that they are assemblages of species, and sometimes there are interesting combinations of species found together, but aside from that, there's nothing more of note about them.

4.4.3 Acceptance of Change: Abandoning Assumptions of Stasis

The need to accept change, to leave behind assumptions of stasis, or of stability, were ideas that several scientists mentioned with regard to the novel aspects of the mountain pine beetle outbreak. Sometimes this was a personal motto that was shared; other times it felt like a principle underpinned by empirical research and informed by the researchers' science. Oftentimes participants made comments about the changing nature of the landscape, and the important role of change. AC (2013) stated: "Change is required. Static approaches to anything to do with natural systems are doomed to failure... Change is good," which echoed the comments made by several other scientists, including KL (2013), DH (2013), and SL (2013). With that change, came assertions for the need to adapt along the way, whether it is finding different applications for research skills, or founding new collaborations and partnerships in response to identified needs.

Relatedly, some scientists' observations regarding the outbreak affirmed personal philosophies that encouraged change, as they did for AP2, who reflected on having to remake themselves academically and technologically every seven years or so (new programs and methods of analysis emerged, new people surrounded them and their work), and in order to keep pace, AP2 felt the need to learn further to stay ahead of research trends. AP2 asserted that all scientists should be doing this.

Scientists were not only aware of changes in responses in the scientific arena. SL (2013) pointed out the unprecedented partnerships between several provinces in combining funding to address the outbreak, such as the Province of Saskatchewan (and more recently the Province of Ontario) contributing funding to preemptively address the mountain pine beetle before it progressed further across the AB-SK border. The Province of Ontario has joined as a partner and contributor to the TRIA Network. Notably, the Province of BC is not listed as a funder. SL commented that he had never before seen such inter-provincial collaboration before. JC (2013) discusses some interprovincial dynamics in Section 4.5.1 as well.

Further, while not tying this observation directly to the novel ecosystems concept formally, or ecological novelty generally, remarking on his research and observations with the MPB outbreak, SL (2013) stated: "...we've been forced to abandon some things that were fairly safe." Scientists have tried to make heads or tails of the outbreak and its changes from the historical patterns as best as possible, and along with that comes the efforts to observe and document these changes. As discussed previously in Section 4.1.6, many scientists viewed the outbreak and its novel components as an opportunity, and sought out ways to get the MPB into their research programmes.

4.4.4 Future Forward: Anticipating Change in the Future, and What Scientists Expect the MPB Will Do Next

To say anything with certainty about what may happen with the beetle in the next 30 years, or the next potential time horizon for an outbreak, is difficult. This interview question elicited a variety of comments from the participants. A group of the participants thought that the mountain pine beetle would not be able to erupt until a longer period of time had passed, because of the high rates of mortality in some areas especially in BC, such that the trees would not be mature enough until 60-80+ years post-*this*-outbreak (VN, 2013; SL, 2013; PB, 2013; AP3, 2013; AP4, 2013). PB (2013) and AP4 (2013) believe that there will be other insects competing and keeping the mountain pine beetle in check; AP4 asserted that this is normally how relationships among forest insects function, while PB thinks that resources and management efforts will go to addressing the spruce beetle, spruce budworm, forest tent caterpillars, and others things that may be accelerated by climate change, such as forest fires.

JC (2013) and DH (2013) believe that the beetle will continue to spread into the boreal forest, with DH thinking it might take 10-30 years to reach the eastern Seaboard; similarly, JC thinks it will continue for at least the next ten years. After that, however, JC guessed that another outbreak may be under way 30 years from now. Both were tentative and non-committal in their predictions. AP4 (2013) somewhat cynically said that he was surprised there weren't more researchers trying to

predict how bad things were going to get; instead, a few will likely build a model, sit back and let it run, and see if their model is correct or not.

RH (2013) refused to really engage in the question, and instead commented that it is difficult to know when an organism starts to outbreak out, and how severe the impact will be at the beginning. His comments underscored the excitement he felt about the work he was doing, which ultimately was trying to figure out the relationships between the beetles and the fungi and whether those associations can give clues about how the beetles adapt to the climate, or into the nature of the trigger for the outbreaks, which he thinks we are still quite far away from knowing.

AP3 (2013) did not think the most important thing were the outbreak dynamics. As he stated, outbreaks are going to happen again and again. Instead, he hoped that this outbreak would make forest managers consider the issues on a bigger scale, and would encourage them to pursue and maintain forests comprising of heterogenous species, and the natural processes that would take place—such as beetle outbreaks—would have a lesser impact in the larger spatial scales, as opposed to what happened this time with everything being nicely prepared for the MPB. KL (2013) agreed with wish that BC forestry management changes would take place, after assertive that the changes needed aren't happening now. There is no “mosaic of diversity on the landscape,” which explains in part why she thinks the beetle will continue to do well in the future. She thinks that the outbreaks will continue to take place, and that some of the small changes, such as changing planted species and encouraging age class diversity in trees, would make a significant difference for future-proofing against massive outbreaks.

While the views among scientists varied significantly about the pattern and quality of future outbreaks, what they may look like, when they will take place, and how severe they may be, scientists pointed out that there are many uncertainties and contingencies when it comes to thinking about the future of the MPB in both BC and the boreal forest.

4.5 Category 5: Science, Policy, and Industry Relations

This category identifies relationships, recommendations, and observations that scientists made about their connections to government, forestry management, and industry. Oftentimes these were reflections or issues of concern that scientists highlighted as a result of the outbreak, which included general statements about how management responses should or could be changed in the future.

4.5.1 Scientists' Responses to the MPB and Forestry Management

Scientists made a number of observations about what they asserted to be ineffective components of the management response to the outbreak. As was explained by KL (2013), forest companies' roles in addressing the management of the outbreak in British Columbia was to harvest beetle affected timber, and remove affected stands, which would inhibit the beetle's abilities to spread. Unfortunately, she said, these methods were not effective, and the opposite happened, whereby some harvesting activities frequently aided the beetle's spread.

To account for the existence of extensive monoculture lodgepole pine forests in BC, AP2 (2013) pointed out that economically, they are very appealing because they make for efficient harvesting and management. AP2 did not, however, acknowledge that there are particular vulnerabilities inherent with plant monocultures, and so there exists an unexamined paradox in claiming that monocultures are easy to manage. AP2 also pointed out that there is quite a diversity among forest companies, with some being more forward-thinking, and others merely focusing on harvesting. They asserted that this was also evident in the harvesting response patterns of companies during the outbreak.

Specifically addressing the Alberta provincial government's response and working with government staff, JC (2013) identified a necessary change in their thinking, and how it impacted the involvement and engagement of TRIA-affiliated scientists:

"It's the ecology of surprise. If this thing [the beetle] had reacted like it had in the '80s, I think that they would just say, "Well, we'll just do what we did in the '80s," which they did in Alberta here, when they started, and it

probably would have been largely effective, and it has been. In the south, beetle in Kananaskis, in Crowsnest, is [at a] very very *very* low population right now. A lot less [tree] mortality. And perhaps the climate factors that helped bring those populations down to a point that the tree can resist. But, the Province, also really went full on in their control, and we don't have proof, but it's my feeling that that mattered. So, they did best on what they learned in the '80s, what they needed to do down there, and it was in historic habitat, and it worked, but the spread to new areas for sure has said, well we *have* to do something different. And that really has opened, their minds and philosophies to, "Okay, it's going to take something different, so we have to do something different. And that has opened the door to receptivity of, of science-based decisions, and there's a spillover effect. The spillover effect is that this has an evolution in mountain pine beetle management, and the spillover is into other forest issues and forest pests, that yeah, science has informed these areas before, but now they can see, here's a way how it works, so let's bring that same philosophy to spruce budworm in eastern Canada, let's bring it to forest tent caterpillar, which is on the upswing here" (emphasis retained from interview).

Being able to extrapolate research and management lessons from one situation to another was discussed by other participants, too (VN, 2013; SL, 2013), though JC also mentioned that one reason the Alberta provincial government gave to approach her in the first place was because of their observations that the BC provincial government's approach to managing the outbreak simply did not work. As they identified: controlling the outbreak didn't work, especially where the beetle spread outside of its historical range; the outbreak still reached hyper-epidemic levels. This, she asserted, helps explain the Alberta provincial government's motivation to try something new.

Similarly, speaking as a federal government researcher who moved to academia, PB (2013) identified that the Canadian federal government's:

"... Mountain Pine Beetle Initiative Program remained fixed on issues of either can it [the beetle] be stopped or can the progression be modelled, just from an empirical model? What is the basis for wood products that can be salvaged from it and they really have never invested in an

ecosystem-based approach, you know, taking a view of you know, the interacting components and what they all mean to each other, nor have they invested in long term studies. Permanent plots, repeated measure experiments will have a legacy into the future because we'll have another one of these outbreaks in the future and then everyone will be scrambling once again to get the big picture and I feel that the research agencies and the government agencies that should have that long term vision whether provincial or federal, just have failed to take advantage of the fact that this is an episodic phenomenon, that we had a chance to get in on the ground and really you know, establish a research legacy to learn from, and they hadn't done so."

This participant asserted that this characterization of frustration is widespread within the research community, and certainly similar comments by KL (2013) and JK (2013) and SL (2013) would support his assertion.

PB also further highlighted that "The Chief Forester's position within BC has since been compromised by being split into two positions, making itself more subject to political interference." The Chief Forester in BC used to make decisions about the Annual Allowable Cut (AAC). PB expressed that he no longer has faith going forward with the current governments in either Victoria or Ottawa. PB thought that the last Chief Forester, Jim Snetsinger, was very understanding of the complexities of the forestry situation in British Columbia, and tried to push the envelope, which could be why his position was changed. PB did not think this was a good change. Snetsinger's duties were changed in 2014, and an interim — though now permanent — Chief Forester, Diane Nicholls, took his place (Penner, 2016).

KL (2013) discussed the historical role of forestry and logging companies, and their problematic system of organization, and saw a great need and opportunity to have government and policy-driven change when it comes to shaping economic diversification in the forestry industry. Living in Prince George, a hub of forestry activity and one of the most intensely hit areas of the outbreak, she detailed seeing logging trucks loaded with wood driving down the local highways through town. At times she was very critical about the fact that some forestry companies were accessing still green (non-beetle killed) wood to keep their mills going, which was as much a

comment about the lack of diversification of local economies, as it was that mill technology and capital hadn't changed to adapt to second-growth or younger forests. KL suggested that government should provide an economic incentive to diversify what they do, as very few do so on their own initiative. This would also enable communities to have jobs and incomes and not be dependent on one type of product or one type of market. This led her to make a recommendations like: "Diversity, diversity, diversity (KL, 2013)" when it came to ideas about how forest management and forestry dependent industries should change in the future. A short discussion of the potential for other value-added timber products such as using different, faster growing (deciduous) tree species for alternative fuel sources, or furniture-making followed. The discussion ended over agreement that diversifying the forest timber and value-added market in British Columbia would be much better than depending on single-species raw log exports and products that are vulnerable to a pest attack like the beetle. PB (2013) agreed that forestry management "requires leadership. Individuals that are willing to go to the map in support of long-term sustainability, and natural forests as opposed to the vision of short-term economic opportunities and the tree farm and agricultural mentality to growing wood."

Overall, several scientists expressed concern about the general trend of forestry management in British Columbia, and as expressed above, not only raised their concerns, but also immediately suggested a variety of ideas to help address the issues they identified, or change the trajectory of engagement with large-scale forestry. By and large, these scientists did not think a continuation of the approach to date was successful, and agreed that something different should be considered.

4.5.2 Science-Policy Connections—Impacts of Research

I asked scientists about their perceptions of the impact of their work, and where they thought it was most effective. While no individual scientist commented on the overall systemic impact of MPB science, there was were a variety of comments that scientists made. The academic scientists (DH, 2013; EC, 2013; AP4, 2013; SL, 2013) primarily focused on producing the science and communicating it through traditional channels for academia (journals, conferences). Two researchers (PB, 2013; AC 2013) were

interviewed for a documentary by the David Suzuki Foundation that featured the mountain pine beetle, though PB's interview was not included due to a lack of space/time in the documentary. In other (fewer) cases, the relationship to policy was clearer, and one scientist described the lobbying activities that he engaged in, and how rewarding it was to hear things that he had explained to politicians be repeated back to him; that was a sign of success (AC, 2013). This was an isolated example.

There were also institutional differences in ability to extend or amplify research impact. As a former federal government employee, PB (2013) described his frustration and sadness about the lack of capacity and care for building a research heritage within the federal government's research program: "In fact, I often, when I do try and compile the data and make it available or archive it for for future years, future generations and send it to a government agency, we find that it always gets lost or it was destroyed during an office move or something, so there's really a lack of continuity and long-term thinking within our research institutions."

