Report # 6:

Climate Change and Forest Health: Impacts to West Kootenay Ecosystems

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1.0 INTRODUCTION

Recent reports by the International Panel on Climate Change (IPCC) confirm that global climate change is underway, and likely to accelerate over the coming decades unless humans make drastic cuts to global greenhouse gas emissions (IPCC 2007). In British Columbia, analysis of the last hundred years of climate data confirms that parallel climatic changes are also occurring in this province (Spittlehouse 2008), and in the Columbia Basin (Murdock et al. 2007). Visible evidence of changes in climate is also becoming increasingly apparent to local people – witnessed through a wide range of changes in a broad variety of different indicators.

Results from downscaled global climate models illustrate the range of potential climate changes for BC over the next century, depending on what assumptions are made about future greenhouse gas emissions. Potential changes for southern British Columbia include increases in annual temperatures and precipitation, decreases in summer precipitation, decreases in snowpack at low elevations, increases in annual and interannual climate variability and increases in the frequency and magnitude of extreme weather events.

The British Columbia government has recognized that the uncertainties associated with climate change demand a forest management approach that differs from the traditional (MoFR 2008). With the establishment of the Future Forest Ecosystems Initiative (FFEI) in 2006, the province began a move toward looking for ways to adapt the forest and range management framework with respect to potential future climates. The province established the Future Forest Ecosystem Scientific Council[1] (FFESC) in 2008 to deliver research grants to support the objectives of the FFEI. This report summarizes some of the findings of one project[2] that was among 16 funded by the FFESC under their 2009 call for proposals.

This paper explores predicted climate change impacts to the ecological roles of forest insects and diseases in West Kootenay ecosystems. Evidence suggests that climate change is already affecting life cycles of insects and diseases, synchronicity between pest life stage and host phenology and, in turn, insect and disease incidence and severity (Woods et al. 2010). Forest insects and diseases have been described as indicators of climate change and therefore are a worthwhile component of climate change monitoring programs (Logan et al. 2003).

The primary goal of this paper is to provide forest and land managers with a list of some of the more common insects and diseases affecting commercial tree species that have been present in the West Kootenay region since

[1] Further information on FFESC: http://www.for.gov.bc.ca/hts/future_forests/council/index.htm
[2] Resilience and Climate Change: Adaptation Potential for Ecological Systems and Forest Management in the West Kootenays. For further information on the project: http://kootenayresilience.org

the early 1900s. This is followed by a description of how changing climate may alter stand susceptibility and possible responses of these insects and diseases over the next few decades. The complexities involved in predicting insect and disease responses to climate change and the need to reflect on novel management approaches in an increasingly less predictable environment are also highlighted. The information presented here is based on (i) a limited literature review of current information relating forest health to climate change, with focus on the West Kootenay region, (ii) Forest Insect and Disease Survey (FIDS) reports and regional assessments that describe historical insect and disease outbreaks for the study area, and (iii) consultation with the regional pathologist and entomologist and other experts.

1.1 Forest Structural Stages

Within the West Kootenay region, the following three scales are considered in our discussion of insects and diseases from a climate change perspective. These scales directly relate to forestry operations.

Mature and old forests*:* In the study area these are almost exclusively natural forests, often extending across large landscapes. In these forests we are usually most concerned about bark beetles and defoliators as they can be extremely destructive over extensive areas of forests in a short period of time (Unger 1992). These agents can dramatically affect planned operations causing reactive forest management. At this scale, we have the opportunity to develop plans that consider high risk insects and diseases.

Existing regeneration and young stands: These forests are at another stage in development at which insects and diseases operate, along with other influential factors such as genetics, especially in plantation monocultures. Insects such as spruce leader weevil (*Pissodes strobi* Peck) and stem rusts such as white pine blister rust (*Cronartium ribicola*) and western gall rust (*Endocronartium harknessii*) favour stands with even-aged management and would become a management problem if changing climatic conditions caused population increases. At this scale, silvicultural treatments can be planned that may offset risks and damages associated with climate change. This may need to be considered not only before free-to-grow status has been achieved, but also after this point in stand development.

New regeneration*:* These are future forests that are in the planning phase, and provide the greatest opportunity to incorporate new knowledge of potential insect and disease responses to climate change before stands are being established. Tree species diversity, planting density and genetics are a few of the variables that can be considered.

1.2 Climate Change Assumptions

The climate of the West Kootenay region is expected to become warmer year round with increased spring, fall and winter precipitation and decreased summer precipitation (Utzig 2012 and references therein). By the 2020s, some models show an increase in average temperature of > 2 degrees Celsius and a drop in summer precipitation of nearly 10%. Annual precipitation is expected to increase. Even with greater annual precipitation however, it is expected that winter snowpacks will decrease, at least at lower elevations, as winter precipitation will consist of more rain due to warmer temperatures. Summers will become increasingly warmer and drier and drought will be more common. It is also predicted that there will be an increase in frequency and magnitude of extreme weather events such as wind storms, heat waves, and high intensity rain storms. Note that climate change is a combination of gradual change with extreme events intermingled.

