The Implications of Climate Change to Forest Health in British Columbia:

A Report to the Chief Forester

March, 2009
BC Ministry of Forests and Range

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EXECUTIVE SUMMARY

The current, historically unprecedented outbreaks of mountain pine beetle and *Dothistroma* needle blight in British Columbia are strong indicators that relationships between pests, hosts and climate are being altered as climate changes. Numerous recent pest epidemics elsewhere in North America provide further strong evidence of the impact of changing climate on forest ecosystems.

The interactions between pests, hosts and climate are complex, have co-evolved over centuries, and in many instances, are not well understood. This, together with the uncertainty associated with how regional climates will change, makes it difficult to predict the responses of specific pests to climate change. However, as climate changes, the environmental parameters under which present forests were established will change. When these changes result in increasingly sub-optimal conditions, trees will become physiologically stressed. Stressed trees are generally more attractive, more nutritious, and less resistant to many forest pests. Changes in thermal and moisture environments, combined with changes to host plant conditions, will interact synergistically facilitating the development of insect and pathogen outbreaks. The incidence of forest decline syndromes is also likely to increase as a result of general reductions in forest health.

Large scale, pest-caused forest decline and mortality will have long-term ecological, social and economic consequences. Timber supplies, water resources as well as other forest resources will be impacted. We anticipate increasing levels of mortality in the standing inventory in many Timber Supply Areas in the province as a result of forest pest activity. Much of the immature growing stock will also be affected by increasing levels of pest-caused mortality, growth losses and regeneration delays. Although the mountain pine beetle epidemic represents a current extreme, in many Timber Supply Areas it is possible that the combined impacts of multiple pests under the influence of climate change could approach a similar magnitude of impact on the remaining timber resource.

Although there is still much uncertainty regarding the severity and extent of climate change, there are strategies, which could be implemented to mitigate the impacts on forest health. We provide concise recommendations that would better track changing forest health conditions, increase our ability to forecast pest related impacts of climate change, increase the effectiveness of forest planning by proactively incorporating forest health issues and improve our abilities to prevent, mitigate and adapt to changing forest pest conditions. The unprecedented and concurrent outbreaks of insects and diseases in BC emphasize the need to expedite an action plan on the following nine recommendations of equal importance:

1. Mandate expanded forest health monitoring for forest health agents at the landscape, watershed and stand level, as a component of ministry responsibility;
2. Build a forest health research section;
3. Implement modelling projects to predict future forest health impacts;
4. Maintain forest health strategies and develop climate change risk assessments for each Timber Supply Area;

5. Review and revise legislation and policy to identify forest health risks and strategies within forest stewardship plans;
6. Institute landscape-level planning for forest health, as well as for other values;
7. Develop and implement hazard- and risk-rating systems for forest insects and diseases;
8. Implement changes to tree species selection and stocking standards to enable facilitated migration;
9. Enable the research and development of products and tactics for the treatment of forest insects and diseases.

The management of forest lands has clearly become more challenging as a result of climate change. We believe that our current forest management paradigm, which assumes stable climates and stable forest conditions, could be improved to better cope with highly uncertain future forest conditions. Forest management needs to respond and adapt to accommodate the diverse and innovative practices we will require to manage our forests into the future.

ACKNOWLEDGEMENTS

We would like to thank the following people for their technical review:
Kevin Astridge, Elizabeth Campbell, Dave Coates, Caren Dymond, Christine Fletcher, Bruce Fraser, Andy MacKinnon, Greg O'Neill and Alvin Yanchuk. We also acknowledge our forest health colleagues within the ministry for their reviews and for contributing some of the original sections and paragraphs. Finally, we thank ministry staff from forest districts, regions and headquarters that reviewed the preliminary report. All review comments were appreciated and contributed to the final report.

PREFACE

This report presents our assessment of the forest health implications of climate change for British Columbia. Our purpose is to inform the Chief Forester and his staff, and related ministry initiatives dealing with climate change. We outline general principles and concepts associated with pests[1] and climate change; provide examples of forest health factors that are already having impacts; provide anticipated changes to our current major forest pests; provide commentary on species selection, facilitated migration and the management of genetic resources; and, finally, provide management recommendations to help mitigate or adapt to climate change impacts.

We have compiled our most realistic expectations of future forest health impacts associated with climate change. In general, we are not optimistic and could be seen by some as claiming that the ‘sky is falling’. We have wrestled with this perception and are quite aware of the implications of being overly pessimistic. The Terms of Reference for this report, contained in the Appendix, provide clear bounds for this report. We do not discuss any potential gains in tree growth or ecosystem productivity associated with increased carbon dioxide levels, temperatures or growing seasons. We have focused our comments on the impacts that climate change will have on forest health and how these impacts will affect the Chief Forester’s areas of responsibility. The current mountain pine beetle epidemic, and all of the associated repercussions, has provided a vivid example of the inter-relationships of climate change and forest health. Please keep this example in mind when reviewing this document and assessing potential impacts into the future; even 10 years ago, we would never have expected the situation we currently face.

We have assumed that current climate trends will continue and have referred to Spittlehouse (2008), for regional climate change scenarios. Predicting the future response of forest pests to climate change is difficult and uncertain. Due to this uncertainty, we believe it is only reasonable to discuss the near future - a maximum of 15 to 20 years. In examining historical trends, we are referencing events relative to the past 200 years. We acknowledge that the climate has changed many times over millennia and has always been in a constant state of change. The concern at this time is the rate at which the climate is changing and, from the perspective of this report, the implications of that rapid change on host-pest interactions.