There were only two instances of scientists mentioning collaborative work across national borders. In accounting for his lack of surprise about the range expansion of the MPB, he cited collaborative work with the US Forest Service developing the West Wide Pine Beetle Model in the 1990s, which ended up being a decision-support tool that the US Forest Service uses. As AP1 explained, with the model, researchers were able to analyze the magnitude of the impact of severe MPB outbreaks in particular regions in the US, and unless there was a climatic event significant enough to abate the attacks over the winter, then the beetle "would basically eat itself out of house and home," and the trees would be killed off, but the beetle wouldn't decline earlier. AP1 emphasized understanding that the beetle is an endemic species that has always been in British Columbia's landscape, and that his perspective is one that looks at the beetle from the landscape scale. He did not further discuss the collaborative work with other US scientists. And as mentioned previously, PB (2013) identified one colleague who left Canada after being dissatisfied with research support here, and instead moved to the US, where he still collaborates with Canadian researchers through the TRIA Network.

4.6. Chapter Summary

This chapter has presented several themes as findings from the qualitative interviews. Scientists expressed their observations of the fast-paced changes in the context of the mountain pine beetle outbreak and some of their implications for their research efforts. Scientists also shared their views on shifts in BC's forest management, describing patterns of response they disagreed with, and ways they think engaging with the outbreak would be better in the future. Further, this chapter presented the mediating role of funding for scientific research, as well as scientists' ideas about rapid change and shifting landscapes, their engagement with ecological novelty generally, and the novel ecosystems concept specifically.

Next, Chapter Five discusses the implications of some of these findings further. In particular, the chapter focuses on themes of science-policy relationships, the importance of the rise of the TRIA Network, the impact of funding cycles, ecological novelty and the mountain pine beetle, and novelty's influence on scientific attention.

Chapter 5: Discussion

Suppose we did our work
like the snow, quietly, quietly,
leaving nothing out.

— Wendell Berry, “Like Snow” in *Leavings* (2010, p. 3)

5.0 Introduction

In this thesis I have sought to understand scientists’ responses to and engagement with a significant ecological event that occurred in western North America: a mountain pine beetle outbreak of unprecedented scale and intensity. While acknowledging that the MPB outbreak was not new, early media accounts, scientists-in-the-media, general discussion, and my own observations of the dead red trees popping up in the landscape around my hometown in southern BC, indicated that there were characteristics about this outbreak that differed significantly from previous outbreaks, and understanding how scientists in their institutional contexts are able to adapt is a timely and relevant inquiry. Since undertaking this research project, it is evident that ample scientific documentation, description, and evidence supports these preliminary observations of ecological novelty. The MPB outbreak presented a fascinating case study for exploring responses to rapid ecological change by scientific professionals that are expected to produce knowledge that helps to understand such an event. And, I wanted to apply the novel ecosystems concept—as it has recently been written about in the literature—to see if the concept aids scientists responding to a climate-exacerbated event and changes the way they think about suitable ways to respond, or if they have found new ways of conducting or adapting their science. In Chapter 2 I presented background on the novel ecosystems concept, as well as situated some of the relevant contextual literature regarding beetle and pest management, which falls under the purview of the Canadian federal government, and forestry management, which falls under provincial jurisdictions. In Chapter 3 I described how scientists from a variety of institutions and with varied research histories were recruited for a series of in-depth, semi-structured interviews. I was curious about scientists’ responses to the outbreak, and recruiting

researchers at various points in their careers was essential for providing a longer-term perspective on how research on the mountain pine beetle has been undertaken. A more detailed presentation of the complete methods of this project are found in Chapter 3. I deliver findings of my research in Chapter 4, organized into five major categories, and broken into multiple themes that present the perspectives of scientists.

In this chapter, I engage the findings and their implications in dialogue with some of the main ideas from the literature—scholarly conversations that started before I arrived eager to undertake this study. This chapter is divided into five main discussion sections: the first three themes focus on social dimensions that became clear from scientists’ research experiences during the most recent outbreak, and include characterizations and insights into scientists’ relationships with policy- and decision-making, and factors that influence their knowledge production. Next, I discuss first scientists’ conceptual level engagement with the novel ecosystems concept, and then implications of their feedback on the concept and its use for understanding the outbreak. This chapter concludes by focusing a set of binoculars to the future: a characterization of the limits of this project, what I may have done differently, and directions for future research.

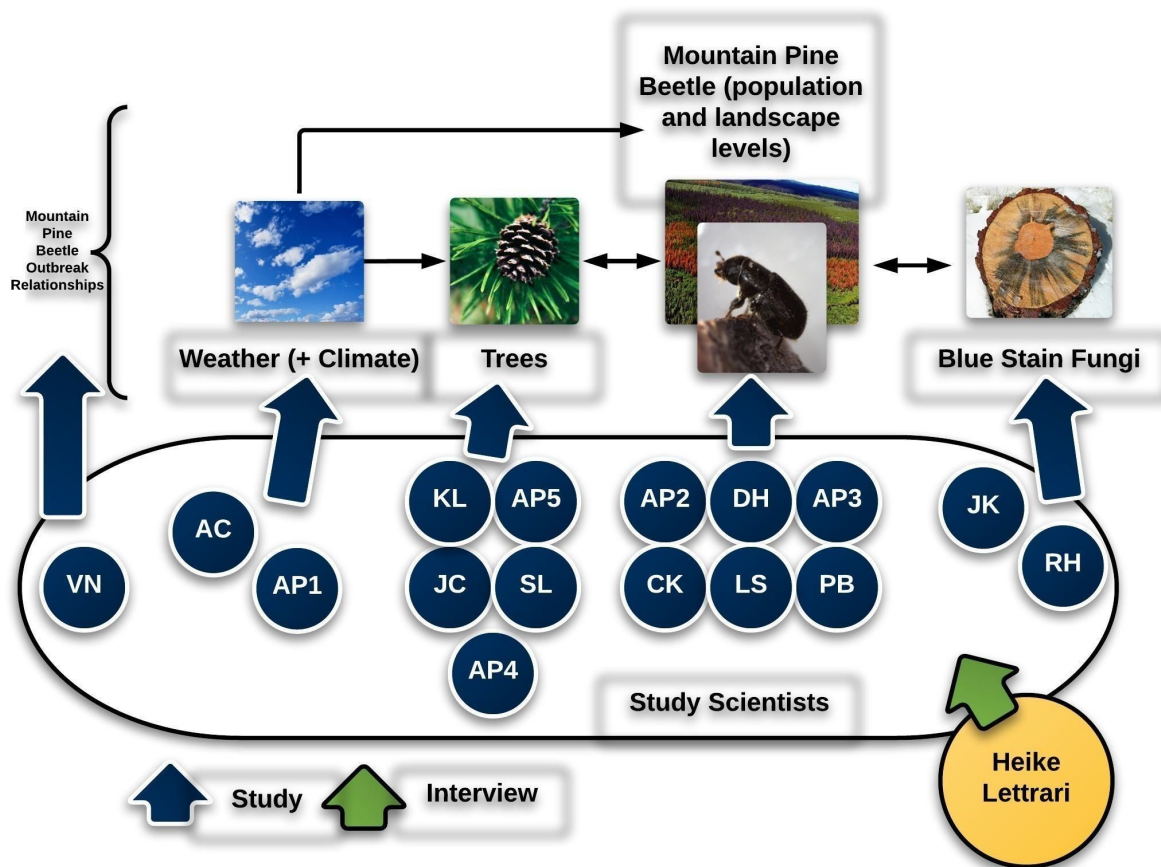


Figure 6: Study relationships between scientists and the outbreak, and me as interviewer of the scientists.

While I understood generally that there was differentiation among my participants for their research (in institutional context, in research focus), I didn't know in what ways that would show up in the interviews, or what that would mean for my research and attempts to understand these scientists. The differences and similarities did not take meaning until I began to hear their accounts and gain a better understanding of their perspectives through the interviews (see Figure 6 above). Each scientist spoke from their training, their institutional culture(s), their backgrounds, their personalities. The interview comments were conversations and ideas filtered by the way these scientists and people organized their worldviews and experiences, which in many cases were different from my own. My interview questions solicited perspectives on various

topics, so I tried my best to situate all of the comments within their contexts: the entomologists had more authority on specifically beetle questions; the fungi researchers supplied more detailed answers and insights into the fungi-beetle relationships; the tree scientists provided perspectives on the beetle-tree aspects of the relationship. Some of the questions, such as probing what scientists think will happen in the next 10-30 years yielded speculative answers, informed by scientists' experiences, worldviews, and professional training—all reasonable, given that none have a crystal ball with which to tell the future, predict when the next outbreak will be, or anticipate how quickly the beetle will continue to move across and through Canada's boreal forests. Fundamentally, though, the common denominator amongst these researchers remained the same: billions and trillions of fast-reproducing, exothermic mountain pine beetles that seasonally and annually respond to the changing weather patterns and climate around them.

5.1 MPB and Science-Policy Relationships

In reviewing the findings of this study, and focusing on the social aspects of MPB scientific knowledge production, a few key observations and assertions can be made:

1) broadly, that scientists' relationships with both policy- and decision-makers in British Columbia can be characterized as haphazard, and that these haphazard relationships become obvious when a major socio-ecological problem (the MPB outbreak) arises;

2) that relationships between the Turning Risk Into Action (TRIA) Network and Alberta policymakers seem to mark a new relationship;

3) that there exist several current science funding processes that are not particularly effective for producing scientific information in areas of research that involve regular outbreak events (that experience the boom-bust cycles signature to MPB outbreaks), and further, that even when the science is produced, it doesn't necessarily go to where it can be most impactful; and

4) that there is great opportunity and benefit in developing more collaborative science-policy relationships in order to better weather such events, which means

having discussions about research with long-term sightlines. Each of these observations and assertions are discussed below.

5.1.1 Science-Policy Relationships

Overall, the interview data suggest that relationships between individual scientists and policy- or decision-makers were marked by haphazardness and tenuousness; there was collectively little direct connection between individual scientists and decision- or policy-makers. For the one scientist that described reaching decision-makers, the impact was not lasting. AC (2013), who (as described in Section 4.5) directly lobbied some decision-makers such that they adopted—for a brief period of time, and much to his excitement—the language and understanding he advocated for regarding the outbreak. However, he admitted that as the furor about the issue died down, his positive influence quickly dissipated. There seems to have been more potential described for improved and more closely connected science-policy relationships emerging out of the TRIA Networks' third round of funding, which was just beginning at the time of my interviews—in fact, JC (2013) had felt comfortable sharing with me that the third round of TRIA funding had been confirmed: she was content that by the time I would publish anything out of my thesis, the news would be public. And indeed, the official announcement appeared several months later in early January 2014 in a press release by the University of Northern British Columbia. JC (2013), as described in Section 4.5.1, discussed some of her interactions with a few of Alberta's provincial government folks during the outbreak. TRIA is discussed below. Otherwise, there was little reported direct interaction between scientists and policy- and decision-makers—certainly there were far fewer existing relationships, communication lines, and ongoing knowledge exchange than I anticipated hearing about. However, these findings would not surprise Dr. Paul Cairney (2016) who recently argued that scientists consistently labour under misconceptions—naive conceptions—about how policy-making processes occur, and that scientists are better off disabusing themselves of two prominent notions: first, that policymakers will ever think like scientists, and second, that there is no perfect timing to inject policymaking procedures with evidence or scientific knowledge. As Cairney describes, policy-makers frequently work quickly,

using both rational knowledge gathering methods such as surveying literature and irrational knowledge gathering evidence such as gut feelings about a given issue in order to support their decision-making. Scientists, Cairney asserts, focus most frequently on the supply of evidence—how much we know about a given thing, and what else we need to research—whereas policymakers focus on the demand for evidence—when they need particular knowledge. With this main distinction in mind, Cairney asserts that there’s little point in translating scientific information if there is no demand for it. This may be an important idea to keep in mind, considering that my findings show that MPB scientists continue to be concerned with identifying answers to very basic questions such as “How do mountain pine beetles kill trees?”—this is a basic question that scientists may well find imperative to answer, but that policy and decision makers may not find as valuable (and based on funding patterns, have not found particularly valuable so far).

That scientists don’t understand policy-making processes enough is an important idea to keep in mind, since as scientists described (reported in Sections 4.2 and 4.3), they had ample, varied constructively critical reflections to offer about the management of and response to the MPB outbreak in BC in particular, and how governmental responses were less effective than they could have been. Along with constructive criticisms about management policies, forest industry roles, and relationships to different government entities, scientists also offered positive reflections about unprecedented proactive provincial collaboration to respond to the outbreak, . For example, the provinces of Saskatchewan and Ontario contributed money to the province of Alberta to aid efforts to stem the beetle’s range expansion into the boreal forest. However, given the seemingly haphazard, rare, and tenuous direct connections between science and policy, scientists, policy- and decision-makers, what seems to emerge is that scientist’s criticisms to governmental responses to the outbreak don’t have an obvious connection or pathway to the people and institutions that may benefit from hearing their comments. The science isn’t available at the right place, in the right form, at the right time, and the existing policy networks may not have been open to hearing it, anyways.

