ASSESSMENT OF
CLIMATE CHANGE AND IMPACTS OF ARMILLARIA ROOT DISEASE
(ARMILLARIA SPP.) IN ALBERTA’S BOREAL FOREST

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Climate Change, *Armillaria*, and Alberta’s Boreal Forest

Abstract

There are many health issues surrounding Alberta’s forests today and for the future. Health impacts of diseases, pests and climate change are currently being predicted in order to implement new management ideas and solutions, and identify specific research needs. This study examines state of the art knowledge on the current impacts of *Armillaria* root disease (ARD) (*Armillaria* spp.) in Alberta’s boreal forest region. It also assesses the biology and structure of the disease within this region to predict the extent to which the boreal forest may be impacted. In the next 50 years, both *Armillaria ostoyae* (Romag.) Herink and *Armillaria sinapina* Bérubé & Dessureault will become more of a problem, due to climate change and the current mature state of Alberta’s forests. *A. sinapina*, as a less-pathogenic but more opportunistic species, is predicted to be more prevalent than *A. ostoyae*, since the former will flourish when there are environmental stresses. Management practices will require research and evaluation of the use of alternative native tree species that have a higher resistance to the *Armillaria* species within Alberta and the impacts of such alternatives to the forestry industry and community structure. Future research is also essential to determine if one promising biological control agent and fungus, *Hypholoma fasciculare* (Huds. ex. Fr.), will be a viable and cost effective method to control *Armillaria* species within Alberta.
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1 Introduction

The climate within Alberta, and also the planet at large, is currently changing and, during the next 50 years, the ecological landscape will start to change as well. While there will be many changes, the main ones will be an increase in temperature; for example, it has already been predicted that, by the year 2050, the mean annual temperature for the boreal region will be three to five degrees above the current temperature (Cerezke, 2009). Higher temperatures in the summer may lead to drier forests and an increased potential for forest fires. There are predictions of longer frost free days, a longer growing season, an increase in the annual moisture index (AMI) and warmer winters (Cerezke, 2009).

Lower winter temperatures will be accompanied by extreme weather events such as severe storms, as well as flooding. In order to adjust to the changes, predictions need to be made that focus on the potential concerns that may emerge with forest diseases, forest practices, and general forest health concerns in the future. As the boreal forest will now be responding to all of these environmental changes, so will the pathogens within this forest.

This is a chief concern in Alberta due to the importance that this province places on its natural resources, and their utilization and manufacturing. So many Albertans depend on this resource for their lifestyle, employment and for their recreation. Forestry, within the boreal plains region of Alberta, can create communities and, with a downturn, also destroy them. It has become vital that scientists be able to forecast what may potentially improve or destroy the health and availability of these resources so that effective management strategies may be created and initiated.

Alberta’s boreal plains zone provides a valuable environmental, economic and social resource, not just for Albertan’s, but worldwide. Timber harvested from this area is utilized and
processed within Alberta, but is also exported to the United States (Natural Resources Canada, 2009; Bogdanski, 2008). This area is also valuable for the recreation industry (i.e., hunting, camping and fishing), agriculture and non-timber related products (Bogdanski, 2008). With such a valuable resource, pro-active steps need to be taken to ensure the health of these forests, especially in the view of changing climate.

*Armillaria* root disease (*Armillaria*) is found worldwide in many forests and gardens and, while sometimes a nuisance, it is not considered to be a major problem. Generally forests will maintain a delicate balance between a pathogen and its host but, when a forest is managed as many in Alberta are, this balance can be altered (Edmonds, Agee & Gara, 2000). Within Canada, *Armillaria* is considered important when looking at stands with natural regeneration and also in conifer plantations since the younger trees appear to be more susceptible (Hiratsuka, Langor and Crane, 1995). Mainly considered to be a secondary disease, this disease will attack an already damaged tree; however, it can also be a primary disease, depending on the conditions within the forest stand.

*Armillaria* root disease (*Armillaria* spp.) is also found in Alberta’s boreal forest. Currently, it is not an epidemic but, with climate change, there is the potential for an *Armillaria* epidemic to develop based on the observed damage this species is causing in the northern United States and southern British Columbia (Edmonds et al., 2000). Physical environment is an extremely important feature in the severity of any disease outbreak, and will play a major role in how *Armillaria* will behave within the forest (Chakraborty, Tiedemann & Teng, 2000). The development and life cycle of a disease will be influenced by environmental conditions which, in turn, can influence the host (Chakraborty et al., 2000) and its susceptibility to pathogens, insects
and human activities (Edmonds et al., 2000). Stress is caused by changing environmental conditions and the ability of a tree to adapt to these conditions.

A healthy forest has reached equilibrium where the amount of diseases and pests will not harm the forest, but help in its natural cycling. Many healthy forests are not stressed as the plants have adapted to the climate and conditions, and are in equilibrium with the pests and diseases. Climate change can alter this delicate balance by increasing seasonal temperatures, especially during the winter, leaving pests with the ability to over-winter instead of dying off. This increased virulence can lead to unhealthy, stressed trees; leaving the door open for more incidences of disease.

Management for Armillaria in Alberta involves maintaining a healthy forest and the balance of pathogen and host. Techniques used to both identify and manage Armillaria include monitoring and surveying, treating healthy stumps or removing them post-harvest, eliminating infected stumps or trees, different logging techniques (i.e. push-over), re-planting with resistant species (i.e. white birch) in disease centres, decrease soil compaction, and also minimizing root and stem damage (Alberta Sustainable Resource Development, 2009a). These have proven effective management techniques for the current situation of Armillaria within the forest.

There is a paucity of information on Armillaria relating specifically to the boreal forest within Alberta, where the major focuses for this region in recent years has been the forest pests, rather than diseases. While mountain pine beetle, spruce budworm and other pests are a major concern, especially as increasing climate change may exacerbate the current pest impacts on the health of the forest, more research still needs to be done on the diseases, which are considered to be secondary, but important problems.
Change and natural disturbances have always been part of a forest ecosystem. It is when disturbances fall outside of the range of natural environmental variation normally experienced by ecosystems where potentially detrimental impacts may occur. Armillaria spp. is an extremely important pathogen of forests today and may become more problematic in the future, particularly with the advent of climate change (Thormann, Myrholm & Mallett, 2001). Currently there is also little information on this disease or its resulting losses to forests in Canada’s prairie provinces (Mallet & Volney, 1999).

1.1 Research questions and objectives

This study will concentrate on the current impact of Armillaria root disease (Armillaria spp.) in Alberta’s boreal forest, in an attempt to predict what the effects of this disease will be 50 years in the future, based on climate change predictions, as well as assessing potential management strategies for mitigation. This involves examining the current state of knowledge to address the following objectives:

- examining the boreal forest community and its current value as a resource to Alberta and Canada;
- summarizing the current state of knowledge on climate change in the region, including current and future predictions;
- assessing the current state of the boreal forest, particularly in relation to Armillaria root disease (Armillaria spp.) and its biology;
- predicting the extent to which Armillaria (Armillaria spp.) may potentially impact boreal forests as climate changes in the next 50 years;
- examine potential management strategies for the mitigation of disease outbreaks; and
• explore the economic, social, and policy dimensions around boreal forests and their implications for effective management.

Identifying and analyzing existing information from other areas, as well as pinpointing information gaps on *Armillaria* spp. is vital to understanding its future interaction with Alberta’s boreal forest under changing climate, and the socio-economic impacts.
2 Literature Review

2.1 Boreal forest

The boreal forest can have differing definitions depending upon the locality (Burton, Messier, Weetman, Prepas, Adamowicz and Tittler, 2003). Generally speaking, the boreal zone is considered to be in the mid-northern to Arctic latitudes (Burton et al., 2003), located to the south of the Arctic Circle, has an area of 26,716,349 km² and is considered to comprise about 33% of the world’s forests in area (Canadian Council of Forest Ministers, 2009). Roughly 60% of the boreal forest is in Russia, Canada has almost 30%, and countries in Scandinavia have approximately 10%. The balance lies mainly in the United States (Alaska) and northern parts of Asia (Canadian Council of Forest Ministers, 2009). Every province contains sections of the 766,041,000 acres of boreal forest located inside Canada (Figure 1) (Canadian Council of Forest Ministers, 2009).
The features that make the boreal zone unique are that it contains only a few broadleaf and coniferous genera, and is considered to be a cold climate with a short growing season (Burton et al., 2003). Other characteristics of the boreal zone are shallow soils and/or glacial till, as well as organic soils on occasion that, in some areas, are poorly drained leading to muskeg creation. Successional stages within this zone are controlled by cycles of wildfire and insect outbreaks (Burton et al., 2003), and trees have a slow growth rate. These are excellent for construction and their fibers are also ideal for pulp production (Burton et al., 2003). Organic matter contained within the boreal stands decomposes slowly and creates an abundance of
nitrogen in the soil (Burton et al., 2003). Most large animal species in this zone tend to be migratory, particularly caribou (*Rangifer tarandus*). There is also a history of indigenous peoples linked to the area, along with many people who work in the oil and gas industry (Burton et al., 2003).