2.0 CLIMATE CHANGE IMPACTS ON FOREST HEALTH

Climate change can affect forest health in many ways, some positive and some negative. Summer drought conditions can stress trees, thereby increasing susceptibility to a wider range of insects and diseases. Trees that are typically only damaged by insects or diseases may now succumb due to the added drought stress. However, these same drought conditions can have a negative impact on certain insect and disease conditions and forest health can improve. For example, larval desiccation may occur with higher temperatures. Warming temperatures can affect tree phenology altering the host-pest relationship, for example desynchronizing defoliator larval emergence with bud break as has been predicted for spruce budworm (Johnstone et al. 2009). Warmer temperatures may reduce time required for insects to complete life cycles. Warmer winters may result in higher insect overwintering survival therefore higher brood success. However, fungi parasitic to insects may also have a higher overwintering survival rates and may cancel out any positive effects on insect overwintering survival.

Increased precipitation can alter humidity affecting spore release for some diseases. Also, expected extreme weather events can affect stand susceptibility. For example, wind storms may create extensive windfall increasing bark beetle susceptibility.

Climate change can also cause range extension or retraction of insects, disease agents or hosts. As tree species ranges change, insects and diseases can follow into new areas or leave existing areas. In general, it is expected that a warmer climate will increase diversity of insects at higher elevations (Woods et al. 2010). In some cases, tree vigour may improve decreasing susceptibility to attack.

The following sections provide summaries of the projected climate-related changes to insects and pathogens in general, followed by a more detailed discussion organized by selected regional tree species. A summary table by tree species is provided in Appendix 1.

2.1 Insects – Summary of Projected Changes

- As insects are primarily influenced by temperature regimes, increases in regional temperature will likely change distribution, frequency and severity of population outbreaks.
- Insects have short life spans and therefore can adapt to climate change much faster than the host species.
- Potential shifts in timing of critical life stages could lead to increased or decreased insect levels (Logan et al. 2003).
- Northern and high elevation forests are expected to experience most change due to anticipated increases in temperature (Logan et al. 2003).
- In the West Kootenays, Douglas-fir beetle, Western balsam beetle, Spruce beetle, Western hemlock looper and spruce leader weevil commonly occur and are considered important insects that may be affected by climate change (Abbott et al. 2007).

2.2 Pathogens - Summary of Projected Changes

- Pathogen levels are generally more influenced by precipitation as compared to temperature (Woods et al. 2010). Note however that changes in precipitation regimes are more difficult to predict than changes in temperature regimes; changes in pathogen levels are therefore also difficult to predict.
- Increases in temperature will allow expansion up in latitude and elevation (Kliejunas et al. 2009).
- Overwinter survival will likely increase with increases in temperatures.

- Warmer night temperatures are conducive to increased spread of diseases.
- Host vigour is an important factor for pathogen susceptibility. Increased carbon dioxide levels have been linked to increased tree growth and reduced susceptibility (Sturrock et al. 2011), while increased drought may increase susceptibility.

2.3 Forest Health Effects by Tree Species

Spruce

It is projected that climate change may reduce current habitat suitability for spruce in the West Kootenay region (Utzig 2012). In the next few decades it can be expected that drought stress will increase in many spruce forests and susceptibility to insects and diseases will increase.

Spruce bark beetle (Dendroctonus rufipennis Kirby) - In mature forests, this beetle may respond to the warming climate by going from a two-year to a one-year cycle (Woods et al. 2010). Predicted increased windthrow due to more frequent extreme weather events (Utzig 2012) may increase breeding opportunities for spruce bark beetle.

For the BC southern interior however, impacts of this beetle are difficult to predict due to potentially complex interactions of several climate-related factors such as changes in distribution and susceptibility of Engelmann spruce, forest succession, incidence and severity of fires and other beetle species, and the order or sequences of different disturbance events (Nitschke et al. 2010).

S*pruce leader weevil (or White pine weevil)* (*Pissodes strobi* Peck) - In existing plantations, spruce leader weevil is predicted to increase in part due to climate change (Woods et al. 2010). Temperature increases are expected to favour an increase in weevil reproduction (Turnquist and Alfaro 1996). To date, this species is less prevalent in the West compared to the East Kootenay region where leaders in up to 72% of spruce in some stands have been attacked, affecting growth. Although first observed in natural stands, the weevil is becoming more prevalent in plantations (Unger 1992) in part due to climate change, but also because stand structure in plantations increases susceptibility as compared to a more natural multi-storied structure.

Two-year spruce budworm (*Choristoneura biennis* Freeman)- Historically, two-year spruce budworm has been more abundant in the East versus West Kootenay region, although infestations have been noted near Nakusp, Slocan and Creston (Unger 1992). While this insect is currently of lesser concern, provincial experts do consider it a potential concern as periods of drought increase (Abbott et al. 2007).