It is very possible that had there been more iterative processes in the science-policy relationships in place, such as those advocated by Dilling and Lemos (2011), and better timing, there may have been fewer of the command and control style management efforts that scientists criticized (described in Section 4.5), and resources would have been spent differently during the early part of the outbreak in British Columbia. Scientists were, by and large, not particularly surprised that there was an outbreak taking place again. And specifically in terms of management recommendations, the Canadian Forest Service's then Director of the Mountain Pine Beetle Initiative and Policy Research Bill Wilson in 2002, stated that: "Mountain pine beetle prevention tools (stand density management, species/age class mix, and harvesting at maturity) are under-deployed, and direct management options (baiting/repellents, fall and burn, pesticides, mosaic burns, and harvesting) are of limited use, and very inadequate at an epidemic stage." When writing this he was restating research conducted by another government scientist in 1974 (Safranyik et al., 1974). It seems that government or academic scientists had not been able to effectively communicate to key decision-makers or managers this information, since there were quite a few traditional direct management actions that the BC government undertook as a part of their response actions to the outbreak. It is possible, however, that government felt pressured to be seen "taking action quickly," which meant that without more creative management options on the table, government did what was easiest, and went to actions that had been taken before. This is speculation on my part, since I have a very limited perspective into government decision-making. It is also possible that this is a situation where fast-paced government (need for) response eliminated the opportunity for engagement with the established science, which, as Cairney points out, can be difficult. Relatedly, Wellstead *et al.* (2006) describe: "the 'mountain pine beetle epidemic policy network' has been from the outset—like many other forest policy networks in the [British Columbia]—a tightly knit collaborative effort between a select few traditional forest policy actors" (p. 4). In order to advance adaptation of forest policy in response to climate change and future changes, the authors suggested that the "closed network" may need to shift to a more pluralist network that would integrate efforts from a wider group of actors that are interested in

the mountain pine beetle. One additional set of such actors would be academic and government scientists, who in this case, seem generally to have been excluded from the policy network in British Columbia, especially during the mid-2000s. However, looking to BC's neighbour to the east, Alberta, it seems possible that the policy network may be shifting there, especially as the outbreak moved eastward; this will be discussed separately below.

Overall, when examining what scientists have said about where their research went and where it was most useful (Section 4.1.3), their primary audiences were other scientists, and perhaps the public (thinking of the occasional media interviews mentioned). If indeed there is to be more direct collaboration between policy and decision-making and science, with the intent of having more timely, applicable, and “useable science” —as has been called for in the climate change adaptation literature (Dilling & Lemos, 2011), then there needs to be a concerted effort to do so, which is where TRIA comes in.

5.1.2 Shifting Science Relationships: The TRIA Network and Alberta

In contrast to the story of the mountain pine beetle outbreak in the early 2000s in British Columbia, the beetle's progression into new territory in the boreal forest may have resulted in the Albertan government opening up its forest policy network, much as (Wellstead et al., 2006) suggested may be necessary. From my understandings of the relationships of TRIA scientists (especially the provincial directors, JC and Dr. Joerg Bohlmann), there are indications that the relationships there may be indicative of a widening of the policy network, though more research is warranted to explore in more depth the dynamics and interactions between TRIA scientists (and in particular the TRIA directors) engaged with Albertan policy and decision-makers. Figure 7 (below) depicts study participants' involvement in and with the TRIA Network. From JC's description of the encounter, however (Section 4.5.1) she affirms what Dilling et al. (2011) argue: that the key to creating usable science is that there needs to be a concerted effort to do so—both major actors (policymakers and scientists) “need to own the problem of producing usable science” (p. 687). There are many ways of creating what they describe as “co-produced knowledge”: everything from fully

fledged boundary organizations to embedding an expert within an organization. Albertan policymakers approaching the director of the TRIA Network can be characterized as both a concerted effort to own the problem of producing usable science, and as a shift to a more plural policy network. Further, it is very possible that both actors (Alberta's policy folks and TRIA scientists) iteratively and equally engaged in setting the information agenda—characteristics of Dilling et al.'s (2011) co-produced knowledge. However, these are early indications that need further research to verify or otherwise characterize what is taking place there. It's also not clear from the data what role individual leadership played, versus a larger shift in institutional culture (policy- *and* decision-makers). Further, it's clear from the interviews that different scientists had different direct relationships to the Alberta policy network. No other TRIA scientists mentioned having contact with the Alberta government in the way that JC described. It makes sense that both JC (the Alberta director of TRIA) and likely the British Columbia director of TRIA (Dr. Bohlmann) had direct contact with the Alberta provincial government because of current hierarchical organization in governance: it's wouldn't be efficient for other TRIA scientists such as RH (2013), DH (2013), AP2 (2013), and AP3 (2013) to each individually connect to individual policy and decision-makers. In the big picture, however, what seems to emerge from observing these interactions is that governmental and science-policy relationships shifted differently in British Columbia and Alberta: the MPB outbreak emphasizing some of the more dysfunctional dynamics between science and policy there, while in Alberta, the rapid ecological changes resulted in an opening up of the policy network there.

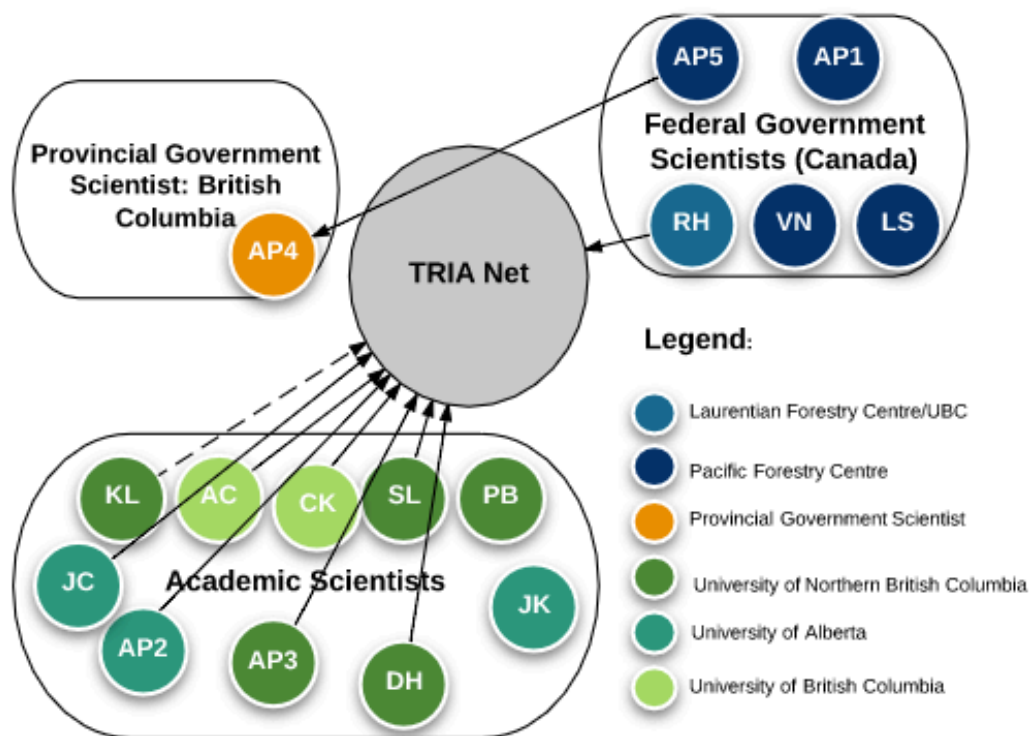


Figure 7: Participants institutional backgrounds and connections to the TRIA Network.

However, even if there are early indications of an instance of “usable knowledge” forming in the case of TRIA, that would not delegitimize scientists’ bid for more basic science to be funded and conducted in the context of the mountain pine beetle, especially outside of the outbreak cycle itself. Basic science is by definition different from usable science: it may become useful or applied science in the future, or eventually support new industries or technologies, but is produced outside of the bounds of needing to be used immediately (Stokes, 1997). And, as scientists asserted, there are simply some very basic questions that have not yet been answered about mountain pine beetle outbreaks (Section 4.1.3). Knowing the answers to those questions may be useful for the next outbreak, or may yield important information about similar destructive forest insects.

5.1.3 Funding Mediates Scientific Knowledge Production

It is reasonable to assert that scientists are influenced, enabled, and constrained by their institutional cultures. In the case of my study, the difference in impact of

institutional culture and support became apparent with differences in funding research between academic and government scientists. My findings show not only that funding can support academic scientists' abilities to undertake research, but that (lack of) funding restricts the ability for research to be undertaken in the first place. In addition to regular granting and funding cycles, scientists also identified that funding priorities can be responsive to the "attention spans" of politicians and decision-makers, who need to respond to the crises, or public issue of concern that vie for their attention, which the mountain pine beetle outbreak certainly did. Scientists were here referring to the emergency funds from the Mountain Pine Beetle Initiative that were made available in 2001 (Wellstead et al., 2006). However, as both (Castree et al., 2014) and Pielke Jr. (2007) discuss, "tornado politics" and/or crisis rhetoric (need to act *now*) suspends robust discussion about multiple possible action pathways and options, and, problematically, can leave the chosen path immune to criticism. From the accounts of scientists, it seems that the provincial government of British Columbia was particularly struck by tornado politics: they were in crisis response in the early years of the outbreak: employing management options to respond to the mountain pine beetle that had been historically somewhat successful, but, that in the assessment of scientists, were no longer effective. In contrast, the provincial government of Alberta—as per JC's (2013) discussion as director of TRIA Net—was characterized as being much more willing to step back, reflect on policies and processes that were deemed ineffective methods of response in British Columbia, and they were more willing to try "something new" (JC, 2013). It was these motivations, JC explained, that led to the engagement with the TRIA Network, and funding followed suit to support those decisions. Based on this account, funding can continue to sustain and support investigations into a given issue. What also becomes clear, however, is that there was a willingness to engage in science-policy collaborations of the sort that the Province of Alberta initiated in approaching TRIA scientists, and as Dilling & Lemos (2011) assert from their research: there needs to be a willingness and concerted effort by both science and policy to create science that is usable and useful by both scientists and policymakers. It seems that the case of the mountain pine beetle, TRIA Net scientists, and key policymakers in the Alberta provincial government exemplified such

willingness. Institutions and organizations need to be mindful of not placing unnecessary constraints on scientists' abilities to undertake research that would yield valuable insights for MPB or similar eruptive insect management.

Relatedly, scientists asserted the need for *funding bodies* to understand the importance of basic and fundamental research—research that has no immediate applicability—that takes place outside of crisis responses cycles when an outbreak is already under way. There are quite a few limits to funding research within only an outbreak context. My findings suggest that funding cycles would do better *not* to mimic the boom-bust cycles of an outbreak and therefore the production of scientific knowledge that may be useful in advance of an eruption beginning. Understanding endemic species' behavioural patterns can be as important as understanding their outbreak patterns of behaviour. Some of the scientists expressed frustration about the boom-bust funding cycle, and the drawbacks of such a funding pattern. And, as the most senior, and now retired, scientist Les Safranyik (2014) pointed out: scientists still do not know what causes the population transition from one state to another, either into an outbreak or out of one again. He characterized this as very basic information about the mountain pine beetle, which is currently still unknown. Another participant, AP4 (2013), relayed an anecdote about having a discussion with a colleague, a bark beetle scientist at Dartmouth College, who one day wants to write a paper answering the question, “How *do* bark beetles kill trees?” because nobody really knows. It is likely that answering these basic questions will not happen with funding that arrives with the bang of a rocket but expires a short period later, when a given outbreak dies down.

As discussed in Chapter 4, several scientists had various ideas about how to change funding structures to ensure that less of their time is spent applying for grants, and more of it can be used constructively for research; whether the suggestions given in Section 4.3.4 are the best ones will require more research, but overall, the bids for basic, guaranteed research funding are similar to the concept of a basic minimum income for individuals in society. It is possible that such a model transposed for scientists, calibrated to reward those who produce work of a certain calibre could be beneficial.

In contrast to the comments of predominantly academic scientists above, senior government scientists reported a large degree of freedom to undertake research they want, and for them it is more likely that they were restricted in different ways, such as by the political culture and legacy of the Harper government (described in Section 3.12). While I cannot speak directly to the experience of any of my particular federal government scientists, other research has well documented the “chill” that the majority of federal government researchers felt invaded their workplace from politics (The Professional Institute of the Public Service of Canada, 2013). It is very likely that some of my participants were directly or indirectly affected by this chill as well. Notably, the new Trudeau federal government recently undertook a fundamental review of science.

