West Kootenay Climate Vulnerability and Resilience Project

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 and Werner 2011, Utzig 2012a). 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 those 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 focus on some of the more common insects and diseases affecting commercial tree species in the West Kootenay region since the early 1900s, and describe how changing climate may alter stand susceptibility and 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 West Kootenay regional pathologist and entomologist and other experts.

1.1 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 2012a and references therein). By the 2020s,

[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

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 windstorms, heat waves, and high intensity rainstorms.

2.0 CLIMATE CHANGE IMPACTS ON FOREST HEALTH

2.1 Mechanisms of change

Climate change can affect forest health and mortality 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 themselves (e.g., larval desiccation may occur with higher temperatures), and forest health can improve. . 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 the time required for insects to complete life cycles. Warmer winters may result in higher insect overwintering survival, leading to higher brood success and rapid increases in population growth rates. 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, windstorms may create extensive windfall increasing the forest's susceptibility to bark beetle.

Climate change can also cause range extension or retraction of insects, disease agents or hosts. As tree species ranges change, insects and diseases can respond and move into new areas or be excluded from existing areas. In general, it is expected that a warmer climate will increase the diversity of insects able to inhabit higher elevations (Woods et al. 2010). In some cases, tree vigour may simultaneously be affected by changes in climate, - affecting the susceptibility to attack.

2.2 Insects, disease and forest succession

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 stands at high risk to insects and diseases.

Existing regeneration and young stands: These are another stage that is particularly vulnerable to insects and diseases. Another factor that can influence susceptibility at this stage is 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.

2.3 Insect and pathogen species summaries

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.

2.3.1 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).

2.3.2 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.

2.4 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 2012b). 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 2012a) 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 future, in part due to climate change (Woods et al. 2010). Temperature increases are expected to favour an increase in weevil reproduction rates (Turnquist and Alfaro 1996). To date, this species is less prevalent in the West compared to the East Kootenay region where spruce leaders in up to 72% of individuals 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 linked 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 relatively low concern, provincial experts predict it may become a species of 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 its response to climate change. Similar to spruce bark beetle, tree 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 outside the study area, has become the primary defoliator in BC in recent years with the frequency, intensity and duration of outbreaks increasing (Westfall and Ebata 2010). Spruce 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, populations have been observed further north and into higher elevation forests where there are no historically known outbreaks (Nealis et al). This trend has been attributed in part to warming climate as well as more susceptible stand structure in plantations. However, in the current extent of IDF these lower elevation forests may become less susceptible through time 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-story 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, so local forests may remain relatively unaffected by this species, as currently.

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 extensive mortality (Unger 1992). This insect may become a concern with climate change as outbreaks are triggered by warm dry conditions (Ferris 1992, and range expansion may also occur as a result of 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 - which may be 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 rates.

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, (after mountain pine beetle; Westfall and Ebata 2010). Provincially, it is recognized as the second most important insect likely to cause significant damage in response to changing climate (Abbot et al. 2007), as a result of potentially increased stress and susceptibility for subalpine fir.

Balsam woolly adelgid (*Adelges picea)* - In plantations and future mature stands, balsam woolly adelgid, an introduced species, may become a concern, with the potential to damage or kill subalpine fir, and to a lesser extent 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 insect creates a physiological drought in the tree that 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 is likely to increase – thereby increasing rates 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'Oreille 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 can also increase following wind throw events (Furniss and Carolin 1977); therefore predicted extreme wind events may also contribute to the build-up of populations..

Western hemlock

Defoliators are common pests of western hemlock, and because hemlock is intolerant of defoliation, mortality rates can be significant. There are five defoliators of concern that usually occur in mature to old stands in the mid to 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 causing mortality for large areas of mature trees in a single year (Unger 1992). During outbreaks, mature and old hemlock in particular, 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 since it appears to respond to multiple climate variables. Outbreaks tend to occur in watersheds that are 1.8 degrees C or cooler (Borecky 1996), so populations may decline, or outbreaks will have less impact, if temperatures increase. . Alternatively, outbreaks also occur in watersheds receiving relatively high 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, with one large outbreak occurring in the study area in the early 1970s (Unger 1992). All ages of hemlock are attacked though understory trees tend to be more heavily defoliated. 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 recently 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) though 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), so overall population response is difficult to predict.