[1] We define a pest as being an insect or disease that negatively impacts resources or constrains resource management objectives.

INTRODUCTION

The effects of climate change on the interactions between forest trees and forest pests are exceedingly complex and difficult to forecast. However, these effects are likely to result in significant changes to many of the established elements of our forest management regime. This view is evidenced in the historically unprecedented outbreaks of mountain pine beetle and *Dothistroma* needle blight in British Columbia (BC). These two outbreaks align with the current scientific literature that predicts increases in the severity and frequency of forest pests as one of the first observable signs of climate change.

The current, historically unprecedented outbreaks of mountain pine beetle and Dothistroma needle blight in BC are strong indicators that relationships between pests, hosts and climate are being affected.

The life cycles of many forest trees and pests are closely linked to seasonal changes. Changes in climate that affect these linkages will alter the biological synchrony between hosts and pests. Although changes have likely occurred historically, it is the speed of the current changes, and how this, in turn, affects distribution, abundance and survival of the host and pest species, that can result in unexpected host-pest interactions. The expanding list of current, or recently active, forest pest epidemics from western North America provide further evidence of this changing synchrony among climate, hosts and pests. For example, pinyon engraver beetles in New Mexico; mountain pine beetle in most western US states and Alberta; southern pine beetle in northern Arizona; Douglas-fir beetle in Wyoming; and spruce beetle in the Yukon and Alaska have all appeared in significant outbreaks over the last decade. Yellow-cedar decline along the coasts of Alaska and northern BC, birch decline over much of BC and sudden aspen decline in Alberta and in many western US states may be additional indicators of a changing climate. Any of these occurrences in isolation would be noteworthy; their simultaneous occurrence is extraordinary. This is significant when one considers that we are in the early stages of climate change.

A recent analysis of climate change impacts suggested that the mountain pine beetle epidemic had contributed to the shift of BC's interior forests from being net carbon sinks to net sources of carbon. Proactive forest management with an emphasis on forest health monitoring can help mitigate future carbon emissions from our forests. Management would include landscape level planning for dealing with forest pests, active detection and treatment programs, and the promotion of increased forest diversity aimed to promote resilient forest ecosystems on the landscape.

In this paper we point out that our current system of forest management is based on predictable ecosystem responses, which is not consistent with the rapidly changing ecology that has been forecasted. The need for change to our forest management system is evident. In addition, our management efforts are limited in geographic extent, whereas forest health phenomena are often widespread. Landscape level assessment, planning and remedial action are required to deal with the multiple and concurrent impacts of climate change. The response effort must be comprehensive and could appear overwhelming if it is not subdivided geographically into operable units.

We must not think of climate change impacts in our forest as solely a timber supply problem, when it is an overall forest problem affecting all values, present and future. The entire natural capital base, therefore, should be managed with a stewardship purpose consistent with the public interest in our forest asset.

Relationships have evolved within the context of historical environmental conditions; climate change is disrupting these co-evolved relationships in substantial and often unpredictable ways.

Climate Change Effects on Insect - Host Interactions

Insects and their host plants have co-evolved over thousands of years. These relationships evolved within the context of historical rates of climate fluctuations. Climate change, and the rate at which it is occurring, is disrupting these co-evolved relationships in substantial and often unpredictable ways.

The response of insects to a change in temperature is immediate and direct, affecting development, survival, reproduction and dispersal of insect populations. Short generation times, rapid and abundant reproduction and general mobility provide many routes for adaptation. Consequently, insects can rapidly expand their ranges, adapt to new conditions and invade new habitats. In contrast, trees have a limited ability to respond and adapt to changing climatic conditions within short time frames. In the past, the inherent genetic diversity within a tree species allowed it to survive pest outbreaks and periods of climate change. The important difference now is the rapid rate at which the change is occurring.

Climate change also has indirect effects on insect population dynamics through altered habitat factors such as the condition of tree hosts, the composition of natural enemy complexes and eventually, stand composition and structure. Predicted increases in temperature alone are not expected to have a significant direct impact on tree survival. However, temperature increases, in combination with shifts in the timing (summer *versus* winter), duration and intensity of precipitation events, will have profound impacts on trees and their associated pests. This combination of direct effects on insects and indirect effects on tree hosts is likely to favour insects over hosts.

Generalized expectations for the impacts of climate change on insect populations include range expansion to higher latitudes and elevations, increased overwinter survival, higher population growth rates, and an extended growing season, all of which are likely to lead to shifts in the frequency, intensity and extent of outbreaks.

Phenological Synchrony

Critical life stages in insect development are often timed to specific stages of tree development or to periods of host susceptibility. Disruption of this phenological synchrony between insect pests and their host plants is a key pathway through which climate change will impact insect populations. Annual tree development (e.g., bud flush, bud set) is regulated through a combination of genetics, photoperiod and climatic conditions. Insect development, however, is generally controlled by temperature, and thus, a changing climate will affect insect development directly.

Depending on the tree species, the level of host stress, and the specific insect, the effects of climate change vary from a positive, to a neutral or negative impact on insect population dynamics.

The co-evolution of an insect and its host has resulted in a set of interactions where critical stages of insect development are relatively well-timed with host development. Phenological changes that improve or disrupt insect-host synchrony can provide advantages to either the host or insect. At lower elevations, the larvae of some defoliators may emerge prior to the bud flush of their host trees, resulting in high levels of larval mortality due to a lack of suitable new foliage on which to feed. However, improved synchrony may allow defoliator larvae to survive better at higher elevations or at more northern latitudes. In time, natural selection pressure may result in insects quickly adjusting to warmer conditions in many ecosystems. Bark beetles also have to synchronize their attack in terms of coordinating a mass attack of individual trees, timing of the attack to when the host tree is most vulnerable to attack and having sufficient time to develop to maximize overwintering survival rates.