5.2 The Mountain Pine Beetle: Novel and Hybrid Ecosystems

The following sections discuss three findings and assertions about the mountain pine beetle in relation to the concept of novel ecosystems, including that the concept, when applied to the case of the mountain pine beetle, reveals hybrid ecosystems with novel characteristics across a patchwork landscape; that ecological novelty results in ample opportunity for research; and that faunal-ecological interactions reveal slightly different implications for management.

5.2.1 Novel Ecosystems and the MPB

When “Novel ecosystems: Intervening in the new ecological world order” (Hobbs, Higgs & Hall, 2013) was published in 2013, it was the first comprehensive effort to give flesh to the conceptual bones of the novel ecosystems concept, which at that point had seen predominantly incidental use in earlier literature. In doing so, the book also provides several empirical case studies for illustrating the application of the concept.

In the context of the mountain pine beetle and its most recent associated outbreak event, I asked scientists about their engagement with the novel ecosystems concept and how they saw it applying to the case of the mountain pine beetle. My findings show that scientists predominantly do not see the mountain pine beetle and associated outbreak characteristics as constituting a novel ecosystem. Instead, I think it more appropriate to characterize the recent event as being characteristic of hybrid

ecosystems, which have novel characteristics (i.e., they have not surpassed a tipping point that would make natural recovery or restoration infeasible). While Western Canada's forests have seen a diversity of land use and harvesting practices (both from First Nations, but predominantly from state and settlers) over the past century, and while these systems remain historically continuous, it is no longer appropriate to classify those forests as historical ecosystems. Instead, the idea of a hybrid ecosystem better suits the varied history of land use management, parks and protected area designations, timber forest areas, and other engagement, as presented in Chapter 2.

As presented in Chapter 4, much of scientists' engagement with the novel ecosystems concept at the time of my interviews was at a very conceptual level. There was some discussion with several participants about the concept itself, but very few scientists were able to apply the concept directly to their research with the mountain pine beetle. Upon further reflection, it is possible that scientists did not or were not able to apply the concept to the MPB case study for three main reasons: first, discussion of the concept during the interview was the first instance of encounter with the concept for some scientists; the concept has seen traction and generation from primarily scientists working in the fields of ecological restoration and ecology, and disciplinary barriers ("silos") may explain a lack of encountering the recent work on the concept; second, that the concept as presented in the literature was too unfamiliar to several in this particular group of scientists, such that any discussion pertaining to the concept remained primarily at the introductory and conceptual level; and third, that the MPB covered an enormous range of varied landscape, that the application of the concept would be much more difficult than walking through the theoretical questions captured in a simplified diagram of Chapter 6 of *Novel Ecosystems* (reproduced below), in which authors ask "Is the target ecosystem altered because of anthropogenic forcing?" For example, Yes, the landscape of the boreal forest is altered through novel presence of the MPB, which was aided by climate change (indirect) and landscape/forest/fire management factors by humans (direct). "Are these changes reversible?" No: there is ample evidence in the MPB literature that the beetle is successfully reproducing and establishing a persistent presence in boreal forests despite the more diffuse and lower density of jack pine trees (as opposed to the high

density of lodgepole pines more typical of British Columbia's landscapes). According to the flow chart in Figure 4, answering Yes and No to the two major questions posed in the diagram would suggest a novel ecosystem. Discussing these details would perhaps have better been done with the diagram in hand or sent along with the interview questions, though that would have changed the nature of the inquiry.

Given the vast landscape that was affected by the MPB outbreak, and considering that most of the novel ecosystems concept-related discussion was stalled with conceptual-level exchanges, there was little room for discussing some more interesting implications of the concept, such as what management should result (or change from historical management options) from the beetle's expansion into the boreal forest, and what updated management or action response implications might be most suitable for different jurisdictions across the vast landscape affected by the beetle, such as from provincial parks, the provinces, or the federal government, or industry (major stakeholders in the state of forests).

Given my understanding of scientists' assertions about MPB's impacts to the landscape and trees in British Columbia and Alberta, there is no definitive categorization of whether the outbreak and beetle range expansion constitute a novel ecosystem or a hybrid ecosystem among my participants. More empirical evidence needs to be gathered from the field (across the beetle's range, both novel and historical) that would substantiate whether the presence of MPB in the boreal forest constitutes or has been a driver for novel ecosystems in very specific locations. Depending on the degree of novelty discovered, it may then become possible to declare that the beetle's range expansion into the boreal forest constitutes a novel landscape. However, definitive categorization may be irrelevant, or at least may indicate the limits of putting hard boundaries between yes's and no's to simple questions. That there have been novel characteristics observed has been well documented, and the presence of novelty has its own implications, as I discuss below. Several scientists mentioned the similarity in function (killing trees) that MPB performs, which other forest insects also already do. What may be interesting to explore—and that wasn't brought up in the interview discussions—would be to examine the ecological impacts of the outbreak when viewing it as a pulse event: millions of trees die in a relatively short period of

time; a mountain pine beetle outbreak may be analogous to the kinds of pulse events seen with seasonal salmon dying in upstream riverbeds they travel to for spawning or seasonal algae blooms, in that the mountain pine beetle outbreaks produce a significant increase of both beetle biomass and dead trees, and as other recent research has shown, an increase in both the frequency and the severity of fire (Alfaro et al., 2008). In response, scientists identified changes to logging pattern changes and policy adjustments that could accommodate increased harvest.

So while functionally, it seems that the beetle behaves not too dissimilarly from other forest insects in the boreal forest, and compositionally, the difference is notable but not of significant ecological consequence, it seems then, that the designation of hybrid ecosystem with novel characteristics may be most appropriate. I think that it is more useful to understand the MPB outbreak and associated range expansion conceptual as producing a hybrid ecosystem, which helps to explain the variability in provincial management responses (as discussed below). As a separate note, the most significant concern on the part of the federal government identified in (Nealis & Peter, 2008) and (Nealis & Cooke, 2014) seemed to be the economic threat that resulted from the beetle killing harvestable and merchantable pine wood at a very rapid pace, as happened especially during the early part of the mountain pine beetle in British Columbia, and the slightly slower and differential pace of outbreak in the boreal forests' jack pine.

While scientists' conceptual engagement with the novel ecosystems indicates a positive reception, one of the main concerns that a scientist mentioned regarded the misuse of the concept: that someone with governance power (whether governmental or industry) would allow the destruction of an ecosystem to take place (a direct human impact) and would then claim that that ecosystem was a novel ecosystem, and absolve that party of any need to restore or otherwise engage with that ecosystem. In other words, the concern was that the novel ecosystems concept would be used as a reason *after* a direct human impact negatively altered an ecosystem, to allow the generation of a novel (good, positive) ecosystem. While I see this as a potentially legitimate concern for the novel ecosystems concept, to me this idea encourages an expanded role for scientists: publicly criticizing and correcting the use of the concept to avoid misuse;

endorsing its use and further framing the concept's familiarity within academia and without; providing further research and examples; further implementation of the concept in research and management programs; and undertaking workshops and cross-institutional collaborations with this concept in mind (not too dissimilar from the head-on approach the 2016 ESA global conference seems to be taking, as discussed below).

Some scientists criticised the concept as being too broad in scope, such that all ecosystems today are novel. Others saw conceptual usefulness in the concept, though not in the same way that I had read in the literature so far. But what is clear to me is that the novel ecosystems concept does not advocate for its own misuse in the way that Murcia *et al.* (2014) feared. Rather, my understanding of Hobbs, Higgs, and Hall (2013), and (Hobbs et al., 2009) is that the novel ecosystems concept (with its accompanying classifications of hybrid and historical ecosystems) has the potential to empower scientists and others by acknowledging the different trajectories for an ecosystem, given its history and current impacts and pressures. A novel ecosystem has passed a threshold that makes practically impossible to return to either hybrid or historical states, on the continuum of historical—hybrid—novel.

In the context of the mountain pine beetle: the intensity of the outbreak in historical beetle territory was unmatched, and current research continues to delineate the differences that that intensity makes for our forested landscapes. In novel, non-historical beetle (primarily boreal) landscapes, it has become clear that it will be nearly impossible to return the boreal forest to a pre-MPB state. The vast range of the beetles' expansion outside of their historical habitat has meant that conditions have only improved for a more active beetle in our forested landscapes. For management, the implications are significant: as one novel ecosystems proponent asserted: when dealing with an outbreak scale so significant, perhaps ditching the "control" management philosophy would be more useful. Hindsight is always twenty-twenty, but this would seem to me to be an important take away from the mountain pine beetle outbreak. As was previously identified, the mountain pine beetle is one of approximately ten insects that may benefit significant from a warmed climate. Should other ahistorical, increasingly intensified beetle outbreaks occur in the near future, governments need to

engage with research communities more proactively to improve responses to the outbreak. Academia, government, and/or industry could do things like pre-emptively explore scenarios for response, or diversify economies to include more value-added products, including those, as suggested by one of my participants, from deciduous trees that typically have shorter lifespans (KL, 2013). From my vantage point, there are many unexplored ideas that could emerge should provincial and federal government budgets respond not to perceived emergencies, but to even out funding over the long-term to respond less to the peaks and falls of an iterant outbreak, albeit one that happens over and between decades. In the short-term, funding implications are also significant: if budgets were designed less to respond to controlling the MPB or other beetle's outbreaks, and instead management let the outbreaks run their course so that budgets could be freed for alternative selective forest harvest practices, innovation, and adaptation strategies of response, one can only wonder what increased government-science-industry collaborations may come up with instead of boots on the ground with chainsaws and torches. Perhaps the opportunity for innovation would have been an opportunity to revitalize a forest industry struggling with the down turn in the US housing market, and complications with the ongoing softwood lumber dispute. With industry trends tending towards local markets and local products, there is arguably ample opportunity for increased value-added, Canadian made wood products, in line with those such as wood used for constructing one of the tallest wooden structures in the world (a new student residence)(UBC, 2015) or for wood-fired pellets (Pinnacle Power).

Similarly, I am encouraged by the rise of the TRIA Network and its seemingly close collaborations with the Alberta provincial government, and that collaborative project's openness to try something new with their approach of "the ecology of surprise" (JC, 2013), which seems to exemplify one of the characteristics for success (iterativity) by Dilling and Lemos (2011). However, I caution an approach to viewing the results of an outbreak as simply an opportunity to expand neoliberal natures — those that would view nature as a commodity to be priced, sold, and traded. My hope is that there will be more equitable ways to engage local First Nations and small

communities and enable more ways of existence than simply that of primarily cashing in on nature.

5.2.2 The challenge of definition-application

While Section 5.2.1 above discussed scientists' conceptual level engagement with the novel ecosystems concept, my findings show that it was challenging for scientists to have a nuanced engagement with the novel ecosystems concept for the case study of the mountain pine beetle outbreak in western North America. If, as I previously asserted in Chapter 2, the challenge of applying the novel ecosystems concept to the case of the mountain pine beetles lies in its not actually being a novel landscape, but rather a hybrid landscape with novel characteristics (presence of the beetle in the boreal, primarily), paired with scientists' unfamiliarity with the recent literature of the novel ecosystems concept, then that may help to situate that scientists were quite broad and imprecise in their use of new terms, but also quite liberal and yet still accurate with applying the adjective *novel* to the events and characteristics they observed during and following the outbreak, as presented in Section 4.7.2. Moreover, it is very possible that disciplinary bias may explain some scientists' unfamiliarity with the concept as well—by this, I mean that entomologists and tree genomicists and MPB fungi researchers may not have yet been following novel ecosystems discussions in ecology generally, and more specifically those stemming from restoration.

Recent research in climate change adaptation has highlighted the importance of working not only across disciplines, but across the boundaries of organizations, across the “knowledge-producer-user divide”, given the complexity of the problems that climate change presents (Lemos & Morehouse, 2005; Lemos, Kirchhoff, & Ramprasad, 2012). I do not see the case of the recent mountain pine beetle outbreak being any less difficult or complex than the projects that their research examined, and assert that my findings support suggestions for more inter- and multi-disciplinary work to be undertaken in the future, following similar calls made by scholars in climate change adaptation such as (Knapp & Trainor, 2013), who advocate for science to be more transparent, collaborative, and accessible, as well as produced in circumstances that involve data-sharing, building networks for knowledge sharing, following through

when opportunities for knowledge extension occur, and creating long-term, place-based partnerships within communities. Similarly, my research findings also show compatibility with Lemos and Morehouse (2005) who highlight that iterative processes of knowledge co-production involve increased stakeholder participation, and produce usable science, both of which are valuable goals.