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. The first large outbreak occurred in 1990 (Unger 1992), when 4000 ha were affected in the northern part of the study area (Stewart 1992, 1994), causing 46% mortality.. Populations are usually found below 1000m elevation and on west aspects 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 currently 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 unseasonable 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 that create high humidity required for spore dispersal in July (Hunt 1995), indicating a possible increase in the study area with predicted climate change. However, risk for this species is thought to increase with cooler and moister summers (Heineman et al. 2010), which is opposite to predicted climate changes in this region.

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). In the past, dothistroma was observed to cause growth loss in young plantations; however, now it is linked strongly with plantation failure and mortality in all ages including mature trees. 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 also caused the loss of a white pine blister rust trial near Duncan Lake, apparently linked to warming temperatures and moist springs (Michael Murray, pers. comm.).

If, as predicted, summers become drier, it is unlikely dothistroma will significantly increase within the study area; however, it is important to be aware that it does occur in the West Kootenay. If variability increases and summer storms result in sufficient precipitation in the warmer climate, outbreaks may occur.

Stem rusts - Stem rusts that affect 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).

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.

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.

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.Pinnell., 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 also increase along with an infection (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 driver, 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 if there is sufficient moisture. .

The effects of predicted climate change are 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 in part due to an ongoing suppression program . Climate change may favour continued small populations: 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 that are predicted to occur with climate change.

Multiple tree species

Root disease **–** Root diseases tend to be more indirectly affected by overall climate though there is evidence that activity increases in areas that become warmer and drier (Heineman 2010, Kliejunas 2011); and activity stays stable 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.

2.5 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, with the potential to shift whole 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 ecology 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 present *after* spacing (e.g., root disease).
- Armillaria is common in young stands in the West Kootenay region, typically identified in 10% of trees.
- Typically pine stands had the most severe problems caused by over ten different insect and disease species. 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).

2.6 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 - known as "decline syndromes" (Ostry et al. 2011) - 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). At least one decline syndrome is thought to affect West Kootenay forests:

Birch decline - The widespread decline of paper birch in the study area appears to be a result of several interacting factors that result in 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 that began in 1930 and was coupled with low winter temperatures and unseasonable spring freezes that killed new growth (Nash 1949). The bronze birch borer was also identified as part of the complex at that time. 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 western redcedar becoming 'stressed' 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 SUMMARY AND CONCLUSIONS

It is not possible to confidently predict future insect and disease outbreaks associated with climate change because of a large number of uncertainties, in particular:

- there is a high degree of uncertainty associated with the specifics of climate change predictions;
- the physiological responses of insects and diseases to changes in climate are difficult (if not impossible) to predict; and,
- the types and rates of adaptation between trees and insects and diseases are complex and also difficult to predict.

An important step towards more informed and possibly effective forestry practices is awareness of the role insects and diseases have on shaping the development, structure and dynamics of forested ecosystems, and by continuing the investigate how climate change may affect each of these. 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. For example, 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.

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

4.0 REFERENCES

Abbott, C.L., K.E. Bennett, K. Campbell, T.Q. Murdock and H. Swain. 2007. Forest Pests and Climate Change Symposium: 14-15 October 2007, Summary Report. Pacific Climate Impacts Consortium, University of Victoria, Victoria BC, 14 pp. Available at: http://pacificclimate.org/sites/default/files/publications/Abbott.ForestPestSymposium.Oct2007.pdf

Alfaro, R.I., and Maclauchlan, L.E. 1992. A method to calculate the losses caused by western spruce budworm in uneven-aged Douglas-fir forests of British Columbia. For. Ecol. Manage. 55: 295-313.