Douglas-fir

Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopk.)– This bark beetle has been regularly observed regionally and is expected to be the next major insect of concern due to climate change. Similar to spruce bark beetle, stress caused by drought and greater windthrow is expected to increase forest susceptibility to this beetle (Woods et al. 2010). Repeated and heavy defoliation, for example from spruce budworm, also increases Douglas-fir susceptibility to bark beetles.

Western spruce budworm (Choristoneura occidentalis Freeman)– This insect which occurs primarily in IDF forests in the southern interior has become the primary defoliator in BC in recent years, although levels dropped in 2010 (Westfall and Ebata 2010). The budworm prefers older, overstocked, multi-storied Douglas-fir stands, causing mortality in the understory with up to 50% reduction in growth in intermediate and mature trees (Alfaro and Maclauchlin 1992). Recently, they have been observed moving further north and into higher elevation forests where no outbreaks have been recorded in the past (Nealis et al). This trend has been attributed in part to warming climate as well as more susceptible stand structure. Frequency, intensity and duration of outbreaks have also been increasing. However, in the current IDF, lower elevation forests may become less susceptible as the insect's life cycle becomes less synchronized with bud break due to warmer temperatures (Woods et al. 2010).

Within the study area western spruce budworm has not been a concern to date though it has caused some damage in the neighboring Boundary and Cranbrook TSAs (Westfall and Ebata 2011). Douglas-fir forests in the study area do not typically have the multi-storey stand structure conducive to budworm outbreaks and although outbreaks can occur in ICH forests they are typically shorter in duration and cause little damage (Maclauchlan and Brooks 2004). First observed near Glade in 1923 (Unger 1992), the next occurrence record of the budworm was not until 1970 near Revelstoke. More recently, it was recorded in grand fir near Nelson in 2009 and 2010 (Westfall and Ebata 2010) and in the Columbia Forest District in 2006.

It is unclear how climate change may affect western spruce budworm populations within the study area. Warmer temperatures may increase the likelihood of outbreaks; however, even-aged management, which is commonly practiced, does not create the more susceptible multi-storied stand structure.

Western false hemlock looper (*Nepytia freeman* Munro) – This insect is an important defoliator of Douglas-fir in the East Kootenays causing growth loss and mortality in immature trees, usually on dry sites. In the West Kootenay region, a heavy infestation occurred in western hemlock and Douglas-fir stands near Nakusp in 1973 causing mortality (Unger 1992). This insect may become a concern with climate change as outbreaks are triggered by warm dry conditions (Ferris 1992). It is possible that the range for this insect will expand with the trend in increasing temperatures.

Swiss needle cast (*Phaeocryptopus gäumannii*) – This pathogen occurs throughout the Douglas-fir range reducing growth rates at high infection levels (Hagle et al. 1987). Although it usually occurs at low levels, it has become abundant in some plantations where Douglas-fir was planted outside its range (Kliejunas 2011). Because of the link between an increase in spring precipitation and needle cast abundance (Hood 1982 quoted in Sturrock et al. 2011) it is possible that incidence will increase with climate change in the West Kootenay. This trend raises the issue that assisted migration practices often recommended as part of a climate change mitigation strategy may result in outbreaks occurring in areas where they have not been observed in the past. Although current and projected growing conditions may favour species such as Douglas-fir, the changing climatic conditions may also favour damaging diseases reducing stand growth and survival of such species.

Subalpine fir

Western balsam bark beetle(*Dryocoetes confusus* Sw) - In recent years, western balsam bark beetle has been the second most abundant bark beetle in the study area, following mountain pine beetle (Westfall and Ebata 2010). Provincially, it is recognized as the second most important insect to potentially cause significant damage in response to changing climate (Abbot et al. 2007). Although it is unclear how climate change may impact this insect, it is possible that any increase in stress will create more susceptible conditions for subalpine fir.

Balsam woolly adelgid (*Adelges picea)* - In plantations and future stands, balsam woolly adelgid, an introduced species, may become a concern, damaging or killing subalpine fir (and sometimes grand fir) of all ages and all degrees of vigour. Although there is only an unconfirmed sighting near Rossland (Art Stock, pers. comm.), this introduced species has been observed on the west coast of BC and throughout Idaho where it has quickly spread (Turnquist and Harris 1993). The damage inflicted by this insect creates a physiological drought in the tree which is exacerbated by actual summer drought (Hain et al. 1991). Extreme winter temperatures can kill overwintering insects although mortality only begins at -20 degrees C and -37 degrees C is required for complete mortality (Canadian Forest Service 2006). With climate change, these winter temperatures become less probable and summer drought may increase rate of mortality associated with this insect.

Grand fir

Fir engraver beetle (*Scolytus ventralis*) – Drought stress over a 2-3 year period has been attributed to significant increases in mortality of grand fir by fir engraver beetles in the southern part of the Nelson Region. In 1989, single trees and up to 50% of the grand fir over areas up to 30 ha were killed in the Pend-d'Orielle area of the West Kootenay (Wood and Van Sickle 1989). Therefore, it is possible that grand fir mortality will increase with the predicted increase in drought conditions. Fir engraver beetle populations will increase following wind throw events (Furniss and Carolin 1977) therefore predicted extreme wind events may also contribute to population build-ups.