Plant Defense Mechanisms & Nutrient Status

Adding to the complexity and uncertainty associated with predicting the impacts of climate change on insects and their hosts are the indirect effects of environmental change on host defence mechanisms. Depending on the tree species, the level of host stress, and the specific insect, the effects of climate change will vary from a positive, to a neutral or negative impact on insect populations.

Resource allocation in plants involves a series of tradeoffs between growth, maintenance, and storage of energy reserves, reproduction and defense. Plant growth requires high levels of resources and consequently, during periods of rapid growth, fewer resources are allocated to other activities, most notably to the production of defense compounds. Drought stressed and diseased trees have been shown to have an impaired ability to produce oleoresin. The resistance to fungi and bark beetles has been frequently associated with the capability of the conifer hosts to generate and accumulate large amounts of resin.

Drought stress has long been hypothesized to alter plant nutritional status, such that it favours insect development. This is a result of sustained levels of photosynthesis with limited new growth resulting in increased nutrient content of existing foliage that is beneficial to insect survival and reproduction. However, a corresponding increase also occurs in the production of allelochemicals, which are often toxic and/or have anti-feedant properties that may prevent insects from taking advantage of the increased nutrients. Different plant species produce varying complements of defensive compounds, which accumulate in different plant tissues. Similarly, different species of insects have different capacities to tolerate or detoxify defensive compounds. These interactions will continue to shift as temperature and moisture regimes change, creating fluxes in conditions that will affect individual pest species differently.

Some insects and diseases that are currently not considered pests will likely be favoured by new climatic conditions. We also expect an increase in the occurrence of 'decline syndromes', as a result of cumulative stresses.

CLIMATE CHANGE EFFECTS ON PATHOGEN - HOST INTERACTIONS

The effects of climate change on pathogen - host interactions are complex and highly uncertain. Fungal development is dependent on temperature and especially on moisture, while environmental conditions can modify host resistance or susceptibility to pathogens. However, given the uncertainty in predicting these changes, it will be difficult to forecast the location and the direction of (increasing or decreasing) pathogenic disturbances with any accuracy.

The role of pathogens as disturbance agents in general, however, will likely increase as their ability to adapt to new climatic conditions will be greater than that of their long-lived hosts. A change in climate conditions can amplify the impact and aggressiveness of pathogens; whereby the status of weak pathogens changes from opportunistic to pathogenic. Wetter springs and summers in some regions will likely result in increased foliage diseases and stem rusts; increased drought in other regions will likely lead to increased mortality or reduced growth of stressed hosts due to root pathogens. Through monitoring and ongoing research the ability to react to and to predict where and when pathogenic disturbances can occur will improve.

PEST SPECIFIC IMPACTS

Most reports on forest health and climate change consider impacts as something that will occur in the future. However, the climate has already begun to change, and we are already experiencing impacts. Numerous pest occurrences in BC are increasing or changing in terms of their population dynamics (frequency and duration of outbreaks) and their impacts. This increased activity has been attributed to warmer winter temperatures, lack of extreme winter cold and to summer drought in some areas, while elsewhere, increases in summer precipitation and overnight minimum temperatures are in part responsible. All of these environmental changes are consistent with projections of climate change.

We provide some key examples from BC of insects, pathogens and abiotic forest health factors that are currently impacting forest resources as a result of climate change, or are anticipated to do so in the near future.

We emphasize that some insects and diseases that are currently not considered pests will likely be favoured by new climatic conditions and may cause significant impacts in the future (e.g., secondary bark beetles, minor foliar diseases). We also expect an increase in the occurrence of 'decline syndromes', as a result of the cumulative stresses owing to changing environmental conditions and multiple pests.

Depending on the extent of climate change and on the outcome of forest management activities, we could be faced with a similar wide-scale MPB outbreak within 70 years.

Bark Beetles

The dynamics of bark beetle outbreaks are complex; numerous conditions and circumstances must coincide and a hierarchy of thresholds must be surpassed for an outbreak to occur. Once a threshold is surpassed, however, prior controlling factors (such as natural enemies) exert little influence on population dynamics. Climate change appears to facilitate the breaching of outbreak thresholds. Bark beetles appear to be highly responsive to conditions created by climate change and are likely to exceed previously observed limits.

Host trees defend against phloem feeders such as bark beetles and weevils through the production of defensive compounds. However, severe drought dramatically decreases the tree's ability to produce these compounds, thereby compromising the tree's ability to defend against pest attacks.

Under low to moderate levels of water stress, trees become less susceptible to attack by bark beetles through increased production of defensive compounds; whereas, under moderate to high levels of water stress, they become more susceptible to attack due to the lack of resin production. While drought may allow bark beetle populations to increase from endemic to outbreak levels, widespread prolonged periods of drought may not be suitable for sustaining population growth of bark beetles due to the declining quality of the phloem resource. Understanding the biology of the individual components does not allow us to accurately predict changes in population dynamics; there is a need to better understand the interactions of the entire system.

Mountain Pine Beetle

Mountain pine beetle (MPB) outbreaks have been recorded in western Canada since the early 1900s; however, the current outbreak affecting over 13 million hectares, with projections that 77 percent of pine will be killed by 2014, is by far the most extensive and severe outbreak in recorded history. MPB has now invaded areas that historically have been climatically unsuitable, including higher elevation forests throughout the province, and the boreal forests of north-eastern BC and Alberta.