Further, it is very possible that scientists' lack of application for the concept is also partly due to the recent evolution and updated presentation of the concept by Higgs, Hobbs and colleagues. Publishing of the concept at the time of my project had really taken place in journals focused on ecological restoration, and so while some of the landscape ecologists among my participants recognized the concept, others, such as the entomologists and biologists, really had not. Without a follow-up interview, focus group, or other contact with participants, it is impossible to verify whether this has changed, but I suspect it has, or will soon. The scientists interviewed for this project are grappling with the novel dimensions and characteristics of the outbreak (discussed further below), but speaking only for the concept, it seems there is a lot of room for it to engage a wider network of scientists engaging with current environmental and ecological issues. Indeed, it seems this engagement is already happening. The context of the novel ecosystems concept has changed rapidly and significantly in the years since I started this project. This year, the Ecological Society of America, the largest annual gathering of ecologists in the world, hosted their 101st annual conference with the theme "Novel ecosystems in the Anthropocene" held in Fort Lauderdale, Florida, in August of 2016 (see Figure 8 below). This conference has regularly seen the attendance of over 3000 ecologists in the past decade.



Figure 8: Screen shot of ESA's conference theme announcement, from the conference website. Source: <http://esa.org/ftlauderdale/>

5.2.3 Novelty in Landscape History

My findings show that scientists who did not support the novel ecosystems concept in my study did not differentiate between anthropogenic drivers (both direct and indirect) in the case of the mountain pine beetle, before or during the outbreak. Doing so would have highlighted differences in baseline drivers of change that help to explain why jack pines were previously found in Mexico, and why the mountain pine beetle has existed in North America for a long time. Both in the *Novel Ecosystem* book (ed. Hobbs, Higgs, Hall, 2013) in Chapter 7, Stephen Jackson, an ecologist at the United States Geological Survey (formerly at the University of Wyoming) and Dooling (2015) articulate that novelty in landscapes is not new. For ecologists taking a long(er)-term view back into the history species composition and landscape change, observing and understanding that ecosystem changes and species shifts have happened in response to climate change, invasions by transformative species, declines of keystone species, alterations in biogeochemical cycles, and severe disturbances of land-cover are not new. A small subsection of the scientists that engaged with the novel ecosystems discussion pointed this out (AP2, 2013; AP4, 2013). At the same time, these scientists were the most inclined to dismiss the value of the novel ecosystems concept. One (AP2) admitted that he likely laughed when someone

mentioned “novel ecosystems” because, he asserted, they don’t really exist. Or, conversely, he pointed out, every ecosystem is novel when looking at a long enough timeframe. However, both of these scientists do not seem to arrive at the same point that Jackson did, when he asserted: “A new kind of novelty seems to be arising in which human activities are accelerating all of the processes that lead to novel ecosystems. Unique features of this ‘new novelty’ include widespread extent and rapid increases in magnitude of multiple drivers and, consequentially, new interactions among drivers and between drivers and biota. Looking into the near-future in the ‘new world’, ecological novelty may arise very rapidly due to unprecedentedly rapid change in climate, introductions of exotic species, human land use and resource exploitation, alteration of global biogeochemical cycles and other factors” (p. 64). It is possible that for now, the mountain pine beetle’s presence in the boreal forest may be considered a hybrid ecosystem, with further climate change, with forest dynamics and changing fire regimes, and other land use change regarding oil and gas development in Northern BC and Alberta’s boreal, there are dynamics that have yet to be understood about the MPB making a new home in the boreal forest. We may see more of the ecosystem shift that AP5 (2013) described in her interview, in which beetle-kill ecosystems shift from tree-dominated to shrub-dominated ecosystems.

The relevance of the novel ecosystems concept is likely only to grow in the near future. Even as the application of the concept to the case of the mountain pine beetle remains conceptual here (and relies on future evidence to determine the implications of the beetle’s range expansion, effects on fire intensity and related soil regimes, shifting ecological relationships, and more), the role of historical policies in shaping vulnerable forests should not be ignored. Reviewing Figure 4 (from Chapter 2): “time without intervention” can lead to novel ecosystems in the near future. Policies need to be adapted to consider future changes, because if we rely on historical policies and approaches, it is likely that we will perpetuate current states of vulnerability or increase vulnerability to rapid ecological changes. Our management and natural resource operations need to anticipate surprises, need to adapt, and need to decrease vulnerability to climate and other changes. A change on the scale of insect events like the recent MPB beetle outbreak is very fast-paced, and the pressure to respond

adequately is high. The novel ecosystems concept helps provide a frame for thinking through relevant biotic and abiotic factors that should be taken into consideration, and underscores the responsibility to actively intervene in ecosystems. It is very possible that we need to increase the scales of interaction with our ecosystems in the future (given the increased size and complexity of shifting beetle outbreak patterns, as one example). It is possible that pressures to ramp up activities such as assisted migration (O'Neill, Carlson, Berger & Ukrainetz, 2009) or radical rewilding, taking them from experiment to widespread deployment and best practices, plus other innovative interventions, will only increase as we see landscapes changing more quickly.

5.2.4 Fauna, Landscape Scale, and Ecosystem Shifts

My findings show that scientists were quite united in remarking on the impressive landscape scale of impact of the mountain pine beetle outbreak. As previously discussed in the literature review found in Chapter 2, there is very little written or dedicated to fauna in *Novel Ecosystems*. The examples of fauna in the novel ecosystems book are limited to the small scale, and to a very small number of species. None of the case studies in the book included a commentary on insects. Few examples of insects pervade the media's attention, and when they do, they seem to be frequently framed within disaster or apocalypse narratives (eg. McLean, 2016).

While Ellis and colleagues (2011) discussed the generation of novel ecosystems within the context of the globally applicable "Anthropocene", noting humans' ever-increasing dominant impacts across the planet, most of their research focused on the usual subjects: development, land-use change, species transport (pertinent for invasive species), and resource extraction at larger and more intense scales, and their resulting landscape use and composition shifts. I note, briefly, that the Anthropocene concept is not without criticism: as has been pointed out, the early authors of the concept have ignored some of the political dimensions of the Anthropocene, not recognizing the ways in which nature and certain types of scientific expertise contributed significantly global conservation and climate change policies (McAfee, 2016); similarly, (Collard, Dempsey, & Sundberg, 2014) criticize the concept with an approach of decolonization, and propose instead a "manifesto for abundant futures".

Animals and insect-animals can be faster to respond to environmental changes than plants, who depend on some form of transport (either of the plant or seed, such as by wind, birds, other animals, or humans) to change ranges. Flying beetles such as the mountain pine beetle, however, can benefit from external factors such as local wind patterns to dramatically alter their range expansion, and do so very quickly (Carroll et al., 2003). Their ability to successfully reproduce within novel habitat has also been demonstrated amply (Nealis & Cooke, 2014; Nealis & Peter, 2008). Nikiforuk (2011) was most frank about the impact of the federal government's shutting down of the Forest Insect Disease Surveys (FIDS) conducted by the Canadian Forest Service, up until the late 1990s. Their last report dates to 2003, focusing on forest insects and diseases in the province of Ontario, but as Nikiforuk described, the last MPB survey was completed in 1998, just prior to the eruption of the mountain pine beetle outbreak. Without key monitoring in place, the beginning of the beetle outbreak wasn't observed or tracked, which may explain why there was such a focus for research to try to determine a necessary understanding of where the beetles came from. Scientists may have very good reason to assert the need to ongoing basic research to be undertaken. Recent research (Cudmore et al., 2010) identified three genetically distinct populations of MPB in British Columbia, only the northernmost of which expanded its range into Alberta and the boreal forest.

If, as exothermic animals, insects are predisposed to being more susceptible to climatic changes at a regional and provincial scale than other animals, both for their ability to reproduce quickly, then governments and scientists and resource managers should be interested in them as the proverbial canaries in coal mines. Resource managers should develop more proactive systems of monitoring and tracking that may begin with a revival of the Forest Insect Disease (FID) surveys. Scientists in my study and the literature have also already identified other species that may positively respond to climate changes in the near term. While that will cover some of the economic dimension of potential impact, it still remains to see whether insects can fundamentally change forest composition and structure. The lodgepole pine is an excellent example in British Columbia. Both from my own impressions of landscape recovery in the Chilcotin region of British Columbia, one of the areas affected most severely by the

mountain pine beetle, and from research indicating the success of forest recovery in this region, the lodgepole pine has quickly and successfully repopulated much of the same habitat as before the outbreak. Some of the regenerating stands have also required thinning, due to their enthusiastic regrowth; the density of saplings would not be beneficial at the mature stand level.

As presented in Chapter 4, scientists exhibited a broad awareness for other examples of insects that have the potential for significant negative economic or aesthetic impact or large scale landscape (ecological) impacts in the near future. While not all insects with the potential for outbreak on the scale or severity of the MPB may have the same result, it is possible that an outbreak by an insect like the emerald ash borer (*Agrilus pluripennis*) may dramatically alter city and urban landscapes, as well as large-scale forested landscapes by causing widespread death among ash trees. Such an outbreak would require immense coordination and effort in response, perhaps similar to that exerted in the case of the mountain pine beetle outbreak. To support basic scientific research now may be a prudent investment in order to understand best management options for the future.

5.2.5 Geography of the Sites of Research: Novel and Hybrid Ecosystems as Research Fuel

Evidence that scientists were particularly interested in understanding the newest developments of the outbreak (*viz.* the beetle successfully spreading to and colonizing the boreal forest in Alberta) became clear when reviewing what the sites of study were that scientists mentioned during their interviews. My findings show that ecological novelty (the beetle spreading into an area it hadn't historically been before) attracted scientists' and research funders' attention. Many scientists expressed interest and motivation in being on the border-zones of the expansion of the outbreak in the northward dimensions of the outbreak, eastward into the boreal forest, and higher up in elevation. As several scientists explained, there were very basic questions that needed to be answered at the beginning of the range expansion, including "Can the beetle survive and successfully reproduce in the boreal forest?" (VN, 2013) and "How much did climatic changes impact the outbreak?" (AC, 2013).

The mountain pine beetle's range expansion into an enormous landscape is an interesting example of an area where training, institutional and professional support, inclination to discover, ask questions, and an expectation to conduct research in an area of growing concern merged: the vast majority of researchers interviewed were based in British Columbia (13 of 16), in line with the historical presence of the mountain pine beetle, and yet the majority undertook research in Alberta with the significant range expansion observed during and post-peak of the outbreak (2007-2009). This isn't to say that researchers based in a particular province necessarily need to take on research sites in their home province, though it is likely easier and costs fewer resources; there are numerous cases where scientists' research sites are in other provinces, or even other countries, and in that sense, the location of the home institution is of lesser importance. It is also common for an academic's degrees and post-docs to have taken place at different institutions, so there is some moving around inherent to becoming an academic, especially in today's competitive work environment.

The flurry of outbreak focused research conducted was also primarily mediated by funding and in some cases, by institutional support. For example, in the late 1990s/early 2000s, SL was the only entomologist at UNBC. In the 2000s, a number of faculty were added to UNBC's roster, including Drs. Lisa Poirier, Dezene Huber, and Brian Aukema. SL (2013) mentioned that he nominated DH for a Canada Research Council Chair based at UNBC, which he was awarded in 2005. As DH (2013) stated about that academic position: "I came here, hired on to work as a forest entomologist and chemical ecologist, that was what my Canada Research Chair Title was specifically when I came here, so I knew I would be working on something like that..." That Canada Research Chair position did not detail undertaking research in Alberta, but was enabled by his position, funding, technology, and collaboration with the TRIA Network. Notably, DH, like the majority of other researchers, quickly adapted and responded their research programmes to the range expansion of the mountain pine beetle. In contrast, Dr. Brian Aukema did not receive the research support he needed to carry out his work, so while he moved his laboratory to the United States (and to where he did have more institutional and financial support), his research continued

with his colleagues and in very similar geographic areas of focus as before. Even his graduate students moved with him, but were conferred degrees from UNBC (Aukema, 2010).

Only two scientists focused their research on solely BC sites where the outbreak took place. This is quite significant, given that MPB outbreaks had historically been a “BC problem” (AP1, 2013). The majority of scientists shifted their research sites to focus on the novel beetle-boreal interactions, and the three Alberta-based researchers shifted into mountain pine beetle research in their home province. Regardless of institutional background, the significant majority of scientists focused on developing research that seems to have engaged with the novel aspects of the outbreak.

The scientists’ attraction to undertaking research in landscape scale *novel* territory for the beetle cannot be mistaken, though what emerges is the challenge of doing so. Different scientists could only focus on different pieces of the outbreak, and it seems there is a challenging tension between building an understanding of the big picture from the much smaller scale components (whether beetle pheromones or fungal associates or tree genomics) that contribute to that bigger picture. Undoubtedly the multiplicity of reasons for undertaking the research are important: to understand beetle and tree and fungi specific relationships, and how climate change affects these relationships, and what economic dimensions or ramifications stem from this event (a branch of TRIA’s work), or what grant applications succeeded in obtaining funding, but none of this would have been possible if billions of beetles hadn’t flown British Columbia’s coop to the one next door in Alberta and the boreal forest.