Western hemlock

Defoliators are common pests of western hemlock and because hemlock is intolerant of defoliation mortality can be high. There are five defoliators of concern that usually occur in mature to old stands in the northern moist ecosystems within the West Kootenay.

Western hemlock looper (*Lambdina fiscellaria lugubrosa* Hulst)– This insect is one of the most destructive defoliators in the study area capable of killing large areas of mature trees in a single year (Unger 1992). During outbreaks, primarily mature to old hemlock is defoliated and western redcedar may also be attacked. Historically, most outbreaks have occurred in the northern parts of the study area along the Columbia River between Revelstoke and Mica although they have also have been observed as far south as Salmo (Unger 1992). The Upper Columbia has experienced some of the most frequent outbreaks in the province (Parfett et al. 1995). There have been six outbreaks in the study area between 1935 and 1995, each lasting between 2 and 5 years (Parfett et al. 1995).

It is difficult to predict response of this insect to climate change. On one hand, outbreaks tend to occur in watersheds that are 1.8 degrees C cooler (Borecky 1996), therefore it could be predicted that populations will decline or outbreaks will have less impact if temperatures are increasing with climate change. However, outbreaks occur in watersheds receiving greater precipitation (2cm/month) (Borecky 1996) and annual precipitation may increase with climate change. In addition, pollen studies of historical stands suggest a link between summer drought and rapid mortality of hemlock, with the agent of decline suspected to be hemlock looper (Haas and McAndrews 2000).

*Filament beare*r (*Nematocampa resistaria* Herrich-Schaffer) - In the northern part of the study area, the Filament bearer is another defoliator often associated with past western hemlock looper outbreaks. All ages of hemlock are attacked and understory trees are more heavily defoliated. One large outbreak occurred in early 1970s (Unger 1992). It is unknown how this insect may respond to climate change; its association with western hemlock looper is of interest however.

Western blackheaded budworm (*Acleris gloverana* Walsingham) - This budworm defoliates primarily dominant and codominant western hemlock as well as spruce, subalpine fir and Douglas-fir. There have been three major outbreaks in the study area between 1923 and 1991 (Unger 1992) and it has been observed in Kootenay Lake and Arrow timber supply areas in 2006 and 2010 (Westfall and Ebata 2010). Similar to western hemlock looper, the larger and more frequent outbreaks have occurred in northern areas (Nakusp to Revelstoke); small populations have been noted in southern parts of the study area (Unger 1992). While it usually affects only the upper crown it can defoliate whole trees. It is considered an important insect to watch for in light of climate change (Abbott et al. 2007). Outbreaks tend to occur in moist to very wet climates; therefore predicted increased precipitation may promote outbreaks (Otvos 2004). However, dry hot summers have been observed to cause larval mortality (Koot 1992), therefore it is difficult to predict the impact of climate change.

Hemlock sawfly (*Neodiprion tsugae* Middleton) – This insect eats older foliage of trees; therefore mortality is not a direct concern. However, in areas where it occurs following a blackheaded budworm outbreak, the accumulated effects often result in greater mortality (Hard et al. 1976). Therefore it is possible that hemlock sawfly will contribute to increased hemlock mortality if blackheaded budworm outbreaks increase in response to climate change.

Gray spruce looper (*Caripeta divisata* Walker) - The gray spruce looper is another defoliator of hemlock that has been observed in the West Kootenay region at low levels over time, with the first large outbreak occurring in 1990 (Unger 1992). In this outbreak 4000 ha were affected in the northern part of the study area (Stewart 1994). This insect can cause reduced growth or mortality, in fact, causing 46% mortality in one area during one outbreak (Stewart 1992). Populations are usually found below 1000m elevation and on west aspects (west side slopes) near lakes (Unger 1992). Drought conditions following defoliation contribute to mortality (Stewart 1994) therefore predicted increases in drought due to climate change may result in higher hemlock mortality caused by gray spruce looper.

Lodgepole pine

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) - Although the recent outbreak appears to have subsided, this insect remains a concern for stands that have not yet been attacked or may soon become susceptible. Within the study area, the hot dry summer in 2007 is suspected of contributing to successful development of double broods that year (Westfall and Ebata 2008). This trend has also been observed in pine engraver beetles (*Ips pini*) (Westfall and Ebata 2008) although this species is uncommon in the West Kootenay region.

Mountain pine beetle expansion may continue to occur in the southern Interior but again predictions with any certainty are difficult to make. Although warmer conditions may allow for double broods or decrease overwintering mortality, physiological changes to the insect's cold tolerance may also occur increasing winter mortality during unseasonal cold weather (Carroll et al. 2006).