Bentz, B.J. J. Régnière, C.J. Fettig, E.M. Hansen, J.L. Hayes, J.A. Hicke, R.G. Kelsey, J.F. Negrón and S.J. Seybold. 2010 Climate Change and Bark Beetles of the Western United States and Canada: Direct and Indirect Effects. BioScience, 60(8):602-613.

Berg, E.E., J.D. Henry, C.L. Fastie, A.D. De Volder, and S.M. Matsuoka. 2006. Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: relationship to summer temperatures and regional differences in disturbance regimes. Forest Ecology and Management 227:219–232.

Borecky, N. 1996. Development of a western hemlock looper *Lambdina fiscellaria lugubrosa* hazard rating system for Interior British Columbia using discriminant function analysis and logistic regression. MSc. Thesis. University of Victoria, Victoria, B.C. In: I.S. Otvos. 2004. Development of hazard rating systems for the western hemlock looper, western blackheaded budworm and forest tent caterpillar. Final Technical Report - Part B. FIA Project R04-007CFS, Min.Forest, Forest Science Program, Victoria, B.C, 16pp. Available at: http://www.for.gov.bc.ca/hfd/library/FIA/2004/FSP_R04-007b.pdf

Canadian Forest Service. 2006. Balsam Woolly Adelgid. Pest Notes No. 3. CFS Atlantic Forestry Centre, Fredericton, NB. 2p.

Carroll, A.L., J. Régnière, J.A. Logan, S.W. Taylor, B. Bentz and J.A. Powell. 2006. Impacts of climate change on range expansion by the mountain pine beetle. Mountain Pine Beetle Initiative Working Paper 2006-14. Canadian Forest Service, Ottawa, Ont.

Cottrell, C.B. and R.D. Erickson. 1977. Annual District Report. Forest insect and disease surveys, British Columbia 1976. CFS Pacific Forestry and Research Center, Victoria, BC. Available at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/27150.pdf

Cottrell, C.B. and R.D. Erickson. 1978. Annual District Report. Forest insect and disease surveys, British Columbia 1977. CFS Pacific Forestry and Research Center, Victoria, BC. Available at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/27142.pdf

Erickson, R.D. and C.S. Wood. 1980. Forest insect and disease conditions 1979, Nelson Forest Region. CFS Pacific Forestry and Research Center, Victoria, BC. Available at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/27032.pdf

Ferris, R. 1992. Western false hemlock looper. Forest Pest Leaflet 59. Pacific Forestry Center, Victoria, B.C. Available at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/3168.pdf

Ferris, R. 1995. Larch casebearer in British Columbia. Forest Pest Leaflet 34. Pacific Forestry Center, Victoria, B.C. Available at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/4699.pdf

Furniss R.L. and V.M. Carolin. 1977. Western Forest Insects. USDA For. Serv. Misc. Publ. No. 1339. 654 pp.

Garbutt, R. 1996. Foliage Diseases in Western Larch in British Columbia. Forest Pest Leaflet 71. Pacific Forestry Center, Victoria, B.C. Available at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/4699.pdf

Garbutt, R., B. Hawkes, and E. Allen. 2006. Spruce Beetle and the Forests of the Southwest Yukon. Natural Resources Canada • Canadian Forest Service Pacific Forestry Centre • Victoria, BC Information Report • BC–X–406.

Haas, J. N. and J.H. McAndrews. 2000. The summer drought related hemlock (Tsuga canadensis) decline in eastern North America 5,700 to 5,100 years ago. In: McManus, Katherine A.; Shields, Kathleen S.; Souto, Dennis R., eds. Proceedings: Symposium on sustainable management of hemlock ecosystems in eastern North America. Gen. Tech. Rep. NE-267. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 81-88.

Hagle, S.K., S. Tunnock, K.E. Gibson and C.J. Gilligan. 1987. Field guide to diseases and insect pests of Idaho and Montana forests. U.S. Department of Agriculture, Forest Service, Northern Region, Montana.