Within Canada, the largest forested ecosystem is the boreal region and, in Alberta, 60% of the province is covered by forest (Sustainable Resource Development, 2009b); of this, the boreal forest covers an area of 455, 550 km² (Bogdanski, 2009). The area generates many cubic meters of timber per year; for example, in 2004, the estimated harvest from the boreal forest was 24.3 million m³ (Bogdanski, 2009). According to Bogdanski (2008); when the 2004 estimated economic impacts of logging, forest timber, paper, and forest products industry are combined; there are 32,121 people employed, $11,927 million of combined total revenue generated, $1,596 million combined total wages earned, and a combined total revenue of $2,060 million created within Alberta. Although the majority of the boreal landscape is forested land, there are many commercial and research nurseries in this area that are also impacted by *Armillaria* (*Armillaria* spp.). These numbers demonstrate how economically and socially significant the boreal forest is to Alberta and Albertans.

While the boreal forest is home to many species of plants and animals, this study will focus on the species that are currently known to be impacted by *Armillaria* root disease (*Armillaria* spp.). These species are important both economically and as a resource for healthy, diverse forest communities. Species including black spruce (*Picea mariana* (Mill. B.S.P.)), jack pine (*Pinus banksiana* Lamb.), lodgepole pine (*Pinus contorta* Dougl. var. latifolia), and white spruce (*Picea glauca* (Moench) Voss), are all hosts for *Armillaria* spp. and are located within this area (Alberta Sustainable Resource Development, 2009; Burton et al., 2003).
2.2 Climate change

As climate change is a certainty, focus needs to be on predicting the most plausible events of the future. Cerezeke (2009) examines how the mean annual temperature (MET) in Alberta’s boreal forest will increase by three to five degrees: there will be longer frost-free days, and longer growing seasons. The mean annual precipitation (MAP) will likely be anywhere from 10% less or 15% more, but predictions are that there will be less moisture available during the summer (Cerezeke, 2009). This can create stresses on the forest ecosystem, as these changes and their frequency may be happening faster than the forest can adapt (Weber & Flannigan, 1997). It is also believed that a change in climate will lead to extreme unpredictable weather patterns and changes (Boland, Melzer, Hopkin, Higgins & Nassuth, 2004), outside of the normal range of environmental variation experienced by these ecosystems, along with an increase in the number of forest fires and insect disturbances (Lempréière, Bernier, Carroll, Flannigan, Gilsenan, McKenny, Hogg, Pedlar, and Blain, 2008).

Climate can influence the effect of pathogens by impacting its host species in a variety of ways. These impacts include altering the host’s distribution (moving southward/northward), decreasing natural defences, affecting nutrient and water availability, and altering forest stand dynamics (Dukes, Pontius, Orwig, Garnas, Rodgers, Brazee, Cooke, Theoharides, Stange, Harrington, Ehrenfeld, Gurevitch, Lerdau, Stinson, Wick & Ayres, 2009). As the host now has to deal with environmental stressors, they become more susceptible to a pathogen, which increases the risk and potential severity of infection (Boland et al, 2004). Other agents of disturbance; such as insects, wildfire and wind vectors, can “work synergistically with” pathogens and create a substantial area of infection (Boland et al, 2004).
To further explain how agents can work together, a tree that has been stressed can be made more susceptible to another agent of stress since it no longer has adequate defences. The initial stress could be a pathogen and, when faced with an insect pest, the tree cannot defend itself and becomes infested by the pest. This tree is then further weakened and, during a windstorm, can be blown down. This can potentially impact many trees within a stand, resulting in a further increase in the amount of litter and available fuel load for future wildfires and their greater frequency of occurrence (Lempière et al., 2008).

2.3 Armillaria root disease

Armillaria spp. can be found in any type of forest throughout the world, along with its wide variety of hosts, ranging from conifers and hardwoods to agricultural species (Edmonds et al., 2000). The Canadian prairie provinces contain four species of Armillaria fungi including Armillaria mellea (Vahl:Fr) Karst, A. sinapina Bérubé &Dessureault, A. calvesense Bérubé &Dessureault, and A. ostoyae (Romagn.) Herink. Armillaria ostoyae is considered to be the most important species, economically, since it is the most common (Hiratsuka et al., 1995) and the major causes of root rot in western Canada (Mallet & Volney, 1999).

Armillaria spp., also known as honey mushrooms (Figure 2), is a basidiomycete fungus and spread primarily through mycelial growth (Figure 3), although it is believed that new infections can be caused through basidiospores (Edmonds et al, 2000). Its rhizomorphs are usually one to two millimetres, dark, string-like structures which will grow in the soil and spread to other trees (Edmonds et al, 2000). When contacting a new host, it can penetrate the roots and infect the tissues, or it can be passed to a new host through contact with infected roots or stumps (Figure 4) (Edmonds et al, 2000). The maximum rate of spread is no more than one to two meters a year (Edmonds et al, 2000) under current climatic conditions.
Figure 2. *Armillaria* mushroom close-up (Source: Canadian Forest Service (Natural Resources Canada) reproduced with permission, 2011).
Figure 3. Mycelial fan shown on a pine tree (Source: Canadian Forest Service (Natural Resources Canada) reproduced with permission, 2011).
Hosts and diseases will generally stay in equilibrium and minor infections will not be evident in a healthy forest (Edmonds et al, 2000) unless there is a disturbance (Dettman & van der Kamp, 2001). When a forest is intensively or poorly managed, this delicate balance can be destroyed (Figure 5) (Edmonds et al, 2000). Climate change, human activity, insects and other pathogens can all impact how Armillaria spp. will respond in the forest.
According to Alberta’s Sustainable Resource Development (2009a), *Armillaria* (*Armillaria* spp.) management techniques include; monitoring and surveying a stand, identification of disease centres, removing healthy and infected stumps and, where centres of infections exist, the planting of resistant species (e.g. white birch (*Betula papyrifera* Marshall)). These techniques have been proven effective for minimizing the spread of this disease and maintaining healthy forests. While monitoring forest stands through aerial surveying to discover disease centre locations is the best and most cost effective method, it is impractical to remove healthy and infected stumps within a natural forest stand; this method is costly and more
effective in plantations (Chapman, Xiao and Myers, 2004). This disease is a worldwide concern so comparisons with other provinces, such as British Columbia, are also valuable to determine if there are more effective methods of controlling *Armillaria*. 
3 Research Methodologies

The research for this paper was completed through an extensive literature review based on articles from scientific journals, government organizations and the latest information from the Intergovernmental Panel on Climate Change (IPCC). There were discussions with experts from the Canadian forest service and one from Alberta Sustainable Resource Development. These discussions were to gather information from the two different organizations to learn more about Armillaria in a natural setting and how to cope with disease outbreaks. Research focused on Armillaria root disease, climate change, forest management practices and general forest health information.

3.1 Climate Change

The International Panel on Climate Change (IPCC) is the global authority on climate change and has the most reliable information on this subject. The IPCC engages scientists from all over the world who are experts in their area and ability to apply it. They update their work every few years and input data from carbon budgets and pollution. This enables them to create realistic models and predictions based on the latest and newest technology. During the literature search, very few articles were found that did not contain information provided by the IPCC; for this reason, predictions from the IPCC were preferred for this research. Although there have been many different papers from this group, the most recent, *Climate Change 2007 Synthesis Report* (IPCC, 2007) was evaluated. Governmental organizations such as Alberta Sustainable Resource Development and the Canadian Forest Service have also researched the impacts of climate change and are utilizing information from the IPCC, as well as their own. Climate change has
been a major focus of their research and what impact it will have on natural resource use, economic problems and, also, sustainable resource management.

Information from databases was vital in aiding in the predictions of this research and determining the importance of forestry to Alberta and Canada. This included the economics behind forestry, employment statistics, land usage, and also land lost by infestations. These numbers were not specifically analyzed, but evaluated as an aid in making predictions. This information came from Statistics Canada (2009) and the National Forestry Database (2009).