Pine needle cast (Lophodermellea concolor (Dearn.) Darker) - Pine needle cast can occur at epidemic levels in the West Kootenays reducing pine growth in young stands by 50 to 70% and causing scattered mortality (Unger and Stewart 1996). Some epidemics have followed moist springs which create high humidity required for spore dispersal in July (Hunt 1995), indicating a possible increase in the study area with predicted climate change. However, cooler and moister summers have been associated with increased risk (Heineman et al. 2010) which is opposite to predicted climate changes.

Dothistroma needle blight (*Mycosphaerella pini* Rost. in Munk) - The recent dothistroma outbreak in lodgepole pine plantations of northern BC has highlighted the possibility of a usually benign pathogen producing unprecedented outbreaks in response to changing climates (Woods et al. 2010). For the first time, infections have been observed in not only immature, but also mature trees. In the past, dothistroma was observed to cause growth loss in plantations, however, now it is linked strongly with plantation failure and mortality in all ages. The outbreak in northern BC follows increased summer precipitation and an increase in warm wet days (Woods et al. 2010). If conditions are warmer and drier, there may be no change or a decrease in the incidence of dothistroma (Sturrock et al. 2011).

Within the study area, dothistroma has been observed during annual FIDS surveys. Between 1976 and 1979 heavy foliage loss in lodgepole pine occurred between Slocan and Nakusp and in the Castlegar and Hall Siding/Salmo areas (Cottrell and Erickson 1977 and 1978, Erickson and Wood 1980). This outbreak followed several wet summers. In 1990, Dothistroma was observed in wet belt forests between Revelstoke and Castlegar as well as in the Kaslo to New Denver area. Over the past decade, dothistroma has increased with warming temperatures and moist springs, and caused the loss of a white pine blister rust trial near Duncan Lake (Michael Murray, pers. comm.).

If as predicted summers become drier, it is unlikely dothistroma will become a problem within the study area; however, it is important to be aware that it does occur in the West Kootenay. Should summer storms create sufficient precipitation in the warmer climate, outbreaks may occur.

Stem rusts - Stem rusts affecting lodgepole pine such as western gall rust (*Endocronartium harknessii* (J.P. Moore) Y. Hirat) and stalactiform blister rust (*Cronartium coleosporioides* Arthur) and commandra blister rust (*Cronartium comandrae* Peck) are widespread in the Southern Interior (Heineman et al. 2010). There is conflicting evidence as to how stalactiform and commandra stem rusts may respond to climate change. Both rusts require cool moist conditions in late spring and summer which is the opposite trend of predicted climate change. However, Heineman et al. (2010) found commandra rust to increase with decreasing summer precipitation and hotter drier summer conditions (possibly due to trees being drought stressed) which coincides with predictions for the West Kootenay region.

Western gall rust is the most common stem rust of lodgepole pine. In one study, all 66 plantations showed infection levels ranging from 3 to 74%, and 55% of infected trees were not suitable crop trees (Heineman et al. 2010). Western gall rust spores require cool moist late spring conditions for infection. With greater spring moisture and warmer spring temperatures predicted it is unclear how disease incidence may be affected. One model suggests an increased risk with higher temperatures in the warmest and coldest months of the year (Heineman et al. 2010), which is consistent with predicted climate change for the West Kootenay region.

Pine needle sheathminer (Zelleria haimbachi) - Pine needle sheathminer occurs in juvenile and immature pines, and is capable of killing 100% of new growth, thereby reducing overall growth (Stevens 1971). Historically, this insect has been observed throughout the study area at low levels; small outbreaks have been observed near Slocan and Yahk (Unger 1992). With climate change this insect may become more common as it prefers drier areas which are expected to become more prevalent.

Western white pine

White pine blister rust (*Cronartium ribicola*) appears to spread more rapidly in cool moist conditions (Sturrock et al. 2011, Kliejunas 2011). Within the West Kootenay region, white pine regeneration in hot dry microclimates near Trail was observed to be free of blister rust whereas nearby stands in moist draws had abundant blister rust infection levels (H.P., pers. obs.). Blister rust is predicted to decrease in warmer drier conditions and no change in infection levels is expected in warmer wetter conditions (Sturrock et al. 2011).

Western larch

Foliar diseases - Larch needle cast (*Meria laricis Vuill.*) and needle blight (Hypodermella laricis Tub.) often occur together affecting all ages of larch. Both diseases typically infect trees in May, and larch needle cast can continue to infect foliage throughout the growing season when moisture conditions are suitable (Garbutt 1996). Minor growth loss is most typical; height growth of severely infected trees can be suppressed by 30% (Unger and Vallentgoed 1991) and mortality has been observed after two to three successive years of severe attack (Westfall and Ebata 2011). Susceptibility to other pests can increase (Henigman et al. 2001). Within the study area both pathogens are generally observed to varying degrees each year. Most recently, larch needle blight peaked in 2006, especially in the Arrow and Kootenay Lake TSAs. There was another outbreak in 2011 though this time most damage occurred in the Boundary and Cranbrook TSAs with some infection occurring in the Arrow and Kootenay Lake TSAs (Westfall and Ebata 2011).