Hain, F. P., R.G. Hollingsworth, F. H. Arthur, F. Sanchez and R.K. Ross. 1991. Adelgid host interactions with special reference to the balsam woolly adelgid in North America. In: Baranchikov, Yuri N.; Mattson, William J.; Hain, Fred P.; Payne, Thomas L., eds. Forest Insect Guilds: Patterns of Interaction with Host Trees; 1989 August 13-17; Abakan, Siberia, U.S.S.R. Gen. Tech. Rep. NE-153. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 271-287.

Hard, J.S., T.R. Torgersen and D.C. Schiege. 1976. Hemlock sawfly. USDA For. Serv. Forest Insect and Disease Leaflet 31. 7pp. Available at: http://www.forestpests.org/acrobat/fidl31.pdf

Heineman, J.L., D.L. Sachs, W.J. Mather, and S. Simard. 2010. Investigating the influence of climate, site, location, and treatment factors on damage to young lodgepole pine in southern British Columbia. Canadian Journal of Forest Research 40:1109–1127.

Henigman, J., T. Ebata, E. Allen, J. Westfall, and A. Pollard. 2001. Field Guide to Forest Damage in British Columbia March 2001, Second Edition, MOF/CFS Joint Publication Number 17. Available at: http://www.for.gov.bc.ca/hfp/publications/00198/index.htm

Hogg, E.H., J. Brandt and M. Michaelian. 2008. Impacts of a regional drought on the productivity, dieback, and biomass of western Canadian aspen forests. Canadian Journal of Forest Research 38:1373–1384.IPCC (Intergovernmental Panel on Climate change). 2007. Fourth Assessment Report: Climate Change 2007. The regional Impacts of climate change. 10.2.1.1. Forests, Grasslands, and Tundra. Available at: http://www.ipcc.ch/ipccreports/sres/regional/267.htm

Hood, I.A. 1982. Phaeocryptopus gaeumannii on Pseudotsuga menziesii in southern British Columbia. New Zealand Journal of Forest Science 12, 415–24.

Hunt, R.S. 1995. Common pine needle casts and blights in the Pacific Region. Forest Pest leaflet 43, For. Can., Pac. For. Cent, Victoria, BC 7 pp.

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Synthesis Report. This report, adopted section by section at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report. 73pp.

Johnston, M., M. Campagna, P. Gray, H. Kope, J. Loo, A. Ogden, G.A. O'Neill, D. Price and T. Williamson. 2009. Vulnerability of Canada's Tree Species to Climate Change and Management Options for Adaptation: An Overview for Policy Makers and Practitioners. Canadian Council of Forest Ministers, Ottawa, ON.

Kliejunas, J.T. 2011. A risk assessment of climate change and the impact of forest diseases on forest ecosystems in the Western United States and Canada. Ge. Tech. Rep. PNW-GTR-236. Albany, CA. USDA, For. Serv., Pacific Southwest Research Station. 70pp.

Kliejunas, John T.; Geils, Brian W.; Glaeser, Jessie Micales; Goheen, Ellen Michaels; Hennon, Paul; Kim, Mee-Sook; Kope, Harry; Stone, Jeff; Sturrock, Rona; Frankel, Susan J. 2009. Review of literature on climate change and forest diseases of western North America. Gen. Tech. Rep. PSW-GTR-225. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 54 p.

Koot, H.P. 1992. Western blackheaded budworm. Forest Pest Leaflet 24. Forestry Canada, Pacific Forestry Centre, Victoria, BC.

Logan, J.A., J. Régnière, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Front Ecol Environ 2003; 1(3): 130–137.