3.2 Armillaria Biology and Occurrence

Discussions were held with Mr. John Quinn, who works in the area of genetic improvement for the Alberta Government, and Dr. Ken Mallett who published many articles on Armillaria for the Canadian Forest Service. These researchers commented about their experiences with the disease and if they predicted it will be a problem. John Quinn has been working at the Alberta Tree Improvement and Seed Centre in Smoky Lake, Alberta. This facility is a major site for genetic improvement research and providing seedlings for Alberta’s forests. His assessment over whether or not Armillaria will become a problem and what they are doing to mitigate outbreaks were taken into account when gathering coping methods and also for conclusions. Dr. Ken Mallett, with the Northern Forestry Centre in Edmonton, Alberta has done much past research in Armillaria within Alberta. Information gained from him was focussed on Armillaria biology, management, control, concerns and mitigation. Many of his past research papers were also used as a source of information for this study.

Both the Canadian and the Alberta governments have put out climate change articles and basic predictions for what will happen in this area. Articles such as Cerezke (2009), Bogdanski (2008) and by Williamson, Colombo, Duinker, Gray, Hennessey, Houle, Johnston, Ogden, and
Spittlehouse (2009) have all shown that various levels of government are concerned about climate change and the country’s natural resources. Many agreed that temperatures will rise in the next 100 years and that this potentially can create a very large impact on the forest resources. While these articles did mention forest diseases, they were more focused on forest pests, such as the mountain pine beetle and spruce budworm. These articles, nevertheless, were used to focus on the importance of the resource to Canadians and Albertans, and also to find agreement as to what the expected temperature increases might be. Although they were not used to predict what the temperatures would be in the future, the intent was to determine if there was expert agreement to support conclusions and develop management strategies.

3.2.1 Armillaria and climate change.

While there was ample individual information available about Armillaria, climate change, and the boreal forest, no specific research was found that linked them all together. Articles from Thompson, Mackey, Mcnulty and Mosseler (2009), Cerezke (2009), Dukes et al. (2009), and Williams, Long, Wargo and Liebhold (2002) were used to link boreal forest and climate change. Other articles such as Lemprière et al. (2008), and Burton et al. (2003), were used to assess the connection between climate change, forest health and forest management strategies. Mallett (1989, 1992), Mallett and Volney (1999), and Shaw and Kile (1991) were sources of information for Armillaria biology. Shortle, Smith, Minocha, Minocha, Wargo and Vogt (2000) and Edmonds et al. (2000) provided information about forest health and Armillaria. Throughout the research, it appeared that most of the concern for forest health, again, was based on how insects will be interacting with climate change rather than on diseases and fungus. While this appeared to be of greatest concern, there was a clear connection between insects and diseases and fungus.
3.3 Predictions and Management

Models were not evaluated for this study since there was ample information available about what can be expected for climate change in the next 50 to 100 years. Following discussions with Dr. Mallett, no models were recommended that give any indication of future possibilities specifically for Armillaria spread.

Predictions were developed based upon the knowledge gained from an extensive literature review and information from experts. Although information on climate change and Armillaria was scarce, there was abundant information on each individually, as mentioned earlier; in particular, information about what will happen with climate change in the boreal forest. While models for Armillaria were not available, knowledge of Armillaria pathology were utilized to predict outcomes. Evaluations were based on the species pathology, as well as biology and optimum growing conditions for Armillaria. While Alberta’s northern boreal forest is divided up into many subregions, this study used the temperature information from the Boreal Forest natural region, due to its predominance in northern Alberta.

Management recommendations were based on what is currently acceptable and feasible. New methods were also explored to discover if there were any innovative strategies for coping and management strategies from British Columbia were also evaluated for effectiveness in Alberta.
4 Results

4.1 Examining the boreal forest community

Alberta is home to many diverse landscapes and plant communities. The province has been classified into five defined terrestrial ecozones. The largest one is the Boreal Plains, followed by the Prairie, Montane Cordillera, Taiga Plains and, lastly, a small corner of the Taiga Shield and Boreal Shield (Figure 6) (Lands Directorate, 1986). The subject area in this study is focused on the Boreal Plains of north-central Alberta, and also includes the Taiga Plains and Shield. Landscapes within these ecozones consist mainly of forested lands, but there are also areas of lakes, wetlands and also human settlements, including agriculture. As these landscapes can be more distinctly organized by physiography, soil type, vegetation, land use and climate; the Natural Regions Committee (2006) has further divided the Boreal Forest Natural Region (BFNR) into eight distinct natural sub-regions (Figure 6).
Figure 6. Natural Regions and Subregions of Alberta (Natural Regions Committee, 2005, reproduced with permission from Alberta Sustainable Resource Development, 2011).
According to the Natural Regions Committee (2006), vegetation within the BFNR is coniferous, deciduous and mixedwood forests. This area is also utilized for agriculture, which includes cultivation and grazing, but only where there is a sufficient growing season (Natural Regions Committee, 2006). The most common deciduous species are the trembling aspen (Populus tremuloides Michx) and balsam poplar (Populus balsamifera (L.) Mill); and the common coniferous species are white spruce (Picea glauca (Moench) Voss), black spruce (Picea mariana (Mill B.S.P)), and jack pine (Pinus banksiana Lamb) (Natural Regions Committee, 2006). The BFNR also contains many wetlands dominated by black spruce with shrubs and fen (Natural Regions Committee, 2006). Dominant soils for this region are the Luvisols, Brunisols, Gleysols, Organic soils and Cryosols (Natural Regions Committee, 2006).

Soil is the main characteristic that shapes the type of vegetation found in the boreal forest region (Bourgeau-Chavez, Kasischke, Mudd, and French, 2000; Lands Directorate, 1986). Luvisols are found on forested sites that tend to be well to imperfectly drained and lack humus, but have a substantial litter layer (Natural Regions Committee, 2006; Pedosphere.com, 2002). This soil type is found in cool to cold, sub-humid to humid climates (Pedosphere.com, 2002). Brunisols are well to imperfectly drained, but also contain weathered calcareous materials and can be acidic and occur in a variety of forest types and environments (Pedosphere.com, 2002).

Gleysols and Organic soils are found within the wetlands and also in other areas with poor drainage (Natural Regions Committee, 2006). Gleysols demonstrate periods of high saturation and poor conditions while being created (Pedosphere.com, 2002). Organic soils contain high levels of organic materials and have been highly saturated for extended periods of time (Pedosphere.com, 2002). The last order found in the BFNR are the Cryosols which are
found in the northern parts of Canada, in some instances north of the tree line, and can be in either mineral or organic materials that contain permafrost (Pedosphere.com, 2002).

The Dry Mixedwood Natural subregion, considered the warmest region in the BFNR, is characterized by aspen forest and fens along with undulating plains and cultivation where soils permit (Natural Regions Committee, 2006). The largest of the natural subregions has upland forests of aspen and mixedwood dominating the Central Mixedwood Natural subregion along with level and gently rolling plains, short summers and long winters (Natural Regions Committee, 2006). Lower Boreal Highlands natural subregions have mixedwood forests with the lodgepole pine x jack pine hybrids, along with hill systems and lower slopes (Natural Regions Committee, 2006). Wetlands at the base of the slopes are common and the climate consists of warmer summers and colder winters than the Upper Boreal Forest natural subregion (Natural Regions Committee, 2006). The Upper Boreal Forest natural subregion is dominated by coniferous forests and also contains the lodgepole pine x jack pine hybrids, hills and plateaus, wet cool summers and cold winters (Natural Regions Committee, 2006).

The Athabasca Plain natural region contains many dune fields and sandy plains with shrub and jack pine (Natural Regions Committee, 2006). Summers tend to be dry and warm while winters are long and cold (Natural Regions Committee, 2006). Lakes, rivers, marshes and creeks leading to meadows and riverine forests comprise the Peace-Athabasca Delta natural subregions (Natural Regions Committee, 2006). This area contains one of the largest freshwater deltas in the world and has summers with long growing seasons and cold winters (Natural Regions Committee, 2006). Northern Mixedwood natural subregions are dominated by wetlands and black spruce bogs in low elevations with short summers and extremely cold winters (Natural Regions Committee, 2006). The last natural subregion is the Boreal Subarctic which has elevated
plateaus, frozen Organic soils and black spruce bogs (Natural Regions Committee, 2006). Summers in this region are cool and short while winters are long and cold (Natural Regions Committee, 2006).

While northern Alberta contains a highly valuable forest community, and forestry is the foremost use of the area, there are many other resources and uses for the area. Many locations in central to northern Alberta are utilized for agricultural purposes, such as grazing or subsistence farming (Natural Regions Committee, 2006; Lands Directorate, 1986). Another large industry that is located within this zone is the exploration and production of oil and gas (Lands Directorate, 1986). Lastly, this area is utilized for recreational purposes such as hunting, camping and trapping (Lands Directorate, 1986).