As reported by scientists in Chapter 4, scientists identified numerous characteristics about the MPB outbreak were new, and these novel dimensions gave scientists an enormous chore and task to first define, then describe and characterize these changes, and then to understand, ask (predominantly) fundable research questions and—in some rare cases—advocate for how their insights applied to responses to these novel outbreak characteristics and their resultant economic and societal implications. These findings suggest that ecological novelty—the generation of novel ecosystems and hybrid ecosystems with novel characteristics—will continue to engage and employ scientists well into the future. Issues of ecological novelty, as they

pertain to the mountain pine beetle and with numerous other examples in the literature (eg. (Hobbs et al., 2014; Hobbs et al., 2009; Lugo, Carlo, & Wunderle, 2012)), generate a flurry of activity, especially when they become significant enough events that citizens, politicians, organizations realize they will negatively be impacted by these issues. Large-scale, rapid ecological change with novel characteristics necessitates further examination and research, and opens up opportunities for scientific enquiry and wider scientific engagement.

With the persistence of carbon dioxide pollution in the atmosphere, and the lifespan of CO₂ in the atmosphere guaranteeing a time-lag effect of warming continuing into the mid-21st Century and beyond, issues of novel or even hybrid ecosystems, rapid ecological change, and landscape level change will undoubtedly continue to challenge those trying to document, understand, and respond to changes, whether they are scientists, policy- and decision-makers, resource managers, or citizens, and even though each of those actors have different options for response. That complex issues such as the MPB outbreak require scientists to think broadly and engage across disciplines, and cause policy and governance networks to shift is becoming more apparent (Doelle, Henschel, Smith, Tollefson, & Wellstead, 2012). In the future, I think my research supports the argument that the novel ecosystems concept—with its attendant differentiations of hybrid and historical ecosystems—may become increasingly important for bringing together and giving a common language for those trying to describe, understand, make prescriptions and recommendations based on observations of fast-paced change (Hobbs et al., 2014). It is possible evidence of this is already being seen with the example of the dominance of novel ecosystems at the Ecological Society of America's 2016 conference (Higgs, 2016).

5.3 Reflections and Directions for Future Research

The questions I asked at the beginning of this project were useful for catalyzing my research efforts, but have long appeared to me to be inelegant, and lacking nuance when it comes to what are very clearly quite complicated relationships between science and policy, and scientists and decision-makers. The story that emerges from my

research indicates a much more complex relationship between scientific knowledge production, its uptake in/influence on policy-making circles, and how important structural and institutional factors are in shaping the context in which knowledge is produced. It is evident now that there are ample ways in which these relationships and connections could be explored. This chapter has already discussed numerous opportunities for further research throughout. However, I would like to highlight that as discussed above (Section 5. 2.2), the TRIA Network and Albertan government relationships seems to have emerged as a fascinating science-policy collaboration, and so much more could be undertaken to understand this emerging relationship further. It's not clear from the comments made there exactly how the relationship between the Province of Alberta and the TRIA Network continues to play out as the beetle moves through the boreal forest in Alberta, but there is a great opportunity here to ask a number of further questions about this unfolding relationship, including: does the TRIA Network (and TRIA scientists) act as a "boundary organization", translating and making more accessible the scientific research it produces, and linking science and policy (Knapp & Trainor, 2013)? Boundary organizations have been emerging recently as a response to answer calls for more usable science (Lemos et al., 2012). Does TRIA constitute an example of "co-produced" knowledge, whereby an iterative and interactive relationship between scientists and policymakers emerges, and, perhaps importantly, *lasts* for the duration deemed useful by its stakeholders? Does the TRIA Network have a net positive effect for translating science and making it more immediately applicable, especially within policy-making and decision-making government contexts? Does this collaboration yield more immediately applicable scientific knowledge for policy? Or, does the TRIA Network augment the effectiveness of the scientific knowledge that was produced in response to the outbreak? Further research to understand how this organization and key scientists built more direct bridges to policy would be interesting, alongside an evaluation of the network's overall effectiveness.

This expansion of research networks and connections likely would not have happened without the climate-exacerbated dimensions of the MPB outbreak (for this I look at the incidence of at least three other major historical outbreaks, and several

smaller localized outbreaks in BC and central western Alberta in the last 150 years (Alfaro et al., 2010), which did not yield a similar kind of unifying organization like TRIA). As such, it seems possible to suggest that increasingly large scale, complex issues increase the need for engagement among multiple jurisdictions and more diverse actors: it increases the need for science and policymakers to work together more closely, and perhaps decrease the gaps between science and policy.

To conclude these thoughts, future research could almost certainly include an inquiry into the policy and decision-making side of government staff engaging with TRIA scientists. Scientists I spoke with criticized the BC government and forestry industry for their responses to the outbreak, but applauded the AB government for engaging more directly with their science; I felt a little bit like rocks were being thrown from one side of the fence (scientists/knowledge producers) to the other, without giving the knowledge-consumer/government/management side a chance to respond. Future research could certainly expand to interview and engage with policy and industry actors to better understand motivations and adaptation responses on their side.

Another reflection that emerges is that this thesis developed farther and father from some of the science studies that initially drew me in, and indeed, there are fewer explicit connections than I had anticipated to make to ANT and science studies in this discussion. Perhaps some of this is explained by my own discomfort with ideas and texts that grew more opaque, the longer I held onto them: like looking at any single word for too long, which then becomes alien. At first, ANT seemed like an exciting concept with great promise. However, further reading muddied the waters. In his essay, "On recalling ANT", Latour (1999) begins: "I will start by saying that there are four things that do not work with actor-network theory; the word actor, the word network, the word theory and the hyphen! Four nails in the coffin" (p. 15). His essay proceeds to take apart and discuss how his perspectives shifted on those four components of his pioneering theory. That essay alone was not responsible for shaking my enthusiasm for ANT (ideas do change and evolve), but more and more I found myself questioning, "What is he talking about?" and more dissatisfied with my understandings of those ideas. I think to sum it up, knowing that several of my

participants (scientists) were interested in my study results, I felt less comfortable in tying more interpretive findings that meshed with ANT ideas than I did focusing on results that connected more clearly with science policy literature. I think the links there are more direct, timely, and recognizable for scientists who shared their experiences of connecting to (or failing to) connect to policy- and decision-makers, and who participated in the gradual network expansion of TRIA. This experience seems to me a lesson in focus and scope: asking broad research questions gets you a lot of information, and making meaning from qualitative data can go in a few different directions. Having kept my participants in mind, I opted to pursue a route that could more clearly speak to them.

On a different but related note: on one hand, I acknowledge the importance for science to be objective, powerful, reliable, and on the other I hold the thought that there are limitations to the way that scientists approach a climate and beetle-impacted landscape (ecological, social, and economic), that there is selectivity in how scientific objectivity becomes active; in other words, that Haraway was on to something when she described the “privileged partial perspective” that she believed was closer to the truth of understanding the world. What emerges from the interviews is transparency that some research questions are clearly more fund-able than others, and that this enables a particular translation or view of the world, painted by research monies. I acknowledge that it is important to understand the contextual factors that influence scientific knowledge production generally, and the mountain pine beetle science specifically, in order to understand how some of our most privileged knowledge production institutions reveal that they are not objective. Being honest to the factors that influence science attunes us more to how power is selectively applied, and consequently, can indicate how and whether scientists are adapting, or not. The case of the mountain pine beetle reveals a lot of barriers and institutional restrictions on how scientists are able to respond to fast-paced, landscape level change, and yet how collaboration and persistence, and a bit of luck pulled together a group of dedicated MPB scientists.

5.4 Conclusion

Thinking across the themes within the findings, my work contributes to building an understanding of places where scientists can provide useful and helpful roles in producing knowledge about an insect that has resulted in significant economic loss and temporary ecological disruption (though I do not characterize that disruption as good or bad). What this study supports is the notion that scientific knowledge production is not a clear cut process, and is very much a social product—a product of its environment, of the political climate around it, and contingencies like conversations between a scientist and a policymaker that go well. My research supports the assertions of those who argue that the usability of science is best maximized through “deliberate science policy design and implementation” (Dilling and Lemos, p. 681), and that there is much more that can be done to balance the production of scientific knowledge with its demand (Cairney, 2016; Sarewitz and Pielke, 2007). Some of the factors that mediate the usefulness of science include the cultural and institutional components, as well as the meaningful, iterative connections between scientists and policy- and decision-makers, such as those exemplified by the TRIA Network. My discussions with scientists were wide-ranging to shed light on their roles during the outbreak, even if they were limited and/or enabled in particular ways, given their institutional contexts. Even though scientific knowledge remains one of our most valuable and reliable ways of understanding the world (Oreskes, 2014), it is clear that this knowledge is not always available in the right form, does not always get to where it needs to go, and that it sometimes does not appear at the right place in the right time. Working on relationships between academia, government, industry, and non-governmental organizations in response to challenging, fast-paced environmental issues of the future will keep many a scientist, forester, entomologist, policy advisor and resource manager very busy, and as with the latest mountain pine beetle outbreak, will likely see more reactive relationship changes between science and policy. Looking forward, I hope that some of these reactive responses may become proactive instead, that scientists have more say in provincial management decisions, and that with the ear of the right decision-maker/funding body there is an increased understanding that climate change is shaking up the predictability and stability of our socio-ecological

systems. We are, I anticipate, due for more ecological and environmental surprises in our future.

Bibliography

- Alfaro, R., Axelson, J., & Hawkes, B. (2008). Mountain pine beetle increases the complexity of fire-origin lodgepole pine stands in British Columbia, Canada. In Mountain Pine Beetle: From Lessons Learned to Community-Based Solutions Conference Proceedings. *Journal of Ecosystems and Management*, 9(3), 1–181.
- Alfaro, R., Campbell, E., & Hawkes, B. (2010). Historical frequency, intensity, and extent of mountain pine beetle disturbance in British Columbia. *Natural Resources Canada*, 1–60.
- Bank, T. W. (2014). Project Performance Assessment Report Brazil: Ecosystem restoration of riparian forests in Sao Paulo. *Report No. 87105, TF-55091*, 1–46.
- Bentz, B. J., Régnière, J., Fettig, C. J., Hansen, E. M., Hayes, J. L., Hicke, J. A., et al. (2010). Climate change and bark beetles of the Western United States and Canada: Direct and indirect effects. [Http://Dx.Doi.org/10.1525/Bio.2010.60.8.6](http://Dx.Doi.org/10.1525/Bio.2010.60.8.6), 60(8), 602–613. <http://doi.org/10.1525/bio.2010.60.8.6>
- Besel, R. D. (2011). Opening the black box of climate change science-Actor-Network, 1–17.
- Biagioli, M. (Ed.) (1999). *The science studies reader*. New York, NY: Routledge.
- Bidwell, D., Dietz, T., & Scavia, D. (2013). nclimate1931. *Nature Publishing Group*, 5(7), 610–611. <http://doi.org/10.1038/nclimate1931>
- Burton, P. J. (2010). Striving for sustainability and resilience in the face of unprecedented change: The case of the Mountain Pine Beetle Outbreak in British Columbia. *Sustainability*, 2(8), 2403–2423. <http://doi.org/10.3390/su2082403>
- Callon, M. (1998). Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St. Brieuc Bay. In M. Biagioli (Ed.), *The science studies reader* (pp. 67-83). New York, NY: Routledge.
- Carroll, A. (2012). *CC and forest insects review* (pp. 1–20). University of British Columbia, Department of Forest Sciences.
- Carroll, A. L., Taylor, S. W., Regniere, J., & Safranyik, L. (2003). Effect of climate change on range expansion by the mountain pine beetle in British Columbia. *The Bark Beetles, Fuels, and Fire Bibliography*, 1–13.
- Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., & Jaeger, J. (2002). Salience, credibility, legitimacy and boundaries: Linking research, assessment, and decision making (No. RWP02-046). *Harvard University: Faculty Research Working Paper Series* (pp. 1–25).
- Castree, N., Adams, W. M., Barry, J., Brockington, D., Büscher, B., Corbera, E., et al. (2014). Changing intellectual climates. *Nature Publishing Group*, 4(9), 763–768. <http://doi.org/10.1038/nclimate2339>
- Christmann, G., Balgar, K., & Mahlkow, N. (2014). Local constructions of vulnerability and resilience in the context of climate change. A comparison of Lübeck and Rostock. *Social Sciences*, 5(1), 142–159. <http://doi.org/10.3390/socsci3010142>
- Collard, R., Dempsey, J., & Sundberg, J. (2014). *A Manifesto for Abundant Futures* (pp. 1–12).
- Cooke, B. J., & Nealis, V. G. (2004). Update on the threat of mountain pine beetle to