While warmer winter temperatures have facilitated the outbreak, it was the pre-existing landscape conditions of extensive areas of susceptible host trees that allowed it to reach its current magnitude and severity. The three-fold increase in susceptible pine seen in the later half of the 20th century provided ideal conditions for MPB to spread across BC and into Alberta. Over the next couple of decades we anticipate that MPB will likely continue to spread into Alberta, northward beyond its current range and to the elevational limits of pine species within BC.

Many areas of mature and immature pine forests killed by MPB will again regenerate to lodgepole pine either naturally or through planting as it is often the species most ecologically suited to the area. Depending on the extent of climate change and forest management activities (e.g., fire suppression, forest health program, harvesting, species selection and regeneration practices), we could be faced with a similar wide-scale MPB outbreak within 70 years. Increasing species diversity would significantly influence future landscape resilience to insect outbreaks and reduce this threat.

Simple modelling shows that an increase of only 1°C in the average temperature adequately warms the climate to convert many spruce weevil hazard zones to high hazard.

Douglas-fir Beetle

Weather-related events that provide either stressed trees, due to summer drought, or windthrown trees are often implicated in the start of Douglas-fir beetle outbreaks. To date, outbreaks of Douglas-fir beetle on the coast remain within historic levels of attack. However, climate change forecasts suggest that summer drought will be more common, as will winter windstorms. Should current climate trends continue, it would be reasonable to anticipate that episodes of tree mortality caused by Douglas-fir beetle will increase on the coast in the near future.

In the interior, Douglas-fir beetle is predominantly a threat in the Interior Douglas-fir (IDF) and Sub-Boreal Spruce zones and to a lesser extent in the Interior Cedar Hemlock (ICH) zone. In addition to windthrow and drought, interior beetle populations also respond to trees stressed by prolonged periods of defoliation from western spruce budworm. Douglas-fir beetle is exploiting the current warm dry conditions and the reduced resistance of budworm-defoliated trees to expand into epidemic populations in several areas. These weather conditions are expected to continue and consequently will intensify the cycles of epidemic activity of Douglas-fir beetle over the next few decades.

Spruce Beetle

The spruce beetle is the most destructive pest of mature spruce forests in western North America. This bark beetle usually has a two-year life cycle but, at lower elevations and during warm summers, they can complete their development in one year. Under such circumstances, outbreaks can arise and spread quickly. A warming climate will increase heat accumulations, likely facilitating the conversion to a predominately one-year life cycle, which in turn will result in larger, more intensive outbreaks. A warmer climate will also result in less snow accumulation causing increased drought stress in some ecological zones presently at high risk from spruce beetle. Spruce beetle populations also respond readily to wind-throw events. When downed host trees are not removed, or otherwise treated, this material can produce high numbers of beetles capable of successfully attacking and killing standing spruce over extensive areas. Increases in severe weather events will result in more blow-down, and hence a greater likelihood for spruce beetle outbreaks.

The implications of climate change will vary between herbivorous insect species with some species increasing in population while others decrease. This underscores the need to understand host-insect-climate interactions.

Spruce Weevil

Spruce weevil is the most damaging insect pest of young spruce in BC. Within high-hazard sites on the coast, it significantly hinders Sitka spruce regeneration. Some areas of the central interior suffer similar levels of damage. The success of weevil broods is strongly regulated by heat accumulation and weevil hazard zones have been delineated on this basis. As the climate warms, areas currently considered to have a low or moderate hazard will become increasingly more suitable for weevil broods. Simple modelling shows that an increase of only 1°C in the average temperature adequately warms the climate to convert many spruce weevil hazard zones to high hazard. Fortunately the identification and propagation of weevil resistant spruce genotypes will help mitigate the impacts of the weevil in regenerating Sitka spruce on the BC coast. Without a similar focus on the resistance of interior spruce, we could be facing significant increases in damage by this insect in the central and northern interior.

DEFOLIATORS

Outbreaks of defoliating insects can arise over extensive areas given favourable weather conditions. The complexity of host-pest-climate interactions makes predictions around specific species responses difficult; however, climate change may result in more frequent favourable weather and therefore more frequent defoliator outbreaks.

The implications of climate change will vary between herbivorous insect species; for example, an experiment in eastern Canada evaluated the impact of drought on aspen defoliators, and found that severe drought decreased the growth and survival of gypsy moth, but had no impact on development of the white-spotted tussock moth.

The effects of water stress on the composition of defensive compounds within foliage are variable in both the classes and amounts of defensive compounds produced. There are also varying abilities of defoliating insects to detoxify or sequester the array of compounds, which produces a wide range of potential responses.

Western Spruce Budworm

Western spruce budworm has a long history of outbreaks both in interior dry-belt Douglas-fir dominated forests and in coastal regions. Early selective harvesting of interior forests promoted the development of Douglas-fir stands with dense understories and multi-structured canopies, conditions that are particularly susceptible to budworm outbreaks. The 1985-1991 outbreak in the BC interior was the largest in recorded history. However, the current outbreak, now covering over 840,000 ha, may surpass this record. The most noticeable difference in the current budworm outbreak is the expansion of its range into the Cariboo and Chilcotin, and into higher elevations.

This change in outbreak dynamics is a response by the budworm to milder, more suitable climatic conditions and to altered forest composition and stand structure. As climate warms, budworm may continue to expand in range toward the limit of its primary host, Douglas-fir, and into higher elevation ecosystems.