4.1.1 Ecological value of the boreal forest.

The majority of Alberta’s 60% forest coverage is boreal (Figure 1 and Figure 6) (Sustainable Resource Development, 2009b). While the boundaries of this paper focus on the boreal forest in Alberta, this forest is not just located in Alberta, as noted earlier, but circumpolar spanning across North America, Asia and Europe (Burton et al., 2003). When comparing the amount of boreal forest distributed around the world, Russia is the only country with more boreal forest (Williamson et al., 2009); Canada is second with 40% of the world’s boreal forest and accounts for one-tenth of all the forested lands within the world (Burton et. al. 2009).

Timber is not the only value of the forest, there is also its ecological value stemming from its many other attributes. This area is the home to a variety of organisms, such as fungi, arthropods, wildlife and microorganisms that help to maintain these forest systems (Brant, 2009). Boreal forests function in the regulation of climate, both regionally and globally, along with purifying air and water quality, aiding in sequestration of carbon, and controlling erosion (Brant,
The removal of forests, such as the Boreal, is believed to be one of the main factors in the increase in carbon dioxide in the atmosphere, along with the burning of fossil fuels (Le Treut, Somerville, Cubasc, Ding, Mauritsen, Mokssit, Peterson and Prather, 2007). The boreal forest, with its slow decomposition rate and organic carbon in the soil, is vital to carbon sequestration within Canada and other global communities.

One of the main ecological functions of these forests is as reservoir of genetic and biological diversity (Brant, 2009). Although this land was glaciated 8,000 to 12,000 years ago, these forest are considered young (Brant, 2009; Burton et al., 2003) but still provide a significant degree of ecological diversity (Shvidenko and Apps, 2006). This diversity is also sustained by forest fire cycles that create various levels of landscape succession (Price and Apps, 1995). Fire creates a mosaic within the forest community of differing aged stands, patches of vegetation and mixed species (Price and Apps, 1995).

4.1.2 Economic and social importance of the boreal forest.

Boreal forests have played a huge part in the development and expansion of communities into the north (Volney and Flemming, 2000). Canada has more boreal forest in natural, never-been-cut state than the other countries that have boreal forest; this provides a vast supply of untapped wood fibre (Burton et al. 2003). The wood is considered to be of high quality because the trees are slow growing and uniform, making excellent pulp, plywood and dimensional lumber (Burton et al. 2003). This has created an industry that employs approximately half a million Canadians (Burton et al. 2003).

Many Albertans who live within the boreal forest are employed either directly or indirectly by the forestry industry, i.e., they could be directly harvesting trees, or working in production of pulp, plywood and particle board. According to Bogdanski (2008), 455,550km² of
forested land in Alberta is boreal and, as of 1996, 14.7% of that land base was utilized for agriculture. There were 3,290,350 people living in Alberta as of 2006 and, of those, 2,772,435 were located in the Prairies, 40,120 lived in the Montane Cordillera, 474,416 in the Boreal Plains, 3,100 in the Taiga Plains, 274 in the Taiga Shield and five in the Boreal Shield (Statistics Canada, 2009). While the majority of the population is located in the southern region of Alberta, in 2006, 15,139 people were employed in the forest products industry (Statistics Canada, 2009). By 2008, this number decreased to 13,705 (Statistics Canada, 2009). As of 2008, the employment rate in Canada’s forest products industry has declined for the eighth consecutive year (Statistics Canada, 2009). Reasons for the decrease in employment rate are likely due to the global economic downturn which caused a slump in the United States housing market and the reduction of newsprint production (Natural Resources Canada, 2009).

There are also employment opportunities that do not relate directly to the forest industry, but are still associated with the boreal forest or a forested environment. Northern Alberta is well known for its large oil and gas industry, as mentioned earlier, which employs many people from all over the country. Other forest related industries are non-timber forest products (e.g., mushroom harvest), recreational activities (e.g., camping, fishing, and hiking), hunting and trapping, and fisheries (Bogdanski, 2008). Many of these activities attract people and revenue from all over Canada and the United States. According to Statistics Canada (2009), the total amount of additional revenue from trapping in Alberta, for example, came to $2,937,729.

In Alberta, the total amount of forested land in 2007 was 27,718 thousand hectares, and the amount of forest harvested was 54,981 hectares, roughly 0.2% (Statistics Canada, 2009). The revenue from the sale of timber from provincial crown land in 2007 was $32,183,000 (National Forestry Database, 2009). While the main focus of a forest is often the value of the fiber, much
of its ecological value, as stated earlier, is in the forest’s ability to provide water, habitat for wildlife, fisheries and the biodiversity that is available within this land base (Edmonds et al., 2000).

4.1.3 Future concerns.

A healthy forest continually changes as a result of many different environmental agents, such as fires, wind, diseases, human disturbance and insects (Edmonds et al., 2000). Forest management practices for the past century have also impacted forest health and ecosystem function (Dukes et al., 2009; Edmonds et al., 2000), but these practices have also been improving and incorporating knowledge about environmental health concerns and issues. A well-managed forest within the ecosystem’s range of tolerance, potentially and theoretically, could reach a state of equilibrium where it will not be adversely affected by disturbance agents. Unfortunately, climate change has already started to alter this delicate balance by providing added stress on the trees’ current ability to adapt. This balance can be altered by a pathogen/pest species attacking the host and affecting its ability to take up available nutrition, utilize their defence compounds, and ultimately affecting species distribution in general at an ecosystem or landscape level (Dukes et al. 2009; Girardin, Raulier, Bernier and Tardif, 2008).

Current economic pressures facing the boreal forest are the potential altering of commercial species, a reduced inventory of available timber, and international competition associated with exporting timber and timber products (Bogdanski, 2008). There is also a requirement for more social and environmental amenities, such as tourism, which would create a more diverse economic base and, hence, a more stable, sustainable community (Bogdanski, 2008). Utilization of non-timber forest products, and also competition associated with exporting timber and timber products is also going to be important economically in the future (Bogdanski,
2008), in order to create a more diverse economy and lessen a complete dependency on the forest resource.

According to Alberta Sustainable Resource Development (2009b), the current structure of Alberta’s forests is considered to be mature and, in the next 20 to 30 years, much of the forest will be over mature. Currently, much of the forest is in the over 60 to 100 year age class and, over the next 30 years, 80% of the forest is anticipated be in this class (Alberta Sustainable Resource Development, 2009b). This may potentially alter the ability of the forest to adapt and adjust to any potential climate extremes and outbreaks.

A loss of the forest resource would create a huge economic problem impacting industry, government, aboriginal and forest dependent communities (Lempréière et al., 2008). While the forest industry is not the only industry within Alberta, many Albertans rely on it for employment - either directly or indirectly. A decrease in the manufacturing and processing of timber could exacerbate the shut-down of many mills, also impacting many small towns that have been built up due to the dependency on a single resource. In general, this would collectively result in a loss of approximately $32,183,000 from Alberta’s yearly economy (National Forestry Database, 2009).

With a potential loss of forest, there will also be a loss of resources that do not necessarily carry a monetary value, but a value-added or social one. Recreation, tourism and wildlife viewing carries a social value that is difficult to quantify, but will remain high. Fragmentation and loss of habitat will also decrease the abundance of wildlife within a forest stand as well as the value-added components described above. Wildlife requires forest for their homes, hunting grounds and places to hide from predators. Water quality and abundance are also influenced by forest resources because the forest will protect rivers and streams from erosion and
sediment control. In turn, this will also protect the fisheries resource by providing fish logs and other important habitat components in the streams and rivers. Generally speaking, forests may not necessarily be lost, but they may be altered and this alteration may not, in turn, provide the same goods and services that people have become accustomed to (Thompson et al., 2009).

4.2 Armillaria and the boreal forest

4.2.1 Biology and pathology of Armillaria.

Armillaria species are known worldwide in all forest types and on a large variety of host species, both natural and agricultural, in almost every environment (Edmonds et al., 2000). These species cause butt rot and root disease in almost every host but can vary in their pathogenicity (Edmonds et al., 2000; Mallett, 1989). While there are many different varieties of Armillaria, approximately 40 species worldwide (Watling, Kile and Burdsall, Jr., 1991), nine species are found in North America (Mallett, 1989). These species are; Armillaria ostoyae (Romagn.) Herink, A. gemina Bérubé & Dessureault, A. calvescens Bérubé & Dessureault, A. sinapina Bérubé & Dessureault, A. mellea (Vahl.:Fries) Kummer, A. gallica Marxmüller & Romagn., and three species that are taxonomically undescribed (Mallett, 1992).