In terms of climate, infection by both these needle diseases occurs following cool wet springs. In 1991 following a moist cool spring, an outbreak of larch needle cast was reported for areas of the West Kootenay region (Unger and Stewart 1992), a trend that was reversed in the following year with a drier spring (Unger and Stewart 1993). Moisture in the form of either rain or high humidity at the time of bud break appears to be an important climate variable, as it is required for spore dispersal and release (Garbutt 1996). Drought conditions reduce risk of spread. Larch needle cast outbreaks can be more of a concern since reinfection can occur throughout summer as long as there is sufficient moisture; it has been known to cause mortality in young trees.

The effect of predicted climate change is difficult to assess. Moist springs may result in greater infection levels while summer drought may decrease extensive spread of larch needle cast. However, if it is especially moist in spring, higher summer humidity may allow for further spread and greater mortality in younger trees.

Larch casebearer (*Coleophora laricella* Hub.) - Larch casebearer was introduced from Europe to BC in 1966, quickly spreading throughout the range of larch (Unger 1992). Various parasites were introduced and, since the mid-1980s, this insect has remained at endemic levels. Although only occurring at low levels due to the suppression program, changing climate may upset this new balance by altering the parasite's life cycle and potentially causing another outbreak. However, in the case of larch casebearer, climate change may favour continued suppression. Moister springs favour high infection levels of needle casts and blights which kill the food source for the casebearer restricting population build up (Ferris 1995). Also, larval mortality has been attributed in the past to hot summers which are predicted to occur with climate change.

Multiple tree species

Root disease **–** While root diseases are more indirectly affected by climate overall activity is likely to increase in areas that become warmer and drier (Heineman 2010, Kliejunas 2011); and stay at current levels in warmer, wetter conditions (Sturrock et al. 2011). Greater root disease activity may also make trees more susceptible to bark beetles and other forest health agents. Models predict this trend in the US for *Armillaria* (Woods et al. 2010), and the assumption is that this could also be true for *Phellinus* and *Tomentosus* root diseases. Although root diseases are thought to be slower to spread as they depend on root contact (Woods et al. 2010), they occur throughout the study area, and activity and expression may increase if trees are more stressed.

2.4 Forest Health of Young Stands

Diversity and abundance of insects and diseases in young stands is often high, influencing species composition and stem density. Typically, they are the main drivers shaping stand development, and any changes to climate may shift the importance from one agent to another shifting ecosystem development. FIDS surveys show that young stands in the West Kootenay region contain a variety of forest health agents, with many trees being affected by, and some succumbing to, one or more of these agents (Unger and Vallentgoed 1991, Unger and Stewart 1992-1996). Climate change could alter the biology of any one of these agents at any time causing an outbreak.

Considerations and illustrative examples regarding forest health conditions of young stands in the West Kootenays include the following points. Note that most stands surveyed had already been spaced, hence occurrence of poor health and mortality are underestimated in standard surveys, assuming unhealthy and dead trees were removed during spacing.

- In several years of surveys in young stands, 4-8% of trees were dead or dying (usually from root disease); and 5-28% had some insect or disease causing growth loss (this includes animal and abiotic damage). Common insects and pathogens included stem rusts in lodgepole pine, needle diseases in lodgepole pine and larch, warren's root collar weevil, and 2-year spruce budworm.
- Up to 90% of surveyed stands had mortality agents (e.g., root disease) present *after* spacing.
- Armillaria is common in young stands in the West Kootenay region, typically identified in 10% of trees.
- Typically pines had the most severe problems caused by over ten different lodgepole pine pests. In addition, there were seven insect and disease species commonly found in spruce regeneration, and six insect and disease species occurring in Douglas-fir stands.
- Surveys in post-free growing lodgepole pine stands found 55% of all trees <30 years old had biotic or abiotic damage (Heineman et al. 2010).

- In some surveys, Atropellis canker (*Atropellis piniphila* Weir) in lodgepole pine resulted in all trees rejected as crop trees (Heineman et al. 2010). Atropellis canker is expected to increase with increasing winter temperatures (Heineman et al. 2010).

2.5 Decline syndromes

Tree mortality is often not attributable to any one agent, but is caused by a number of pathogens and insects acting in combination (Woods et al. 2010). These phenomena are known as “decline syndromes” (Ostry et al. 2011) which are typically widespread and associated with moisture stress followed by insect and/or disease attack. The interactions of agents and ultimate impacts of declines likely will increase in importance as climate change puts additional stresses on forests (Kliejunas et al. 2009).

Birch decline - The widespread decline of paper birch in the study area appears to be a result of several interacting factors including reduced tree growth, limited defensive processes, top-kill and ultimately tree death. An insect–pathogen complex of bronze birch borer (*Agrilus anxius*), several non-native birch leaf miners (*Fenusa pussila* and *Profenusa thomsoni*) and Armillaria root disease are involved, but climatic change may be a pre-disposing factor (Westfall and Ebata 2010). Summer drought stress, temperature variability and freeze–thaw events have likely reduced tree vigour and growth, and increased the incidence of these pests. In 1949 a similar decline in birch was documented following a period of drought beginning in 1930 coupled with low winter temperatures and unseasonal spring freezes that killed new growth (Nash 1949). The bronze birch borer was also identified as part of this complex. As the frequency of such climate events is expected to increase in the future, birch may become much less common in the region (Woods et al. 2010).