The ability to predict spruce budworm population behaviour in a changing climate is complicated by the potential for asynchrony with tree development – a key factor in budworm population dynamics. Budworm can respond to changing weather more rapidly than trees. If early summer temperatures induce emergence of larvae prior to buds being available, the insect is forced to mine old, less nutritious needles and suffers higher mortality rates. A warming climate may allow for a more synchronized emergence with host phenology in more northern and higher elevation sites where suitable hosts are available. Budworm may become less successful at warmer, lower elevations due to asynchrony with tree development.

Western Hemlock Looper

Outbreaks of western hemlock looper have been forecast to occur more frequently and to be more widespread on the coast of BC as a result of a warming climate. Most climate change models predict warmer and drier summers for coastal BC; the very conditions that seem to have historically triggered outbreaks of this looper. Entire stands of western hemlock can be killed following only one year of severe defoliation and once dead, western hemlock becomes unmerchantable within a few years. Within the past 100 years there have been seven recorded outbreaks on the coast and eight in the interior that have involved substantial hemlock mortality and salvage harvesting.

FOLIAR DISEASES

Foliar fungi may be one of the most responsive forest disease pathogens to a changing climate of warmer and wetter conditions, since fungal fecundity (sporulation and spore germination) is directly controlled by temperature and moisture. Foliar diseases cause premature leaf mortality, which leads to a loss of photosynthetic efficiency and a reduced capacity of the host to obtain necessary nutrients. Repeated severe defoliation increases host susceptibility to secondary pests and can eventually lead to direct mortality due to nutrient deprivation.

Foliar disease fungi may be some of the most responsive forest disease organisms to climate change.

From the few documented landscape-level estimates of hard pine rust incidence, it seems that all hard pine rusts have increased.

Foliar diseases generally have minor impacts in BC due to high levels of host resistance; however, the example of *Dothistroma* needle blight in northwest BC suggests this historical trend may no longer hold. The *Dothistroma* epidemic has coincided with a marked increase in summer precipitation and an increase in the frequency of warm, wet days. Although the specific environmental requirements of other foliar diseases are not as well known, it is reasonable to assume that conditions that favour *Dothistroma* needle blight would favour many similar foliar diseases. Reports of other foliar diseases of lodgepole pine and other tree species including western redcedar, hybrid spruce, subalpine fir, black cottonwood and trembling aspen are also now more common. In general, areas of the province where summer precipitation has increased, foliar disease incidence and attack severity have also increased.

The influence of global climate change on precipitation patterns is very difficult to predict. As such, projections of climate change impacts on foliar disease behaviour are similarly challenging and highly uncertain. There is, however, general consensus that daily minimum temperatures are expected to increase more than daily maximums, and evidence of increased overnight minimum temperatures in BC already exists. Increases in precipitation and in overnight minimum temperatures and the potential for greater over-winter survival of foliar fungi due to warmer winters could all favour the development and spread of foliar diseases.

Stem Rusts

Pine stem rusts are one of the most damaging groups of forest pathogens of young pine in BC. The life cycle of all rust species are strongly influenced by environmental conditions, particularly precipitation during the growing season. When specific optimal environmental conditions are met, peaks of rust infection or "wave years" occur, historically once every decade. Wave years for western gall rust require cool, moist conditions in late spring. Wave years for other stem rusts, including white pine blister rust, comandra and stalactiform blister rust, require cool, moist conditions in mid- to late-summer. The frequency of wave years appears to have increased over the past decade throughout central BC suggesting a climatic shift to wetter late springs and summers; the timing and conditions that favour rusts.

Evidence from the 1980s and early 1990s of hard pine rust incidence at the landscape-level suggests that all hard pine rusts have increased, particularly comandra blister rust. More recently, a genetic resistance trial of hard pines in central BC found a 60 percent infection rate of comandra blister rust after only four years. Perhaps the clearest indication of increasing rust incidence at the landscape level is found in the Morice Timber Supply Area (TSA). Three repeated large-scale surveys found that in both 1996 and 1999 only seven percent of surveyed stands contained a combined hard pine rust incidence of >20

%, whereas in 2008, 41 percent of surveyed pine stands had hard pine rust incidence of >20 %.

Changes in climatic conditions that result in warmer and wetter late springs and summers will likely increase the risk of damage in most areas of the province that already suffer losses to hard pine rusts. However it should be noted, for areas in the southern interior that currently suffer significant rust damage, such as the Montane Spruce zone, the climate may become too dry for rust fungi.

By reducing the effectiveness of mycorrhizal fungi as a suppressive agent and by increasing host stress and vulnerability, climate change may increase root disease-caused timber losses.

ROOT DISEASES

There is no conclusive study linking climate change to increased root disease activity in BC. Elsewhere in the world such studies do exist and were some of the first to suggest that climate change was responsible for altered forest pathogen behaviour. In those studies, climate change was linked directly to drought stress, which predisposed host trees to a root disease.

Current and future climates will place large areas of southern interior forest under greater drought stress and therefore at higher risk to root disease. *Armillaria* root disease is prevalent throughout the ICH zone on a wide host range causing significant growth loss and moderate rates of mortality. In contrast to the ICH, within the IDF zone, *Armillaria* root disease is less common, but a much more effective tree killer. If climate change results in large areas of the ICH becoming dryer, it is very likely that the impacts of *Armillaria* root disease will increase significantly. In general, areas of the province where host trees are under greater stress, the activity of major root diseases such as *Armillaria*, *Phellinus*, *Tomentosus* and *Annosus* will probably increase.

Climate change could also alter tree relationships with mycorrhizal fungi and other beneficial microbes that currently suppress root disease. The protective effects of mycorrhizae against various root diseases may be affected by changes in the relative fitness of different mycorrhizal fungi under conditions of altered soil temperature or moisture regime.