Maclauchlan, L. and J. Brooks. 2004. Spatial and Temporal Patterns of Western Spruce Budworm Outbreaks in Southern British Columbia. Final FII Technical Report, BC Min. Forest, Kamloops, B.C. Available at: http://www.for.gov.bc.ca/hfd/library/FIA/2004/FSP_R04-030a.pdf

Murdock, T.Q. and A.T. Werner, 2011. Canadian Columbia Basin Climate Trends and Projections: 2007-2010 Update. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 43 pp. Available at: http://pacificclimate.org/sites/default/files/publications/Murdock.CBT2007-2010Update.Jul2011.pdf

Ministry of Forests and Range. 2008. Adapting to climate change: Future Forest Ecosystem Initiative 2007/08 – 2009/10 strategic plan. Available at: http://www.for.gov.bc.ca/ftp/hts/external/!publish/web/ffei/project/FFEI_Strategic_Plan.pdf

Nash, R.W. 1949. *In* Forest insect investigations bi-monthly progress report. Vol. 5 Rep. 1. Dominion Dept. of Agriculture, Science Service, Division of Entomology. Ottawa, Ont. 24pp. Available at: https://afc-fr.cfsnet.nfis.org/fias/pdfs/afc/atlantic_bimonthly_1949-5(1-6).pdf

Neales, V.G. M.K. Noseworthy, R. Turnquist and V.R. Waring. 2009. Balancing risks of disturbance from mountain pine beetle and western spruce budworm. Can. J. For. Res. 39: 839-848.

Nitschke, C., A-H. Mathey, and M. Amoroso. 2010. An integrated assessment of species and ecosystem vulnerability to climate change from the tree- to stand- to landscape-level in the Sub- Boreal forests of northwest British Columbia, Canada. Forest Sciences Program Report for Y10-3200. Available at: http://www.for.gov.bc.ca/hfd/library/FIA/HTML/FIA2010MR341.htm

Ostry, M.E., R.C. Venette and J. Juzwik. 2011. Decline as a disease category: Is it helpful? Phytopathology 101:404-409.

Otvos, I.S. 2004. Development of hazard rating systems for the western hemlock looper, western blackheaded budworm and forest tent caterpillar. Final Technical Report - Part A Landscape Level Hazard Rating For Western blackheaded Budworm In British Columbia. FIA Project R04-007CFS, Min.Forest, Forest Science Program, Victoria, B.C, 16pp. Available at: http://www.for.gov.bc.ca/hfd/library/FIA/2004/FSP_R04-007b.pdf

Parfett, N., I.S. Otvos and A. Van Sickel. 1995. Historical Western Hemlock Looper Outbreaks in British Columbia: Input and Analysis Using a Geographical Information System. Pacific Forestry Centre, Victoria, B.C., 36 pp.

Spittlehouse, D. 2008. Climate change, impacts and adaptation scenarios: Climate change and forest and range management in British Columbia. BC Min. Forests and Range. Victoria, BC. Technical Report 45.

Sturrock, R.N., S. J. Frankel, A. V. Brown, P. E. Hennon, J. T. Kliejunas, K. J. Lewis, J. J. Worrall and A. J. Woods. 2011. Climate change and forest diseases. Plant Pathology (2011) 60, 133–149.

Stevens, R.E. 1971. Pine needle sheathminer. USDA For. Serv. Forest Pest Leaflet 65. 5pp. Available at: http://dnrc.mt.gov/Forestry/Assistance/Pests/Documents/FIDLs/PineNeedleSheathMiner065.pdf

Stewart, A.J. 1992. The Impact of Defoliation by Gray Spruce Looper on Western Hemlock in the Nelson Forest Region. Forest Insect and Disease Survey FIDS Report 92-15, For. Can., Pac. For. Cent, Victoria, BC 2 pp.

Stewart, A.J. 1994. Gray Spruce Looper. Forest Pest leaflet 78, For. Can., Pac. For. Cent, Victoria, BC 4 pp.

Turnquist, R.D. and J.W. Harris. 1993. Balsam woolly adelgid. Forest Pest Leaflet 01. Pacific Forestry Center, Victoria, B.C.