Of these nine species, only two are found within Alberta (Mallett and Maynard, 1998). Armillaria ostoyae is the most common form and also the primary cause of root disease in conifers (Mallett and Maynard, 1998; Mallett, 1992). Armillaria sinapina, can also be found within the province (Mallett and Maynard, 1998). Both of these species are pathogens that forest managers need to concern themselves with (K. Mallett, personal communication, November 17, 2009).

In general, Armillaria is a soil borne Basidiomycetes fungus that spreads by rhizomorphs and/or mycelial growth by root contact (Edmonds et al., 2000; Mallett, 1992; Mallett, 1989).
Disease spread is slow - an approximate maximum rate of one to two meters per year - and, although this is a fungus, its spread by basidospores is limited (Edmonds et al., 2000). Infection occurs when uninfected trees roots make contact with infected roots (Edmonds et al., 2000) or make contact with rhizomorphs (Mallett, 1992), i.e., mycelia that are arranged into a root-like configuration (Edmonds et al., 2000), and appears to be the principal means of infection (Mallett, 1992). *Armillaria* species can either be a primary pathogen or a secondary pathogen in combination with an insect epidemic or other diseases (Edmonds et al., 2000). As an adapted pathogen, *Armillaria* does not intend to kill the host, although in many instances it may, as the tree is more valuable alive as a continuing nutrient source (Figure 7) (K. Mallett, personal communication, November 17, 2009).
Visible tree symptoms of stress that may indicate *Armillaria* infection include chlorosis of the needles, reduced leader growth, thinning foliage, excessive cone crops and resin flow near or at the base of the infected tree (Figure 8) (Edmonds et al., 2000). Signs of *Armillaria* infection include white mycelial fans under the bark near the base of the tree and also in the soil surrounding the tree (Edmonds et al., 2000). *Armillaria ostoyae*, fans will have dichotomous branches with decay looking “water-soaked” or spongy if advanced; also common in the wood is the appearance of black zone lines (Edmonds et al., 2000). There are three long-term signs used to recognize a disease centre or host-spot within a forest stand; dead trees in a radial pattern, random patches of dead trees, and young stands with small patches of mortality (Figure 9), but
the mortality does not generally continue in the older trees as the stand ages (K. Mallett, personal communication, November 17, 2009; Mallett, 1992).

Figure 8. Young pine trees killed by Armillaria (Source: Canadian Forest Service (Natural Resources Canada) reproduced with permission, 2011).
Armillaria ostoyae and A. sinapina both have very different approaches to parasitizing and creating a nutrient base from woody material. Armillaria ostoyae is a primary pathogen and is pathogenic on most host species (K. Mallett, personal communication, November 17, 2009; Dettman and van der Kamp, 2001a; Mallet, 1992). This particular species will create a high quality rhizomorph that contains enzymes and phytotoxins, enabling it to attach itself to a healthy root and attack. Armillaria ostoyae is then able to overcome the plant’s natural defences (K. Mallett, personal communication, November 17, 2009). Younger trees do not seem to have the same defences to Armillaria species that older trees have developed, so young stands are more at risk (K. Mallet, personal communication, November 17, 2009). Many older, healthy hosts can keep A. ostoyae within a “pocket” in the root; here the fungus can maintain a food
source and survive for many years. If host conditions turn unfavourable for the pathogen, it will have the energy and ability to grow and expand within the soil to find a new host or hosts (K. Mallett, personal communication, November 17, 2009). As this species of Armillaria is not able to compete against other pathogens and diseases, it uses the above-mentioned methods to survive (K. Mallett, personal communication, November 17, 2009).

Armillaria sinapina may still cause the same damage as A. ostoyae, but takes a very different approach to infection, as it is not a strong pathogen (K. Mallett, personal communication, November 17, 2009; Dettman and van der Kamp, 2001a). Rather than making a single rhizomorph, it makes many, which enables it to flood the environment and then sit and wait, opportunistically, for the “right” environmental conditions that will weaken hosts and make them easier to attack, acting as a secondary pathogen (K. Mallett, personal communication, November 17, 2009). This species, by comparison, is a very good competitor and will survive even in the presence of other pathogens and diseases (ibid). Environmental factors that may impact the ability of Armillaria to spread within a stand include soil conditions, moisture, pH, and organic layer depth, sand content and nutrient availability; these factors will all impact stand productivity (K. Mallett, personal communication, November 17, 2009; Mallett and Maynard, 1998). The reason for this is that, much like the tree, stands that show higher productivity, especially lodgepole pine stands, will also have more incidences of Armillaria than stands that are less productive (Mallett and Maynard, 1998).

A major concern of forest managers caused by Armillaria species is the volume loss from tree stands (K. Mallett, personal communication, November 17, 2009). When the Armillaria infects an individual tree, that tree must expend substantial energy in order to “fight” against infection (K. Mallett, personal communication, November 17, 2009; Wargo and Harrington,
Energy reserves that would normally be utilized for growth, are now employed in “fighting” the pathogen; therefore, an infected tree will not grow as well as an uninfected one (K. Mallett, personal communication, November 17, 2009). As this can happen within a stand for many years, a stand which looks healthy may not be as profitable due to the decrease in the volume of wood available when compared to a stand of a similar age that has never been infected (K. Mallett, personal communication, November 17, 2009). In many cases, the trees surrounding disease centers will show improved growth when compared to outside trees, but it will be due to the reduced number of trees competing for resources such as light and nutrients (K. Mallett, personal communication, November 17, 2009; Mallett and Volney, 1999). When this happens, there are no overall gains as, eventually, the whole stand may succumb to infection and there is the potential for a massive loss of wood volume, depending on the duration of the Armillaria infection (K. Mallett, personal communication, November 17, 2009; Mallett and Volney, 1999).

4.2.2 Description of a healthy forest.

While there are many definitions for what makes a healthy forest, this is basically a forest that is in balance (Edmonds et al., 2000). A balanced forest means that stressors, both biotic and abiotic, are present but are not creating problems for forest planning, and diversity is sustained within the landscape (ibid). Another way to view this is the Disease Triangle (Figure 10) (ibid). Each point represents a different factor; the host, the pathogen and the environment (Edmonds et al., 2000; Chakraborty et al., 2000). A host can only be infected adversely by a pathogen if the environmental conditions enable the disease to manifest (Dettman and van der Kamp, 2001b; Edmonds et al., 2000; Chakraborty et al., 2000).
Figure 10 was removed due to copyright restrictions.

Figure 10 demonstrated the disease potential of a forested environment and how it is influenced by the three factors shown on each side of the triangle. These factors are the environment, the host and the pathogen.

*Figure 10. Disease triangle (adapted from Edmonds et al., 2000)*

In the context of this study, the environment which, in the case of the disease triangle, can be considered climate, can influence all the phases of the lifecycle of the host and the pathogen (Chakraborty et al., 2000). Without the proper weather conditions, it does not matter how virulent the pathogen is or how susceptible the host - no infection can happen if the environment does not provide the proper conditions (Chakraborty et al., 2000). In the case of *Armillaria*, the pathogen is frequently found near its hosts but not in epidemic proportions. What can cause an epidemic are stressors on the host provided by the environment, such as drought, temperature, and length of growing season (K. Mallett, personal communication, November 17, 2009).

4.2.3 *Armillaria* and a healthy forest.

Within a healthy forest, the presence of many *Armillaria* species will not be a problem. For many years, *Armillaria* has been considered a “natural thinning” agent, and therefore accepted as an important tool in forest management (Mallett and Volney, 1999). It does play another, more notorious role in the forest as a “hidden enemy” since the host tree will look
healthy with no noticeable symptoms while still being infected (K. Mallett, personal communication, November 17, 2009). Generally, there is equilibrium between the host, pathogen and the environment that, in the absence of any other stress, will have a minor impact on the health of the forest. In many cases, this is beneficial as stresses can create gaps which will open up the forest stand to light and nutrients for other trees, thus increasing healthy tree growth and greater ecosystem diversity (Edmonds et al., 2000; Dettman and van der Kamp, 2001b).

4.2.4 Armillaria in British Columbia.

Armillaria is a problem worldwide and there are many different ways to deal with and treat the problem. Although there are many different species of the disease, there may be some overlap in the ways to mitigate the effects. Armillaria is commonly found in the central and southern interior of British Columbia and it is considered to be the most detrimental pathogen to forest health in this region (Dettman and van der Kamp, 2001a). As British Columbia is located so close to Alberta, and the provinces do have similar vegetation and many comparable climates, evaluating the disease in British Columbia is illustrative and significant to this research.