- boreal and eastern pines (pp. 1–27).
- Creswell, J. W. (1994). *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks, CA: Sage Publications.
- Cudmore, T. J., Björklund, N., Carroll, A. L., & Staffan Lindgren, B. (2010). Climate change and range expansion of an aggressive bark beetle: evidence of higher beetle reproduction in naïve host tree populations. *Journal of Applied Ecology*, *47*(5), 1036–1043. <http://doi.org/10.1111/j.1365-2664.2010.01848.x>
- Dilling, L., & Lemos, M. C. (2011). Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change*, *21*(2), 680–689. <http://doi.org/10.1016/j.gloenvcha.2010.11.006>
- Doelle, M., Henschel, C., Smith, J., Tollefson, C., & Wellstead, A. (2012). New governance arrangements at the intersection of climate change and forest policy: Institutional, political, and regulatory dimensions. *Public Money & Management*, *90*(1), 37–55. <http://doi.org/10.1111/j.1467-9299.2011.02006.x>
- Dukes, J. S., & Mooney, H. A. (1999). Does global change increase the success of biological invaders? *Tree*, *14*(4), 135–139.
- Ellis, E. C., & Ramankutty, N. (2008). Putting people in the map: Anthropogenic biomes of the world. *Frontiers in Ecology and the Environment*, *6*(8), 439–447. <http://doi.org/10.1890/070062>
- Gayathri Samarasekera, G. D. N., Bartell, N. V., Lindgren, B. S., K, C. J. E., Davis, C. S., James, P. M. A., et al. (2012). Spatial genetic structure of the mountain pine beetle (*Dendroctonus ponderosae*) outbreak in western Canada: Historical patterns and contemporary dispersal. *Molecular Ecology*, *21*(12), 2931–2948. <http://doi.org/10.1111/j.1365-294X.2012.05587.x>
- Gotzek, D., Brady, S. G., Kallal, R. J., & LaPolla, J. S. (2012). The importance of using multiple approaches for identifying emerging invasive species: The Case of the Raspberry Crazy Ant in the United States. *PLoS ONE*, *7*(9), e45314. <http://doi.org/10.1371/journal.pone.0045314.s002>
- Gusterson, H. (1998). *Nuclear rites: A weapon's laboratory at the end of the Cold War*. Berkeley, CA: University of California Press.
- Hamish Kimmins, J. P., Seely, B., Welham, C., & Zhong, A. (2012). Possible Forest Futures: Balancing Biological and Social Risks in Mountain Pine Beetle Epidemics (No. 2005-11). *Mountain Pine Beetle Initiative Working Paper 2005-2011* (pp. 1–59). Canadian Forest Service.
- Haraway, D. (1988). Situated knowledges: The science question in feminism and the privilege of partial perspective. In: M. Biagioli (Ed.), *The science studies reader* (pp. 172-188). New York, NY: Routledge.
- Harvey, W. S. (2010). Methodological approaches for interviewing elites. *Geography Compass*, *4*(3), 193–205. <http://doi.org/10.1111/j.1749-8198.2009.00313.x>
- Harvey, W. S. (2011). Strategies for conducting elite interviews. *Qualitative Research*, *11*(4), 431–441. <http://doi.org/10.1177/1468794111404329>
- Higgs, E. (1997). What is good ecological restoration? *Conservation Biology*, *11*(2), 338–348.
- Higgs, E. (2016). Novel and designed ecosystems. *Restoration Ecology*. <http://doi.org/10.1111/rec.12410>
- Hobbs, R. J. (2013). Grieving for the past and hoping for the future: Balancing

- polarizing perspectives in conservation and restoration. *Restoration Ecology*, 21(2), 145–148. <http://doi.org/10.1111/rec.12014>
- Hobbs, R. J., Arico, S., Aronson, J., Baron, J. S., Bridgewater, P., Cramer, V. A., et al. (2006). Novel ecosystems: Theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*, 15(1), 1–7. <http://doi.org/10.1111/j.1466-822X.2006.00212.x>
- Hobbs, R. J., Higgs, E. S., Hall, C. M., Ewel, J. J., Hallet, L. M., Standish, R. J., et al. (2013). *Novel ecosystems: Intervening in the new ecological world order*. Wiley-Blackwell, 1–386.
- Hobbs, R. J., Higgs, E., & Harris, J. A. (2009). Novel ecosystems: Implications for conservation and restoration. *Trends in Ecology & Evolution*, 24(11), 599–605.
- Hobbs, R. J., Higgs, E., & Harris, J. A. (2014). Novel ecosystems: Concept or inconvenient reality? *Trends in Ecology & Evolution* 29(12), 645–646.
- Holt, A. (2010). Using the telephone for narrative interviewing: a research note. *Qualitative Research*, 113–121.
- Jenkins, M. J., Hebertson, E., Page, W., & Jorgensen, C. A. (2008). Bark beetles, fuels, fires and implications for forest management in the Intermountain West. *Forest Ecology and Management*, 254(1), 16–34.
- Keeling, C. I., Henderson, H., Li, M., Yuen, M., Clark, E. L., Fraser, J. D., et al. (2012). Transcriptome and full-length cDNA resources for the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, a major insect pest of pine forests. *Insect Biochemistry and Molecular Biology*, 42(8), 525–536. <http://doi.org/10.1016/j.ibmb.2012.03.010>
- Knapp, C. N., & Trainor, S. F. (2013). Adapting science to a warming world. *Global Environmental Change*, 25(5), 1296–1306. <http://doi.org/10.1016/j.gloenvcha.2013.07.007>
- Kurz, W. A., Dymond, C. C., Stinson, G., Rampley, G. J., Adger, N., Carroll, A. L., et al. (2008). Mountain pine beetle and forest carbon feedback to climate change. *Nature*, 452(7190), 987–990. <http://doi.org/10.1038/nature06777>
- Latour, B. (1999). On recalling ANT. In J. Law & J. Hassard (Eds). *Actor Network Theory and after* (pp. 15–25). Malden, MA: Blackwell Publishers.
- Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.
- Latour, B., & Woolgar, G. (1986). *Laboratory life: The construction of scientific facts*. Princeton, NJ: Princeton University Press.
- Law, J. & Hassard, J. (Eds.) (1999). *Actor Network Theory and after*. Malden, MA: Blackwell Publishers.
- LeBrun, E. G., Abbott, J., & Gilbert, L. E. (2013). Imported crazy ant displaces imported fire ant, reduces and homogenizes grassland ant and arthropod assemblages. *Biological Invasions*, 15(11), 2429–2442. <http://doi.org/10.1007/s10530-013-0463-6>
- Lemos, M. C., & Morehouse, B. J. (2005). The co-production of science and policy in integrated climate assessments. *Global Environmental Change*, 15(1), 57–68. <http://doi.org/10.1016/j.gloenvcha.2004.09.004>
- Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature Publishing Group*, 2(11), 789–794. <http://doi.org/10.1038/nclimate1614>

- Lindquist, E., & Wellstead, A. (2001). Making sense of complexity: Advances and gaps in comprehending the Canadian forest policy process. In M. Howlett (Ed.), *Canadian forest policy: Adapting to change* (pp. 419–446). University of Toronto Press.
- Lindsay, R. W., & Zhang, J. (2005). The Thinning of Arctic Sea Ice, 1988–2003: Have We Passed a Tipping Point? *Journal of Climate*, *November 2005*, 4879–4894.
- Logan, J. A., & Powell, J. A. (2001). Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). *American Entomologist*, *47*(3), 160–173.
- Logan, J. A., Regniere, J., & Powell, J. A. (2003). Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment* *1*(3), 130–137.
- Lugo, A. E., Carlo, T. A., & Wunderle, J. M., Jr. (2012). Natural mixing of species: Novel plant-animal communities on Caribbean Islands. *Animal Conservation*, *15*(3), 233–241. <http://doi.org/10.1111/j.1469-1795.2012.00523.x>
- Majer, J. D. (2009). Animals in the restoration process — Progressing the trends. *Restoration Ecology* *17*(4), 315–319.
- Mbogga, M. S., Hamann, A., & Wang, T. (2009). Historical and projected climate data for natural resource management in western Canada. *Agricultural and Forest Meteorology*, *149*(5), 881–890. <http://doi.org/10.1016/j.agrformet.2008.11.009>
- McAfee, K. (2016). Whose Anthropocene? Revisiting Dipesh Chakrabarty's four theses. *RCC Perspectives: Transformation in Environment and Society*, *2*, 65–72.
- McFarlane, B. L., Stumpf-Allen, R. C. G., & Watson, D. O. (2006). Public perceptions of natural disturbance in Canada's national parks: The case of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins). *Biological Conservation*, *130*(3), 340–348. <http://doi.org/10.1016/j.biocon.2005.12.029>
- McNie, E. C., Parris, A., & Sarewitz, D. (2016). Improving the public value of science: A typology to inform discussion, design and implementation of research. *Research Policy*, *45*(4), 884–895. <http://doi.org/10.1016/j.respol.2016.01.004>
- Misof, B., Liu, S., Meusemann, K., Peters, R. S., Donath, A., Mayer, C., et al. (2014). Phylogenomics resolves the timing and pattern of insect evolution. *Science*, *346*(6210), 763–767. <http://doi.org/10.1126/science.1257570>
- Mogi, M., & Tuno, N. (2014). Impact of climate change on the distribution of *Aedes albopictus* (Diptera: Culicidae) in Northern Japan: Retrospective analyses. *Journal of Medical Entomology*, *51*(3), 572–579. <http://doi.org/10.1603/ME13178>
- Murcia, C., Aronson, J., Kattan, G. H., Moreno-Mateos, D., Dixon, K., & Simberloff, D. (2014). A critique of the “novel ecosystem” concept. *Trends in Ecology & Evolution*, 1–6. <http://doi.org/10.1016/j.tree.2014.07.006>
- Nealis, V. G., & Cooke, B. J. (2014). *Risk assessment of the threat of mountain pine beetle to Canada's boreal and eastern pine forests* (pp. 1–31). Canadian Council of Forest Ministers.
- Nealis, V., & Peter, B. (2008). Risk assessment of the threat of mountain pine beetle to Canada's boreal and eastern pine forests. *Government of Canada*, 1–45.
- Nelson, D. R., Adger, N., & Brown, K. (2007). Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources*, 1–27. <http://doi.org/10.1146/annurev.energy.32.051807.090348>
- Nelson, H. (2007). Does a crisis matter? Forest policy responses to the mountain pine beetle epidemic in British Columbia. *Canadian Journal of Agricultural Economics*, *55*, 459–470.

- Neuman, W. L. (1997). *Social research methods: Qualitative and quantitative approaches* (4th ed.). Boston, MA: Allyn and Bacon Publishing.
- O'Neill, G., Carlson, M., Berger, V., & Ukrainetz, N. (2008). Assisted migration adaptation trial. *TICtalk*, December 2008, 1-2.
- Oreskes, N. (2014). Why we should trust scientists. TED Talk.
- Parkins, J. R., & MacKendrick, N. A. (2007). Assessing community vulnerability: a study of the mountain pine beetle outbreak in British Columbia, Canada. *Global Environmental Change*, *17*, 460–471.
- Peters, G., Andrew, R., Boden, T., Canadell, J., Ciais, P., Le Quere, C., et al. (2013). The challenge to keep global warming below 2°C. *Nature Climate Change*, *3*(January 2013), 4–6.
- Petersen, B., & Stuart, D. (2014). Explanations of a changing landscape: A critical examination of the British Columbia bark beetle epidemic. *Environment and Planning A*, *46*(3), 598–613. <http://doi.org/10.1068/a4672>
- Pigott, D. (2012). *Whitebark pine in British Columbia* (No. Factsheet 1) (pp. 1–8). Forest Genetic Council of British Columbia.
- Raffa, K. F., & Berryman, A. A. (1987). *The American Naturalist*, *129*(2), 234-262.
- Raffa, K. F., Aukema, B. H., Bentz, B. J., Carroll, A. L., Hicke, J. A., Turner, M. G., & Romme, W. H. (2008). Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. *BioScience* *58*(6), 501. <http://doi.org/10.1641/B580607>
- Safranyik, L., & Wilson, B. (2006). The Mountain Pine Beetle. Canadian Forest Service.
- Safranyik, L., Shrimpton, D. M., & Whitney, H. S. (1974). *Management of Lodgepole Pine to Reduce Losses from the Mountain Pine Beetle*. Victoria, B.C., Pacific Forest Research Centre, Canadian Forestry Service.
- Sagan, C. (1996). The demon-haunted world: Science as a candle in the dark. Toronto, Canada: Random House.
- Sambaraju, K. R., Carroll, A. L., Zhu, J., Stahl, K., Moore, R. D., & Aukema, B. H. (2012). Climate change could alter the distribution of mountain pine beetle outbreaks in western Canada. *Ecography*, *35*(3), 211–223. <http://doi.org/10.1111/j.1600-0587.2011.06847.x>
- Sarewitz, D., & Pielke, R. A., Jr. (2007). The neglected heart of science policy: Reconciling supply of and demand for science. *Environmental Science & Policy*, *10*(1), 5–16. <http://doi.org/10.1016/j.envsci.2006.10.001>
- Scheffer, M., & Carpenter, S. R. (2003). Catastrophic regime shifts in ecosystems: Linking theory to observation. *Trends in Ecology & Evolution*, *18*(12), 648–656. <http://doi.org/10.1016/j.tree.2003.09.002>
- Scott, R. (2007). Economic impacts of the Mountain Pine Beetle on municipalities in B.C. *Municipal World*, (December 2007), 1–4.
- Seastedt, T. R., Hobbs, R. J., & Suding, K. N. (2008). Management of novel ecosystems: Are novel approaches required? *Frontiers in Ecology and the Environment*, *6*(10), 547–553.
- Shaw, I. G. R., Robbins, P. F., & Jones, J. P., III. (2010). A bug's life and the spatial ontologies of mosquito management. *Annals of the Association of American Geographers*, *100*(2), 373–392. <http://doi.org/10.1080/00045601003595446>