Although we expect that timber losses to root disease will increase under climate change, the expansion of root pathogens into new ranges will be slower than that of rusts and foliar diseases. The latter two groups spread primarily by airborne spores, capable of considerable travel, while root diseases tend to spread through root contacts among host trees.

DWARF MISTLETOES

Dwarf mistletoe infections weaken tree hosts and may predispose them to further damage from other biotic agents. Climate change may play a role, with drought and warmer winter temperatures affecting tree resilience and mistletoe biology. Cold temperatures and snow may limit dwarf mistletoe reproduction, while warming temperatures would allow for geographic and elevational range expansion. Differences in the incidence and severity of mistletoe among geographic areas reflect the effects of different climates on seed production and spread; on stand composition; tree growth rates; and on dwarf mistletoe biotypes. Decreased snow loads and warmer winter temperatures could facilitate the migration of Douglas-fir mistletoe to the coast and hemlock dwarf mistletoe inland.

Alien invasive pests in tandem with climate change present a unique challenge.

The mountain pine beetle epidemic has substantially reduced the quantity of mature hosts of lodgepole pine dwarf mistletoe, thereby reducing the impact of this disease for the time period covered in this document.

ALIEN INVASIVE PESTS

Alien invasive pests pose serious threats to BC forests. Through increased international trade and movement of goods the likelihood of accidental introductions of invasive species remains high. The unintentional introduction of alien forest insects and disease can irrevocably alter forest biodiversity. While climate change does not directly affect the rate of introduction of new pests, it can provide host trees that are stressed and less able to defend themselves or provide environmental conditions that are more amenable for pest establishment. For example, the brown spruce longhorn beetle was able to establish in Nova Scotia forests following a hurricane that provided ample dead and dying host material for the insect to colonize and subsequently adapt to the local host tree species. To date, a cold winter climate that is not favourable to many exotic pests has been our best natural defense.

Climate change is forcing us to re-evaluate our system of monitoring for alien pests. Historic risk analysis delimited areas where the climate was not suitable for alien invasive pest development, such as for gypsy moth. Under climate change we are re-evaluating trap distribution for gypsy moth within areas that were previously considered unsuitable.

White pine blister rust is an alien invasive pathogen that was introduced into the forests of North America in the early 20th century. It has devastated western white pine and other five-needle pines including whitebark pine in BC. Although the introduction of white pine blister rust was not related to climate change, its introduction illustrates that alien pests attacking tree species with little or no host resistance can have devastating consequences. The foliar blight, *Phytophthora pinifolia,* is currently affecting Monterey pine stands in Chile. This disease is either a previously unknown species of *Phytophthora*, or one that was not previously known to infect conifers. This example emphasizes the point that future environments will provide conditions that can facilitate shifts to new host tree species as well as result in the emergence of new pest species. Alien invasive pests in tandem with a changing climate will present unique challenges to forest ecosystems.

PEST COMPLEXES

Individually, many insects and diseases have only a minor impact on tree health. However, when multiple pests interact, the health of stands can be compromised. As our climate continues to change and trees become more stressed, relatively innocuous insects and diseases acting together could become significant.

Another challenge with multiple pest complexes is that certain pests predispose forests to attack by other pests. Defoliators such as western spruce budworm can predispose their host to attack by bark beetles by stressing trees so severely that they have few defensive resources left to repel attack. For over five consecutive years throughout the Cariboo and Chilcotin, budworm has been severely impacting Douglas-fir stands. As a result of this stress, in combination with drought conditions, populations of Douglas-fir beetle are now at epidemic levels.

The emergence of pest complexes in young stands presents a particularly serious concern. The current mountain pine beetle epidemic has intensified the pressure placed on regenerating forests to contribute to mid-term timber supplies. In young lodgepole pine stands, it is common to encounter western gall rust, stalactiform and comandra blister rusts, *Atropellis* canker, terminal weevil and more recently, mountain pine beetle and pine engraver, all coexisting in one stand. The interaction and ultimate impacts of these pest complexes will increase in importance as climate change puts additional stresses on regenerating forests. Species selection, silviculture treatments and pest management are all critical to the success of these future forests and the interaction of these factors must be closely monitored. Manipulation of stand density influences pest dynamics and, in some cases, makes trees and stands more susceptible to attack by insects and diseases. Careful consideration and planning are required to conduct stand - tending activities that will reduce susceptibilities. The interaction of the environment, treatment, host and pests must be monitored and adaptive management applied.

A decline syndrome is not attributable to any one agent, but is the result of a number of stressors acting in combination that is beyond an environmental balance.

DECLINE SYNDROMES

Changing climates will result in stress responses from trees as their environments increasingly become sub-optimal for them. Physiologically stressed trees are more susceptible to attack by many different pests. While often these impacts are quickly evident, such as with bark beetle mortality, the slow decline of tree health as a result of less evident stresses can go undetected until it is too late to intervene. In such instances, tree mortality is often not attributable to any one agent, but is the result of a number of diseases and secondary insects acting in combination, and as such these occurrences have been termed 'decline syndromes'. Many declines are associated with moisture stress that predisposes trees to attack by pathogens and insects. As such, declines are often geographically widespread. Occurrences of decline syndromes have increased in recent years in many of the world's forests, including many in western North America such as western boreal aspen forests, coastal yellow-cedar forests and interior birch stands.

High elevation forests could be especially vulnerable to climate change as they are less tolerant of drought and fire, and both could increase in frequency and severity in the coming years.