Armillaria ostoyae is the most common pathogen within the Interior-Cedar Hemlock biogeoclimatic zone and other interior regions of British Columbia (Dettman and van der Kamp, 2001b). In the central interior of British Columbia, both A. ostoyae and A. sinapina, are prevalent and all age classes of trees can be infected by these species within the province (Edmonds et al. 2000; Cruickshank, Morrison and Punja, 1997).

Current management practices, such as such as pre-commercial thinning and selective cutting can actually increase the inoculum levels in a forest stand (Morrison, 2000), especially in the case of Armillaria ostoyae (Dettman and van der Kamp, 2001b). This is prevalent in pre-commercial thinning of crop trees and also selective cutting because stumps left behind provide a
great nutrient base for the disease (Morrison, 2000). This study also suggests that the climate plays a major role in the incidence of Armillaria as the tree has to adapt to new climactic conditions which adds additional stressors (Morrison, 2000).

4.2.5 Armillaria and its interaction with other forest pests.

Certain Armillaria species are opportunistic when it comes to infections of trees, as discussed earlier with A. sinapina. It has also been noted that when a tree has been attacked by a natural defoliator (i.e., spruce budworm), Armillaria will increase within that stand (Mallett, 1989). There have also been many incidences when Armillaria is found in the roots of trees that have been attacked by a combination of pests including spruce budworm (Choristoneura species), mountain pine beetle (Dendroctonus ponderosae Hopkins), jack pine budworm (Choristoneura pinus Freeman), or wood borers and woolly aphids (Mallett, 1992; Mallett and Volney, 1990). Mallett and Volney (1990) concluded one reason for the connection is that insects, such as the jack pine budworm (Choristoneura pinus Freeman), may become attracted to a tree stressed by Armillaria which will produce a larger crop, and pest food source, of male cones (Mallett and Volney, 1990). The stress of one infestation appears to attract another infestation since the tree is already weakened.

4.3 Current state of knowledge on climate in Alberta

The general climate of northern Alberta, based on information from the pre-dominant boreal plains ecozone, is cold winters and warm summers with 80 to 130 yearly frost free days (Bourgeau-Chavez et al., 2000; Lands Directorate, 1986). The mean July temperatures range from 12.5 °C to 17.5 °C and the mean January temperatures from -22.5 °C to -17.5 °C (Lands Directorate, Environment Canada, 1986). When Bourgeau-Chavez, et al. (2000) later gathered...
their information for this section of Alberta, they found that the mean summer temperatures were slightly higher, 13 °C to 15.5 °C, as well as the mean winter temperatures, -17.5 °C to 11 °C. This is significant since the information found was similar to the Lands Directorate (1986) but, as the paper was written 14 years later and the temperatures were slightly different, this suggested that temperature ranges have increased slightly since the initial report in 1986.

The Natural Regions Committee (2006) stated that the mean annual temperature between the most northern and most southern natural sub region within Alberta could have a temperature difference of 5º C, and these differences are also in mean annual precipitation and degree-days. Growing degree days is a cumulative measurement of accumulated heat units that are above a 5 ºC threshold temperature (Natural Regions Committee, 2006). This area also has shorter summers that will only reach about 15 ºC, on average, for no more than two months (Natural Regions Committee, 2006). Winters are cold with up to four months of temperatures below -10 ºC and, near the northern boundary of Alberta, it can be below -20 ºC for up to two months of the winter season (Natural Regions Committee, 2006). The majority of the precipitation, 60% to 70%, occurs between April and August (Natural Regions Committee, 2006).

Vegetation type is associated with the climactic conditions in Alberta’s boreal forest (Natural Regions Committee, 2006). In the most northern areas where permafrost is common, the vegetation type is black spruce dominated (Natural Regions Committee, 2006). Conifer forests tend to have mean annual temperatures between 2 ºC and 1 ºC, and greater than 500 mm of mean annual precipitation but this can range from 400mm to 1000mm (Natural Regions Committee, 2006). Lodgepole pine x jack pine hybrids occur in the coniferous forests and are associated with areas with greater than 500 mm mean annual precipitation (Natural Regions Committee, 2006). Conifer-Mixedwood forests mean annual temperatures are higher than those of just coniferous
forest by 1.5 °C to 2.3 °C, mean precipitation greater than 500 mm, and 1000 to 1150 growing degree days (Natural Regions Committee, 2006). Deciduous forests have mean annual temperatures of 0.2 °C to 1.1 °C, with 1000 to 1300 growing degree days (Natural Regions Committee, 2006). In stands where conifers dominate, the frost-free period is longer, while precipitation is lower in these stands (Natural Regions Committee, 2006).

4.4 Climate research and predictions for the future

Worldwide, there have been observed increases in temperature, with higher temperatures in the northern climates (IPCC, 2007). According to the IPCC (2007), out of the past 12 years, 11 of them have reached the global surface temperature record, and temperatures from the northern hemisphere were higher in the last half of the twentieth century than any other period in the last 1300 years (IPCC, 2007). The IPCC (2007) also believes that these trends will influence, or already are influencing hydrological and terrestrial biological systems.

The predictions that the IPCC (2007) has made for North America are as follows (see Figure 11):

- the western Rocky mountains are warming year round leading to decreased snow and reduced summer run-off from snowpack, causing a decrease in available water resources;

- possible increases of summer rainfall (5 to 20%), but with much regional variability;

- higher than normal city heat waves will continue, but with increased heat and longer periods (IPCC, 2007). This is due to air pollutants in cities which chemically react with heat and sunlight creating smog, and add to the “heat island” effect that is already found in cities. The results are higher temperatures in a city than the surrounding areas (Environment Canada, 2004); and
some of the greatest changes for temperatures are predicted to occur in the northern
hemisphere where the boreal forest is prevalent (Figure 11).

Figure 11 has been removed due to copywrite restrictions.

Figure 11 demonstrated what the predicted average global temperatures would be from 2090 to
2099. This diagram also shows that the higher global temperatures will be found in the northern
hemisphere with the highest temperatures located in the Arctic Circle.

*Figure 11*. Changes for the late 21st century (2090-2099) in surface temperature. Projected from
the multi-AOGCM average projection for the A1B SRES scenario. Taken from the *Climate

Climate is extremely vital to maintain the growth and production, health, and even the
distribution of species in forest systems (Cerezke, 2009). Cerezke (ibid) predicts that, by the year
2050, many of the following climatic changes and effects will have taken place within Alberta:

- mean annual temperature will rise by 3 °C to 5 °C;

- mean annual precipitation will range from -10% to +15%, but summers will see the
  largest decrease in rainfall, resulting in droughts;
• growing degree days may increase by 30% to 50% and an increase in the amount of frost-free days which means an earlier spring and summer, and decreased number of frost-free days;

• decrease in available soil moisture caused by an earlier spring and evapotranspiration;

• annual moisture index increases of 20% to 30%;

• winters having more precipitation and being warmer, but within the guidelines of mean annual temperature and mean annual precipitation;

• water scarcity; and

• more extreme weather events such as severe summer storms and resulting forest fires.

Currently, the dry cool boreal ecoclimatic province spreads across the majority of northern Alberta, Saskatchewan, Manitoba and a portion of Manitoba (Figure 12) (Environment Canada, 2009). Under a possible scenario in which carbon dioxide concentration in the atmosphere is doubled over the next 100 years, the cool dry boreal ecoclimate changes significantly (Figure 13) (Environment Canada, 2009). The grassland regions would be distributed further north and very little, if any, of the boreal area would remain in the prairie provinces (Environment Canada, 2009).
Figure 12 was removed due to copywrite restrictions.

Figure 12 demonstrates the current ecoclimates located in Canada and the area that they cover.

*Figure 12. Distribution of ecoclimatic provinces of Canada (Environment Canada, 2009).*

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Figure 13 demonstrates that with an increase in carbon dioxide the future ecoclimatic provinces will change in area and distribution. It also shows that the boreal forest will become much smaller, no longer continuous across Canada, and will be found further north than it is currently.

*Figure 13. Distribution of ecoclimatic provinces under the two times carbon dioxide model (Environment Canada, 2009).*

4.4.1 Possible impacts of Climate Change.

The majority of the climate change literature is in agreement that there will be potentially serious changes to the climate and the boreal forest environment (Cerezke, 2009; Gayton, 2008; Lemprière et al., 2008; IPCC, 2007; Barnett, Adam and Lettenmaier, 2005; Loehle, 2000). An increase of temperatures and a decrease in summer rainfall, but more precipitation in the winter, could lead to earlier spring run-off, creating a decrease in water availability for trees in their
prime growing season (Cerezke, 2009; Barnett et al., 2005). Although water availability may be a concern; with a longer growing season, higher temperatures, and an increase in nitrogen deposition, trees may grow better at first due to nutrient availability through fertilization effects and resulting positive impacts, (Cerezke, 2009).