Birch decline may also contribute to an increase in the activity of Armillaria root disease in the region. Birch roots often provide a barrier to the spread of the root disease, thus protecting neighbouring conifers from infection (Westfall and Ebata 2010). When birch are harvested, or killed by other causes, the Armillaria fungus is able to quickly spread along dead birch roots and transfer to conifers.

Western redcedar decline – Although not a true decline syndrome, it is important to note that over the past decade, drought-related mortality and dieback of western redcedar (*Thuja plicata* Donn ex D. Don) has been observed in many areas of BC. Periods of drought over the past decade and during the summer of 2007 in particular, have resulted in stressed western redcedar appearing in large numbers throughout the southern interior of BC (Woods et al. 2010). In 2009 alone, hot dry conditions experienced throughout the province resulted in 65,817 ha of drought damage, primarily to western redcedar (Westfall and Ebata 2009).

3.0 CONCLUSIONS

It is not possible to confidently predict future insect and disease outbreaks associated with climate change because of the high degree of uncertainty associated with climate change predictions. Also, very few models exist that attempt to predict responses of insects and pathogens to climate change; hence no guidelines are available for adjusting forestry practices. An important step toward more informed and possibly effective forestry practices is awareness of the role insects and diseases have on shaping forests, and understanding potential impacts climate change may have on this role. By looking at historic patterns of insect and disease outbreaks in West Kootenay forests and by increasing our understanding of how climate conditions affect life cycles we can gain some confidence in predicting future potential impacts.

It is important to keep in mind when evaluating climate change impacts to forest health that it is only one variable affecting insect and disease trends. Management practices such as silvicultural system selection (i.e., even- versus uneven-aged management), planting stock genetics (e.g., monocultures), species diversity in planting stock, and stand tending practices (e.g., species selection during spacing) also affect insect and disease risk. Stand tending practices have been associated with increases in Atropellis canker, stalactiform and commandra stem rusts (Heineman et al. 2010).

Earlier in the paper structural stages were presented that may be useful for considering impacts of insects and diseases: natural forests, existing plantations and future plantations. Although many insects and diseases operate at all three stages, many are more of a concern at a single stage.

Strategies for reducing climate change impacts to forest health should include activities such as monitoring outbreaks, risk assessments, susceptibility modeling, provenance and species trials, tree breeding and assisted migration (Woods et al. 2010, Sturrock et al. 2011).

Mature and Old: Outbreaks of Douglas-fir beetle, western balsam beetle, spruce beetle and western hemlock looper have regularly occurred in mature West Kootenay forests. Evidence suggests that climate change may contribute to increased risk of outbreak of these insects in the short to medium term. Continued annual monitoring of susceptible areas using aerial surveys is an important first step in predicting potential outbreaks (Sturrock et al. 2011). Monitoring these priority insects in combination with responding to small outbreaks and participating in development of risk rating systems provide a foundation for reducing climate change impacts in mature forests.

Regeneration and Young Stands: FIDS surveys indicate there are many insects and diseases affecting growth and causing mortality in young stands. Spruce leader weevil, stem rusts in lodgepole pine, foliar diseases of lodgepole pine and larch and Armillaria root disease are routinely encountered in plantations. Lodgepole pine plantations appear to be at risk to a wide range of insects and diseases (Heineman et al. 2010). And in recent post free-growing surveys in the Kootenay Lake TSA, white pine blister rust was found to be the most prolific disease observed (Michael Murray, pers. com). Overall, climate change is predicted to increase incidence of most of these damaging agents.

Monitoring forest health is part of routine free-to-grow surveys making data available for assessing forest health patterns. Aerial forest health surveys coordinated by the provincial government also provide data on young stands. By highlighting the importance of tracking unusual occurrences, climate change-related outbreaks may be identified sooner. This information is useful for planning stand tending activities (e.g., species selection for spacing; retaining deciduous to screen leaders from spruce leader weevil detection) for the affected as well as nearby plantations.

Future regeneration: Future plantations and natural regeneration are potentially subject to attack by insects and diseases found in existing plantations and young stands. In addition, as climate changes in the short to mid-term it is possible that new insects and diseases that have only occurred in low numbers may reach outbreak levels in future plantations. These may include insects and diseases that are triggered by drought conditions such as western false hemlock looper. In addition, certain diseases that in the past have only caused growth loss may now contribute to mortality as observed with larch needle cast and dothistroma.

As mentioned before, being aware of common and unusual forest health concerns in nearby existing plantations provides valuable guidance when planning future plantations. Silvicultural system selection, species and genetic diversity as well as planting densities are some of the important variables to consider when planning new forests. The uncertainty associated with climate change and its potential impacts to forest health requires forest managers to plan future forests with maximum flexibility to respond to changing conditions.