Drought- Related Declines

In 1998, and again in 2003, the southern interior of BC experienced a significant drought. As a result of the 1998 drought, over 10,000 ha of drought-related tree mortality was mapped in the aerial overview surveys within the Kamloops, Okanagan-Shuswap and Cascades forest districts. Some of this mortality was a direct result of water stress on sites that were drought prone such as those having shallow soils and areas of transitional grassland. However, much of the mortality was a result of secondary insect attack on stressed trees (e.g. *Ips*, *Pityogenes* and others) and on increased root disease activity. This case exemplifies the rapid and immediate response of insects and disease to a severe climatic event.

With climate change, chronic stresses will continue to increase and manifest in various ways but will result, presumably, in similar outcomes. Mortality of subalpine fir in permanent monitoring plots located throughout the southern interior increased during this same period of drought. The mortality was caused by a known tree killer, the western balsam bark beetle, and by a typically innocuous *Pissodes* weevil acting like a primary bark beetle. High elevation forests will become increasingly vulnerable to these opportunistic pests as dramatic climate fluctuations increase in frequency. High elevation forests are also less tolerant of drought and fire, and both could increase in frequency and severity in the coming years.

The decline of Douglas-fir on ridges and steep slopes, especially on southwest slopes in the Kootenay-Boundary area is supporting sustained populations of Douglas-fir beetle, which are killing groups of drought-stressed trees. *Armillaria* root disease is undoubtedly also associated with this decline. The Rocky Mountain and Kootenay Lake districts experienced a mid-July windstorm in 2007, creating significant blowdown where Douglas-fir beetle populations increased further. This again illustrates how the combined direct and indirect impacts of climate change can compromise forest health.

Over the past decade mortality and dieback of western redcedar has been observed within the driest biogeoclimatic zone variants on the coast of BC. This was especially evident following the dry summer of 1998 and repeated throughout the early 2000s. Although it is still too early to be definitive, it does appear that as a result of the increasing incidence of summer drought on the coast, western redcedar is slowly dropping out of the forests within the Coastal Douglas-fir zone. Periods of drought over the past decade and during the summer of 2007 in particular, have also resulted in stressed western redcedar appearing in large numbers in the southern part of the ICH in the Kootenay-Boundary area. Trees in many areas have experienced severe winter flagging, with dead tops and mortality also occurring.

YELLOW-CEDAR DECLINE

Yellow-cedar decline has been identified as a problem in south-eastern Alaska for several decades but, until recently, its occurrence and impact was poorly documented in BC. Recent assessments along the coast indicate that large areas within the range of yellow-cedar are exhibiting the effects of the decline and this may affect the future range of this species. To date, over 40,000 ha of decline have been mapped in BC including both small patches and larger contiguous areas of damage.

Yellow-cedar decline is considered to be a result of long-term climate change. The hypothesis is that declining snow depths at lower elevations of the range of yellow-cedar are leading to increased susceptibility of fine roots to late season frost events. If this scenario is correct, then yellow-cedar will continue to decline if snow packs recede earlier in the spring due to lower annual snowfall.

The decline of paper birch has become very prominent throughout much of BC, particularly in the southern interior.

BIRCH DECLINE

The decline of paper birch has become very prominent throughout much of BC, particularly in the southern interior. The syndrome appears to be a result of several factors working in concert that prevent normal tree growth, limit defensive processes and hasten top-kill and tree death. An insect-pathogen complex of bronze birch borer, several birch leaf miner species, and pathogens are involved; however, climate change may well be the underlying cause. Summer drought stress, temperature variability and freeze-thaw events likely reduce tree vigour and growth, and influence the incidence of pests. Several studies suggest that region-wide birch dieback is caused by extreme freezing and/or moisture fluctuations, which permanently damage functional living tree tissues. The frequency of such climate events is expected to increase in the future. This may push paper birch beyond its adaptive limit leading to large-scale dieback throughout its current range.

IMPLICATIONS FOR FOREST MANAGEMENT

TIMBER SUPPLY CONSEQUENCES

We anticipate that increasing levels of insect and disease activity in forests resulting from climate change will increase mortality in standing mature forests, and cause increased mortality, growth loss and regeneration delay in regenerating and immature forest stands. In mature stands, we expect most of the mortality will be non-recoverable due to the scope and timeframe in which it will occur as well as to accessibility issues. In some TSAs, the current MPB epidemic has resulted in a loss in the standing timber inventory of close to 70 percent, without taking into account beetle attack in stands younger than 60 years. Although the MPB epidemic represents a current extreme, in many TSAs it is possible that the combined impacts of multiple pests under the influence of climate change could approach a similar magnitude of impact on the remaining timber resource.

The combination of direct and indirect effects of climate change on forest health will fundamentally affect our current concepts of forest productivity such as long-run sustained timber yield.

The combination of direct and indirect effects of climate change on forest health will fundamentally affect our ability to make reasonably accurate projections of forest dynamics and outputs over the long term. Large or frequent disturbances present a challenge to forecasting sustainable timber supply, particularly when the extent and severity of the events are uncertain and subject to ongoing changes in the climate. While historical parameters have been used in timber supply projections, such information will now form an inadequate basis for timber supply modeling. The most up-to-date information on forest pest occurrences and damage should be incorporated into timber supply analyses and harvest level decisions. This could be facilitated by improvements in both stand- and forest-level monitoring practices.

It would be worthwhile exploring how forest disturbance scenarios affect timber supply, and whether changes to the manner in which forest health information is modelled in timber supply analysis are warranted. It may also be worthwhile to model the forest-level implications of potential management responses to forest health issues (e.g. short rotations). Such information would help in developing forest health strategies that meet landscape-, forest- and stand-level objectives.