Climate change will impact all biotic disturbances including succession, insect disturbance, and the frequency and intensity of wildfire activity within the boreal forest (Lempréiere et al., 2008). While it may appear that many of these impacts will be individual, they will create complex interactions with others to generate either positive or negative results for the forest (Lempréiere et al., 2008).

As noted above, the general consensus amongst researchers suggests that climate change will create many extreme weather events, more droughts and an increase in temperatures all over North America, including the boreal forest (Cerezke, 2009; Gayton, 2008; IPCC, 2007; Barnett, et al, 2005; Loehle, 2000). Barnett et al. (ibid) even go as far to say that temperature may increase by as much as 8 °C during winter months if atmospheric carbon levels double. Generally, many forests do not adapt well to a changing environment outside of a natural range of tolerance which tends to alter little throughout their life span (Thompson et al., 2009). Many of the changes that will happen will initially start with single species, not large scale ecosystem disruptions (Gayton, 2008). These individual species will not be able to adapt and therefore face dieback and a more northward distribution to more suitable environmental conditions (Cerezke, 2009; Gayton, 2008; IPCC, 2007; refer also to Figure 13).

As noted earlier, the maximum rate of spread of Armillaria is no more than one to two meters per year (Edmonds et al, 2000), under current climatic conditions. Armillaria rhizomorphs isolates show maximum growth at 20 °C (Garraway, Hütterman &Wargo, 1991);
however, these isolates will also grow at temperatures between 10 ºC and 26 ºC. Outside of these temperatures Armillaria growth will slow down drastically (Garraway et al., 1991). While no information found was aimed at the boreal forests specifically, it is probable that the regular rate of spread may be increasing in the next few decades, as an increase in the number of growing degree days and increases in temperatures is observed.

4.5 Effective treatments for Armillaria

Finding an effective treatment for Armillaria has been very difficult due to the challenge of getting to mycelium and rhizomorphs that can be extensive and deep within the soil (Fox, 2000). In many cases, it is very difficult and expensive to carry out in a forest stand, but many mechanical methods have been used in tree nurseries and orchards (Fox, 2000). The Alberta Tree Improvement and Seed Centre carry out important research on tree species and has extremely valuable clone and seed stands throughout the province used for genetic research and replanting of harvested stands (J. Quinn, personal communication, August 13, 2009). When an infected tree is found in one of their stands, the tree is pulled, the area around it dug up for its roots and the contaminated materials burned in an area away from the stands (J. Quinn, personal communication, August 13, 2009).

Currently Alberta does not utilize any treatment methods for Armillaria, but the province does stress education about the disease and practice of creating well-managed stands to increase Armillaria resistance (Alberta Sustainable Resource Development, 2009a). While digging up the roots of exposed trees would be the most effective, it is too expensive to carry out province-wide (ibid).

British Columbia is currently practicing two methods to deal with Armillaria infection. The first method is finding tree species that are not as susceptible as others; however, all native
tree species are susceptible to *Armillaria* to differing degrees (Chapman and Xiao, 2000). The second method is mechanical removal but, as previously mentioned, this is expensive and also disruptive to forest ecosystems (ibid).

A new method of biological control is being researched in British Columbia and is proving to be effective against *Armillaria* (Chapman and Xiao, 2000). This method was developed because the only methods to lower the amount of *Armillaria* within a stand were costly and required large soil disturbances (ibid).

Fruiting bodies of *Hypholoma fasciculare* (Huds. ex. Fr.) - a common, but poisonous, woodland mushroom - have been found to be present in areas where there was little to no infection from *Armillaria*, but absent in areas where levels of *Armillaria* were high (Chapman and Xiao, 2000). *Hypholoma fasciculare* works due to its ability to competitively displace *Armillaria*, by colonizing a woody substrate quicker (Chapman et al., 2004). *Hypholoma fasciculare* is plentiful and ubiquitous in British Columbia and many other places around the world (Chapman et al., 2004). Laboratory tests have also confirmed that *Hypholoma fasciculare* appears to be “antagonistic” to *Armillaria* (Chapman et al., 2004). Chapman and Xiao (ibid) discovered *Hypholoma fasciculare* could out-compete *Armillaria* by examining stands that carried the disease and comparing them to stands nearby that showed no sign or incidence of *Armillaria* infection. The use of this species as a control method has been demonstrated to show promise within British Columbia (K. Mallett, personal communication, November 17, 2009).
5 Discussion

5.1 Predictions

The next 50 years will be difficult for Alberta’s forests. With the prediction of longer, warmer summers with less precipitation (Cerezke, 2009), the southern boundary of the boreal forest may start to slowly move further north to a more suitable climate (refer to Figure 13). With this change, current habitat quality may deteriorate and make it more hospitable to invasive species (Gayton, 2008). Plant species that need to be pollinated may lose these vectors due to changes in synchrony as the plants may flower before or after the time to when the pollinators have become accustomed (Gayton, 2008). Changes in Alberta’s vegetation, especially under the possible doubling of carbon dioxide scenario, may result in a transition from the boreal species to that of grassland and temperate species moving northward into the boundaries of the boreal community (Environment Canada, 2009). Many insect pests will have a greater chance at survival with the longer summer and milder winters, leading to more epidemics over larger areas; an example of this is the mountain pine beetle (*Dendroctonus ponderosae* Hopkins). Although the boreal region is resilient and supported by natural disturbance, such as wildfires and insect outbreaks, it is predicted to see the highest rises in temperature in the upcoming years (Thompson et al., 2009; IPCC, 2007), as the mean temperature is expected to increase 3ºC to 5ºC (Cerezke, 2009). This can create more disturbances that the boreal forest can handle since the trees will not have time to adapt to stressors caused by climate change and the resulting stressors caused by natural disturbances, such as fire and insect outbreaks.

Predictions for the boreal region include increased incidence of pathogens, insects, and drought and in the frequency and duration of wildfires (Cerezke, 2009; Lemrière et al., 2008). Increases in forest fires are a concern as the summers are expected to be drier and hotter
Much of Alberta’s current forest structure is of a mature class and, in the next 20 to 30 years, approximately 80% of this forest could be in the over-mature stage (Alberta Sustainable Resource Development, 2009b). As aging stands tend to be more vulnerable to pathogens and insects, these outbreaks may cause a shift to a younger forest stand (Cerezke, 2009; Alberta Sustainable Resource Development, 2009b). This would change the successional stage of the forest potentially causing migration and extinction of some species, while other species move into the area (Cerezke, 2009). Ultimately, the whole forest dynamic could change, altering the forest stand composition.

*Armillaria* species will be a problem for Alberta’s boreal forest in the next 50 years. A good deal of the research and current evidence supports the supposition that forest pathogens and insects will be a problem for the future because a changing climate will create stress for healthy trees, as well as unhealthy ones (Cerezke, 2009; Dukes et al, 2009; Alberta Sustainable Resource Development, 2009b; IPCC, 2007; Boland et al., 2004; Shortle et al., 2000). Although *Armillaria* species are slow moving, an increase in the growing season and milder springs and falls could increase the growing time, not only for the vegetation but also for the fungus as well. The increase in winter temperatures could create a shorter dormant period for fungal pathogens with increased winter survival, leading to the fungus having high levels of inoculum in the spring (Williams et al., 2000). Many stresses acting on a tree, such as a change in climate, alteration of precipitation, and insect outbreaks will also make it easier for less virulent, but opportunistic *Armillaria* species such as *A. sinapina* to infect a tree and either weaken or kill it.

*A. ostoyae* and *A. sinapina* have the potential to create many patches of die-off and also many large patches within the forest under conditions of stress. Initially, this could benefit the forest, as it will open up patches for young tree growth and understory growth but, as young trees
are more susceptible to both species, they would eventually die back as well. This could create patches in the forest for colonizing invasive species, and these invasive species could potentially choke out all other native species and prevent them from taking hold. This will also positively and negatively impact the mammal and avian species that live in the forest. Although there are potentially many benefits to the forest community, through habitat creation and the creating of gaps in the forest canopy, there are many negatives as well, especially from a forest health standpoint.