Turnquist, R.D. and R.I. Alfaro. 1996. Spruce weevil in British Columbia. Forest Pest Leaflet 02. Pacific Forestry Center, Victoria, B.C.

Unger, L. and J. Vallentgoed. 1991. Forest Insect and Disease Conditions Nelson Forest Region – 1990. FIDS Report 91-3, For. Can., Pac. For. Cent, Victoria, BC 51 pp.

Unger, L. 1992. History of Population Fluctuations and Infestations of Important Forest Insects in the Nelson Forest Region 1923-1991. Forest Insect and Disease Survey FIDS Report 92-13, For. Can., Pac. For. Cent, Victoria, BC 104 pp.

Unger, L. and J. Vallentgoed. 1991. Forest insect and disease conditions, Nelson Forest Region, 1990. FIDS Report 91-3. Forestry Canada, Victoria, BC. 51 pp.

Unger, L. and A. Stewart. 1992. Forest insect and disease conditions, Nelson Forest Region, 1991. FIDS Report 92-3. Forestry Canada, Victoria, BC. 41 pp.

Unger, L. and A. Stewart. 1993. Forest insect and disease conditions, Nelson Forest Region, 1992. FIDS Report 93-3. Forestry Canada, Victoria, BC 36 pp.

Unger, L. and Stewart, A. 1994. Forest insect and disease conditions, Nelson Region, 1993. FIDS Report 94-3. Forestry Canada, Victoria, BC 49 pp.

Unger, L. and Stewart, A. 1995. Forest insect and disease conditions, Nelson Region, 1994. FIDS Report 95-3. For. Can., Pacific and Yukon Region, Victoria, BC 49 pp.

Unger, L. and Stewart, A. 1996. Forest insect and disease conditions, Nelson Region, 1995. FIDS Report 96-3. CFS, Pacfic Forestry Centre, Victoria, BC 28 pp.

Utzig, G. 2012a. Climate Change Projections for the West Kootenays. Report # 3 from the West Kootenay Climate Vulnerability and Resilience Project. Available at www.kootenayresilience.org

Utzig, G. 2012b. Ecosystem and Tree Species Bioclimate Envelope Modeling for the West Kootenays. Report #5 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: www.kootenayresilience.org

Westfall, J. and T. Ebata. 2008. 2008 Summary of Forest Health Conditions in British Columbia. BC Min. Forests and Range, Forest Practices Branch, Victoria, B.C. Available at: http://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/2008/Aerial%20Overview%202008.pdf

Westfall, J. and T. Ebata. 2009. 2009 Summary of Forest Health Conditions in British Columbia. BC Min. Forests, and Range, Forest Practices and Investment Branch, Victoria, B.C. Available at: http://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/2009/Aerial%20OV%202009%20Final.pdf

Westfall, J. and T. Ebata. 2010. 2010 Summary of Forest Health Conditions in British Columbia. BC Min. Forests, Lands and Mines, Forest Practices and Investment Branch, Victoria, B.C. Available at: http://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/2010/FH%20Conditions%202010.pdf

Westfall, J. and T. Ebata. 2011. 2011 Summary of Forest Health Conditions in British Columbia. BC Min. Forests, Lands and Mines, Forest Practices and Investment Branch, Victoria, B.C. Available at: http://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/2011/BC%20FH%20Conditions%20Report%202011.pdf

Wood, C.S and G.A. Van Sickle. 1989.Forest insect and disease conditions British Columbia & Yukon 1989. Forestry Canada, Pacific Forestry Centre, Victoria, B.C.

Woods, A.J., D. Heppner, H. H. Kope, J. Burleigh and L. Maclauchlan. 2010. Forest health and climate change: A British Columbia perspective The Forestry Chronicle Vol. 86, No 4.

Woods, A.J. 2003. Species diversity and forest health in northwest British Columbia. Forestry Chronicle. 79: 892–897.

APPENDIX 1: TABULAR SUMMARY OF INSECT AND DISEASE INFORMATION

Table A1 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	