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5.0 APPENDIX 1

Appendix 1 describes common insects and diseases historically encountered in the West Kootenays as well as climate related conditions that may initiate or suppress outbreaks. Column 2 includes a rating that indicates priority insects and diseases that may approach outbreak levels in the near future based on climate change predictions. The ratings are defined as:

+ Low incidence in study area but outbreaks common elsewhere in the East Kootenays in drier ecosystems
++ Low incidence in study area but endemic populations commonly observed
+++ Few outbreaks in study area and increasing susceptible habitat
++++ Frequent outbreaks in study area (at least 3 since 1923) and increasing susceptible habitat

In addition, separate ratings are provided for introduced insects and diseases:

* introduced and currently at low levels
** introduced and currently at high levels

Table A1. Common insects and diseases in the West Kootenays and potential climatic impacts.

Species (Alternate host)	Insect/Pathogen Species (importance)	Stand age	Impact	Climate related conditions that may initiate an outbreak	Climate related conditions that may suppress an outbreak
Spruce	Spruce beetle ++++	Mature	Mortality	Warm temperatures may shorten life cycle from 2 year to 1 year; Increased windthrow; Drought stress	
	Spruce leader weevil ++	Immature	Growth	Warm weather favours rapid completion of life cycle	Cool wet weather
	2-year spruce budworm +	All	Growth or mortality	Drought stress	
Douglas-fir	Douglas-fir beetle +++	Mature	Mortality	Increased windthrow; Drought stress	
	Swiss needle cast ++	Plantations	Growth	Moist spring	

Species (Alternate host)	Insect/Pathogen Species (importance)	Stand age	Impact	Climate related conditions that may initiate an outbreak	Climate related conditions that may suppress an outbreak
Douglas-fir (cont-d) (Grand fir)	Western spruce budworm +	All	Growth (mature) or mortality (regen)	Warmer temperatures extend geographic and elevation range; Drought stress	Warmer temperatures may desynchronize larvae emergence with bud break
(Western hemlock)	Western false hemlock looper +	Immature	Growth or mortality	Drought stress; Warm dry conditions trigger outbreaks and extend range	
Subalpine fir	Western balsam beetle ++++	Mature	Mortality	Drought stress	
(Grand fir)	Balsam woolly adelgid *	Mature and immature	Growth or mortality	Drought stress	Cold winter (-37 degrees C)
Grand fir (Douglas-fir)	Fir engraver beetles ++	Mature	Mortality	Drought stress; Increased windthrow	
Western hemlock (Western redcedar)	Western hemlock looper ++++	Mature and old	Mortality	Drought stress (summer); Higher annual precipitation	Cooler annual temperatures
	Western black-headed budworm ++++	Mature	Growth	Moist to wet climate	Dry, hot summer causes larvae mortality
	Filament bearer ++(+)	All	Growth	Unknown – associated with Western hemlock looper outbreaks	
(Engelmann spruce)	Gray spruce looper ++	Mature	Growth or mortality	Drought contributes to mortality in previously defoliated trees	
Lodgepole pine	Mountain pine beetle ++++	Mature	Mortality	Increased temperature may produce 2 broods in one year; Warmer winters increase overwintering success	Early (unseasonal) cold winter weather
	Pine needle sheathminer ++	Immature	Growth	Drought stress	
	Dothistroma ++	Immature	Growth or mortality	Spring and fall (and summer) moisture can contribute to spread; Warm wet summer	Drought in summer

Species (Alternate host)	Insect/Pathogen Species (importance)	Stand age	Impact	Climate related conditions that may initiate an outbreak	Climate related conditions that may suppress an outbreak
Lodgepole pine (cont'd) (Ponderosa pine)	Western gall rust ++	Mature and immature	Growth	Cool and moist in late spring; Warmer summer and winter temperatures	Hot and dry spring
(Ponderosa pine)	Stalactiform rust Commandra rust ++	Immature	Growth or mortality	Cool and moist in late spring and summer; Hot and dry summer conditions	Hot and dry summer
	Pine needle cast ++	Immature	Growth	Wet spring creates high humidity during spore dispersal in July	
Ponderosa pine)	Pine engraver +	Mature	Mortality	Increased windthrow; Drought in spring	
White pine	White pine blister rust **	Mature and immature	Growth or mortality	Cool an moist spring/summer	Hot and dry spring/summer
Western larch	Larch needle cast ++++	All	Growth (mature) or Mortality (immature)	Moisture at bud break (spring); Calm, cool, wet spring	Summer drought
	Larch needle blight ++++	All	Growth or Mortality (rare)	Moisture at bud break and spore release (spring); Calm, cool, wet spring	Summer drought
	Larch casebearer *	All	Growth	Unknown; may depend on climate impact on parasites controlling this introduced insect	High incidence of casts and blights causes starvation of casebearer; Hot summers
Multiple species	Armillaria ++++	All	Growth and mortality	Drought stress Warmer, drier conditions	