- Shermer, M. (1997). *Why people believe weird things: Pseudoscience, superstition, and other confusions of our time*. New York, NY: W.H. Freeman and Company.
- Shore, T. L., Brooks, J. E., & Stone, J. E. (Eds.). (2004). *Mountain Pine Beetle Symposium: Challenges and Solutions* (No. Information Report BC-X-399, 399 ed.). *Natural Resources Canada* (pp. 1–284). Victoria.
- Spittlehouse, D. L., & Stewart, R. B. (2003). Adaptation to climate change in forest management. *BC Journal of Ecosystems and Management*, 4(1), 1–11.
- Swart, R., Biesbroek, R., & Lourenço Capela, T. (2014). Science of adaptation to climate change and science for adaptation. *Frontiers in Environmental Science*, 2(July 2014), 1–8. <http://doi.org/10.3389/fenvs.2014.00029/abstract>
- The Professional Institute of the Public Service of Canada. (2013). *The big chill: Silencing public interest science, a survey* (pp. 1–8). The Professional Institute of the Public Service of Canada.
- Traweek, S. (1988). *Beamtimes and lifetimes: The world of high energy physicists*. Cambridge, MA: Harvard University Press.
- Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. *Science*, 277(5325), 494–499. <http://doi.org/10.1126/science.277.5325.494>
- Wallis, C. M., Huber, D. P. W., & Lewis, K. J. (2011). Ecosystem, location, and climate effects on foliar secondary metabolites of lodgepole pine populations from central British Columbia. *Journal of Chemical Ecology*, 37(6), 607–621. <http://doi.org/10.1007/s10886-011-9958-8>
- Wang, T., & Aitken, S. (2011). *Development of a climate based seed transfer system for British Columbia* (pp. 1–44). Centre for Forest Conservation Genetics.
- Wang, T., Hamann, A., Spittlehouse, D., & Carroll, C. (2016). Locally downscaled and spatially customizable climate data for historical and future periods for North America. *PLoS ONE*, 11(6), e0156720. <http://doi.org/10.1371/journal.pone.0156720.s007>
- Wellstead, A., Davidson, D. J., & Stedman, R. C. (2006). Assessing approaches to climate-change related policy formulation in British Columbia's forest sector: The case of the mountain pine beetle epidemic. *Journal of Ecosystems and Management*, 7(3), 1–10.
- Westfall, J., & Ebata, T. (2014). *Summary of Forest Health Conditions in British Columbia* (No. Pest Management Report Number 15) (pp. 1–88). Ministry of Forests, Lands, and Natural Resource Operations.
- Williams, J. W., & Jackson, S. T. (2007). Novel climates, no-analog communities, and ecological surprises. *Frontiers in Ecology and the Environment*, 5(9), 475–482. <http://doi.org/10.1890/070037>
- Wilson, B. (2002). An overview of the Mountain Pine Beetle Initiative. *Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre*, 1–7.
- Wilson, B. (2004, January 14). The mountain pine beetle initiative. Natural Resources Canada, Pacific Forestry Centre.
- Yin, R. K. (2003). *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.

Appendix 1

Here follows a detailed account of the process I used to walk through my data with software NVivo 8 (please see Chapter 3 for more comprehensive information about methods).

1. My first run through the data, I superficially categorized interview questions to understand their frequency, accompanied by a glance through at the substance and preliminary themes emerging from the answers. This was in part to establish whether or not saturation of the data had been reached (get a sense of when I was seeing similarities or repetitions in the types of answers that I was hearing, and had thereby sampled reasonably across my pool of potential interviewees or not), and to see numerically how many times I had been able to ask each research question. In some cases there were external time constraints that meant that I only had a certain amount of time with a scientist for the interview, and because I had 18 interview questions, some ranging from specific and relatively straightforward to answer, to big questions that required more reflective, contemplative responses, this meant that if a participant only had an hour, we likely didn't have a chance to get through all the questions. Depending on the participant and the background research I had conducted on them prior to meeting with them, I prioritized the questions I thought they may be best-suited to answer, especially if we were short on time.
2. My second run through the data I began to identify broad and specific themes that were emerging through the interviews. These were content-based themes such as “mountain pine beetle metaphors,” or “funding” or “historical factors of the outbreak,” many of which were closely and directly related to specific research questions, though some were also not. Every section of every transcript was divided into the main content theme of the paragraph or comment. This stage took the most time, as I was keen to not skip or miss any of the content of the interviews. However, this led to so many themes that it was clear they needed to be sorted and clumped in some sort of tree structure which was more conducive for organizing the data, so I went through a third time.

3. My third run through then, refined the themes that I had found in my second run through, by clumping together very closely related themes, or realizing that I had called two themes the same thing. I clarified which themes were parent codes that encompassed smaller more specific themes that had emerged, or whether they were so specific and unrelated to others that they were an orphan node, and belonged to their own category. I also sorted out content that was outside of the scope of my research question, and which consequently I would not incorporate into the findings of my study. These were also ideas that were often peripheral to my study, which a scientist spoke about because they misinterpreted my interview question, or that was simply too unrelated to the central research questions I was asking.
4. On my fourth run through, I chose specific quotes that were exemplary of the kinds of ideas that the researchers had expressed during the interviews. This fourth run was undertaken to find segments of the interview transcripts that would lend themselves well for exemplifying the ideas that were shared during the interviews, and that would suit the writing of my findings in Chapter 4, the Findings.
5. As qualitative research analysis is a very iterative process, the final analysis part of the analysis process was dedicated to looking for contradictions in the data, and checking whether participants made statements in direct opposition to each other, or to ensure that I had accurately described the nuance and richness of the perspectives shared.

Appendix 2

List of Participants

The following table shows a complete list of this project's participants, their codes, their institutional affiliations, and the date when they were interviewed.

Table 1: List of Participants

| Scientist | Code | Affiliation | Date Interviewed |
|-------------------------|------|--|-------------------|
| Anonymous Participant 1 | AP1 | Federal Government, Pacific Forestry Centre | 25 June 2013 |
| Janice Cooke | JC | University of Alberta, TRIA | 3 July 2013 |
| Justine Karst | JK | University of Alberta | 3 July 2013 |
| Anonymous Participant 2 | AP2 | University of Alberta | 4 July 2013 |
| Phil Burton | PB | University of Northern British Columbia (formerly federal government) | 17 July 2013 |
| Kathy Lewis | KL | University of Northern British Columbia | 25 July 2013 |
| Anonymous Participant 3 | AP3 | University of Northern British Columbia | 26 July 2013 |
| Staffan Lindgren | SL | University of Northern British Columbia | 26 July 2013 |
| Dezene Huber | DZ | University of Northern British Columbia | 29 July 2013 |
| Anonymous Participant 4 | AP4 | BC Provincial Government | 14 August 2013 |
| Vince Nealis | VN | Federal Government, Pacific Forestry Centre | 28 August 2013 |
| Anonymous Participant 5 | AP5 | Federal Government, Pacific Forestry Centre | 10 September 2013 |
| Christopher Keeling | CK | University of British Columbia, TRIA | 4 October 2013 |
| Allan Carroll | AC | University of British Columbia (formerly federal government) | 28 October 2013 |
| Richard Hamelin | RH | University of British Columbia; Federal government, Laurentian Forestry Centre, TRIA | 1 November 2013 |
| Les Safranyik | LS | Retired, Federal Government, Pacific Forestry Centre | 6 March 2014 |

List of Abbreviations

AAC - Annual Allowable Cut

AB - the province of Alberta

BC - the province of British Columbia

CFS - Canadian Forest Service

LFC - Laurentian Forestry Centre

MLA - Member of the Legislative Assembly (provincial government)

MPB - mountain pine beetle

MPBI - The Mountain Pine Beetle Initiative (Government of Canada)

MPBO - Mountain pine beetle outbreak

MPBTF - The Mountain Pine Beetle Task Force (Province of British Columbia)

NE - Novel Ecosystem

NRCan - Natural Resources Canada

PFC - Pacific Forestry Centre

SK - the province of Saskatchewan

TRIA/The TRIA Network - Turning Risk Into Action for the Mountain Pine Beetle Epidemic Project

UBC - University of British Columbia

UNBC - University of Northern British Columbia

UofA - University of Alberta

Ethics Approvals (Scans)

The following two images show the University of Victoria Ethics Approvals and Ethics Renewal that this project received.

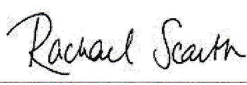


University
of Victoria

Human Research Ethics Board

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Certificate of Approval

| | |
|--|---|
| PRINCIPAL INVESTIGATOR: Heike Lettrari | ETHICS PROTOCOL NUMBER 13-153 |
| UVic STATUS: Master's Student | Minimal Risk - Delegated |
| UVic DEPARTMENT: ENVI | ORIGINAL APPROVAL DATE: 08-May-13 |
| SUPERVISOR: Dr. Eric Higgs | APPROVED ON: 08-May-13 |
| | APPROVAL EXPIRY DATE: 07-May-14 |
| PROJECT TITLE: The Mountain Pine Beetle, Climate Change, and Scientists: Understanding the Implications of Rapid Ecological Change | |
| RESEARCH TEAM MEMBER Dr. Eric Higgs, Supervisor (UVic) | |
| DECLARED PROJECT FUNDING: Pacific Institute for Climate Solutions Graduate (Master's) Fellowship; SSHRS Grant (Master's) (pending) | |
| CONDITIONS OF APPROVAL | |
| This Certificate of Approval is valid for the above term provided there is no change in the protocol. | |
| <p>Modifications To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.</p> <p>Renewals Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.</p> <p>Project Closures When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.</p> | |
| Certification | |
| This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants. | |
|  <hr/> Dr. Rachael Scarth Associate Vice-President, Research | |


Certificate Issued On: 08-May-13

13-153
Lettrari, Heike



Human Research Ethics Board
 Office of Research Services
 Administrative Services Building
 PO Box 1700 STN CSC
 Victoria British Columbia V8W 2Y2 Canada
 Tel 250-472-4545, Fax 250-721-8960
 Email ethics@uvic.ca Web www.research.uvic.ca

Certificate of Renewed Approval

| | |
|--|---|
| PRINCIPAL INVESTIGATOR: Heike Lettrari | ETHICS PROTOCOL NUMBER 13-153 |
| UVic STATUS: Master's Student | Minimal Risk - Delegated |
| UVic DEPARTMENT: ENVI | ORIGINAL APPROVAL DATE: 08-May-13 |
| SUPERVISOR: Dr. Eric Higgs | RENEWED ON: 28-Apr-14 |
| | APPROVAL EXPIRY DATE: 07-May-15 |
| PROJECT TITLE: The Mountain Pine Beetle, Climate Change, and Scientists: Understanding the Implications of Rapid Ecological Change | |
| RESEARCH TEAM MEMBERS: Dr. Eric Higgs, Supervisor (UVic) | |
| DECLARED PROJECT FUNDING: Pacific Institute for Climate Solutions Graduate (Master's) Fellowship; SSHRS Grant (Master's) (2012) | |
| CONDITIONS OF APPROVAL | |
| <p>This Certificate of Approval is valid for the above term provided there is no change in the protocol.</p> <p>Modifications To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.</p> <p>Renewals Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.</p> <p>Project Closures When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.</p> | |
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|  <hr/> <p>Dr. Rachael Scarth Associate Vice-President Research Operations</p> | |

13-153 Lettrari, Heike

Certificate Issued On: 28-Apr-14