Disease outbreaks can impact both harvesting and management activities leading to a considerable economic impact (Kile, McDonald and Byler, 1991). Volume loss will be one of the greatest concerns to forest managers in the future (K. Mallett, personal communication, November 17, 2009). While there will be a loss of available trees to harvest, the ones that do not die from Armillaria and grow while infected will be inferior in quality to uninfected trees due to energy expended on “fighting” rather than growing. Alberta is already facing an aging forest and added stressors acting upon the resource may create devastating impacts. As the boreal forest is not isolated within Alberta, these impacts can also occur in other provinces and many other parts of the world. Currently, British Columbia is already suffering a major outbreak of Armillaria and, since much of the landscape and climate is somewhat similar to that of Alberta’s boreal forest, resource managers within Alberta need to be aware of management activities in British Columbia, including new information on control methods generated through research. While this is not the only industry open to Albertans, many people do work either directly or indirectly within the forest industry and many communities depend upon it for their continued survival. Creating poor quality timber products will decrease the revenues expected from a currently struggling industry, creating massive lay-offs and community economic down-turn.
5.2 Management strategies for mitigation of disease outbreak

Armillaria species are very difficult to detect and control once found. Many mechanical strategies, such as trenching and digging out the roots, are the best methods but, in a forested environment, this can be extremely costly and impractical. Hypholoma fasciculare is a somewhat new biological method that is being tested in British Columbia and other countries. Initial studies are showing that H. fasciculare will out-compete Armillaria and not adversely harm the tree; preliminary testing is also proving effective in British Columbia. Most of the work on H. fasciculare has been carried out in the laboratory environment, and research needs to be carried out to determine if it can become an effective method of field control in Alberta. Another method is to find tree species that are not susceptible to Armillaria; this is not an easy task as Armillaria is a problem worldwide. Species that are less susceptible to Armillaria include Ponderosa pine (Pinus ponderosa Dougl. ex P. & C. Laws.) and Douglas fir (Pseudotsuga menziesii (Mirb.). The best way to create strategies to mitigate Armillaria is to promote education and awareness of the disease, by creating fact sheets and scientific reports aimed at forest industries and governmental organizations. This would inform forestry industry practitioners of practices that may increase Armillaria inoculum levels within a stand and enable them to make choices that will mitigate Armillaria outbreaks. Other approaches would be to implement management strategies that would maintain a healthy forest, such as managing stands with regular rotations of harvest every 80 to 100 years, so the stands do not become over-mature and retain a more-diverse age structure.

More research on disease mitigation and control does need to be carried out in Alberta. Potential research would include setting up inoculum trials for Hypholoma fasciculare in known
Armillaria disease centres. Inoculum, for example, could be grown on sawdust and bran, and transported to the site using plastic bags (after Chapman et al., 2004). This mixture would then be buried near the base of trees in the disease centre and these trees would be marked (ibid). After three to five years (ibid) the plots would be evaluated to see which fungus, if any, they were infected with. This would be done by visual examination of the plots for fruiting bodies and checking the bases of the tree under the bark for the mycelial fans associate with Armillaria. Digging through the soil near the base of the tree would be conducted to check for the presence of rhizomorphs.

Research needs to be completed on less susceptible species to Armillaria, such as Ponderosa pine and Douglas fir (K. Mallett, personal communication, November 17, 2009), in order to determine which would be most suited to future climate conditions. Research needs to be done to see if there are any tree species that may be able to produce forest-like conditions if the future climate, for example, does favour grassland and temperate species. While it is currently not an acceptable management practice to bring in non-native species to a location, if a future forest resource is required in this area, the above mentioned varieties may be one answer. This could drastically change the forest since these trees may not grow and produce timber at the same time scale as the current forest and timber quality and, as a result, their value may not be equal to that of current commercial species. Another method would be to create mixedwood forests for commercial use. This may increase the potential for fewer outbreaks of either insects or diseases as the stand would no longer be a “monoculture”. It would also increase the ability to maintain regular harvest for the forest industry. Changing the forest species composition may also potentially impact the wildlife, soils and water quality within northern Alberta. While
changing the species composition planted may not follow current management strategies, these approaches are one way to continue to maintain the forest resource for future generations.

Other mitigation strategies could be employed during harvesting and replanting. Leaving as little of the stump as possible in known disease locations during harvest, may make it economically feasible to manually dig up the stumps and *Armillaria* inoculum around the former diseased trees. Once the stumps have been removed, these should be burned to ash in order to effectively kill the disease organisms. When replanting the forest, highly susceptible trees should not be planted in known disease centre locations. Where possible, trees would not be planted in these locations for at least five years, in order to cut off the nutrient supply for Armillaria.

Currently Alberta does not monitor stands to detect disease centres (Alberta Sustainable Resource Development, 2009a). This will need to be conducted in order to keep the forests healthy and well managed. While it is difficult to identify an outbreak from an aerial survey (Alberta Sustainable Resource Development, 2009a), this could be combined with ground-truthing through the use of existing permanent sample plots by researchers located throughout Alberta’s forests to recognize the signs of *Armillaria* disease very quickly. A database should be executed to record locations of “found” disease centres in order to monitor incidence and distribution.
6 Conclusions and Recommendations

Alberta currently has forests that are generally healthy, but is expected to have mature and over mature stands no more than 30 years into the future. In the past few years, there has been growing concern about the impacts of the mountain pine beetle outbreak and also many other forest pests. Many of these pests are normally found in the forest; however, with the winters of the past 10 years being fairly mild, more and more insects are surviving the winter dormancy.

There are two major species of *Armillaria* that can be found within the province. *Armillaria ostoyae* and *A. sinapina* can be found in every forest stand and can find a potential host in all native trees in the province. While *Armillaria* has not been considered to be an “outbreak” in Alberta, it does cause problems for foresters and forest management practices including small patches of dieback and mortality. Although it has been considered a “natural thinning agent”, *Armillaria* can also be a “hidden enemy” since it is often not possible to tell if a tree has been infected. This can create many long-term problems including volume loss, and a decrease in the quality of wood and in the value of the stand in relation to neighboring stands.

Future predictions for climate change are an increase in summer temperatures with a decrease in precipitation for this same time period. Spring thaws will be earlier, creating a greater number of frost-free growing days. Winters are predicted to be milder, but with a higher accumulation of precipitation, and higher average temperatures which, in combination, will decrease the amounts of available water. This will also result in more extreme weather events and potentially more forest fires due to summer drought conditions and a drier growing season. While trees can adapt to a range of changes within their environment, these events will add extra
“stressors” to the trees. This becomes even more serious when an already aging forest base is added into the equation.

*Armillaria ostoyae* attacks and infects healthy forests; this pathogen does not wait for stress or the opportune moment. It creates single, high quality rhizomorphs and will spread out and infect individual trees. Once a host is found, *A. ostoyae* will utilize the host as a nutrient base and, when the host is not longer useful, this species will spread out to find a new host. As this species of *Armillaria* is a primary pathogen, it will be a problem in the future, but it is not necessarily dependent on the added forest stress from climate change.

*Armillaria sinapina* is a secondary pathogen and considered to be more opportunistic than the other species. This species will create many rhizomorphs to spread throughout the forest floor and then wait until the opportunity is right. As a result, *A. sinapina* has a tendency to infect hosts that are already weakened by other health problems and trees under stress. This fungus will be a concern for the future in Alberta under future climate change scenarios. Many trees will be under stress due to the changes to climatic conditions, and other potential infestations. This will create many ideal opportunities and hosts for a fungal disease such as *A. sinapina*.

Managing for *Armillaria* species will not be an easy task. The best management strategies are those which support a healthy forest with a regular rotation so stands do not become over mature. Although they will work in orchards, most mechanical removal techniques do not work in commercial forestry due to the cost and the area that would need to be covered. Although it will be difficult to find a species that *Armillaria* will not use as a host, there are species that are not as susceptible to *Armillaria*. Non-native species, such as Ponderosa pine and Douglas fir, also need to be considered. Creating stands of mixedwood may also improve forest productivity and decrease outbreaks from insects and diseases. These options may go against current policy
for reforestation; but may offer the best solution to continue utilization of the forest resource in Alberta. More research does need to be done on these alternatives in order to explore their feasibility. British Columbia is also researching a biological solution to Armillaria using the common woodland fungus, *Hypholoma fasciculare*. This tool also needs to be researched in Alberta to test its effectiveness for the boreal forest.

Preventing *Armillaria* will not be an easy task, but can start by full tree removal during harvest when trees are showing *Armillaria* signs and burning the stumps and other infected material. Once removed, not re-planting susceptible trees in known disease centres or leaving these areas unplanted for five years in order to remove the nutrient base will also assist in control. Lastly, Alberta must start to monitor for *Armillaria* outbreaks and distribution in order to track the severity of the disease. This would best be done by aerial surveys combined with a ground survey database where forest researchers can input information about the location of disease centres found.

In conclusion, *Armillaria* will become more of a problem in the next few decades than it currently is now due to changing climate and the ageing resource base. A number of methods to minimize these problems have been discussed in this study, but more research has been identified and is needed to explore and determine the best options for Alberta’s boreal forest and its future health under current climate change.
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