Old Growth Strategies and Wildlife Habitat Areas

Increased forest pest activity is compromising many old growth and wildlife habitat reserves. In the Cariboo, current outbreaks of mountain pine beetle and Douglas-fir beetle have already killed most of the trees within many of these reserves. Climate change is clearly impacting the province's objectives for wildlife habitat and old growth representation. Strategies should be developed in anticipation of continued pest impacts. This may require additional reserves for replacement or recruitment, and new concepts and techniques for achieving the objectives. This will place additional strain on the timber harvesting landbase. From a forest health perspective, infested reserves can be problematic as they can function as reservoirs of unmanaged pests. Forest health issues need to be better incorporated into the management assumptions and objectives for these land use designations.

Forest Genetics

Increasing the number of species and seedlots of a species on the landscape – each having a slightly different climatic/adaptive optimum - provides a buffer against increased pest risk. Most forest pests are species specific so the simple act of increasing the number of species directly reduces the risks of a plantation, and our management goals, being compromised by any one pest species.

Increased species and genetic diversity in combination with facilitated migration is the most effective, efficient, and durable method to maintain healthy plantations in the face of climate change. Planting species and populations (seedlots) that are adapted to future climates helps preserve the host-pest balance that has been created over millennia. The importance of assisted migration in mitigating losses to forest pests in a changing climate cannot be over-stated. Provenance tests reveal that the incidence of pest attack increases sharply when populations are planted in climates that differ significantly from their origin. Clearly, assisted migration of seedlots alone would not have affected the course of the current mountain pine beetle epidemic, however, assisting the movement of species while simultaneously increasing diversity in a manner that tracks climate change, may help keep pest levels below outbreak thresholds in the future.

The world renowned Illingworth lodgepole pine provenance trial provides both an indication of which families of lodgepole pine that might be more productive under climate change, as well as a stark reminder of the influence of insects and diseases.

There is a growing consensus that planting species and seedlots adapted to the anticipated climate of the site at 1/3 of the rotation (i.e., 20-30 years after planting) would help ensure that trees are adapted throughout the rotation. This requires migrating species and seedlots approximately 1.1 and 1.5 °C (mean annual temperature) to account for climate change over the last 100 years (in coastal and interior BC, respectively), and an additional 0.5 °C to account for changes anticipated during the next 20-30 years. Integrating all aspects of climate change, however, not just mean annual temperature, into existing species and seedlot selection systems requires a fundamental re-evaluation of BC's stocking standards and seed transfer system. To facilitate migration, species should be selected on the basis of future, rather than present, biogeoclimatic variants. Research Branch staff are developing a climate-based seed transfer system that will facilitate integration of assisted migration into seedlot selection.

Climate change will challenge our ability to redistribute populations to projected climates where they will be best adapted in the future, as well as maintain projected levels of genetic gain in growth in those areas (i.e. genetic worth of the seedlots). With elevated activities of pests and diseases induced by climate change, it is most appropriate to now increase the focus on resistance traits, as well as growth potential.

While successful resistance breeding programs in trees are not common, examples exist in BC, including programs for spruce leader weevil and white pine blister rust. These successes have required decades of development. With climate change, factors affecting host-pest interactions are changing rapidly, generally in favour of pests. This rate of change may exceed the current capacity of breeding programs to keep pace. For instance, a recently established genetics trial for resistance to comandra blister rust exemplifies this rate of change: only four years after its establishment more than 60 percent of the lodgepole pine trees have become infected with comandra blister rust. While this is ideal for evaluating genetic resistance, it also shows the speed at which we may need to respond.

The policy of free growing provides a benchmark in stand development, but climate change indicates a need for a policy to monitor post free-growing stands.

The unprecedented level of uncertainty of climate trends, host conditions and changes in pest dynamics, signals a need to investigate resistance mechanisms that will provide a general pest tolerance or resistance in addition to species specific resistance. The current projects in the forest genetics program should be considered important 'starting positions' to do further testing of selected materials in the breeding and seed orchard programs, to various classes of pests and diseases not currently a threat. Such general or 'generic resistances' will be important additions to our stand and/or landscape 'resilience' strategies.

Gene conservation will be critical as climate change unfolds, both for maintaining and enhancing the resilience of forests, and for the hope of improving forest level resistance to pests. To this end, conservation of seed sources both *in-*, *inter-* and *ex-situ* for all tree species in BC, as currently being undertaken by the Forest Genetics Council, is essential. Even with those efforts, given the magnitude of projected climate change, it is conceivable that over the next century threatened tree species, such as whitebark pine, could become locally extirpated over much of their current range. Direct interventions to preserve species may be required but such efforts will have to be weighed against the expectation of success and on other demands on limited resources.

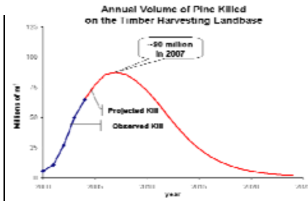
FREE-GROWING ASSUMPTIONS

The concept of free-growing, defined as a minimum number of preferred species above a minimum height, was developed well prior to the recognition of climate change and its potential impacts on forests and forest management. Free-growing designations are based on the premise that young trees will continue to grow according to current growth and yield models that were developed assuming stable environmental conditions. The validity of this premise is questioned as the indirect effects of climate change on insects and diseases in BC forests are already being manifested.

In 2005, the Forest Health Program, at the request of the Forest Range Evaluation Program (FREP), initiated a study designed to examine how well the timber productivity expectations that have been placed on free-growing stands are currently being met. Although results from the initial FREP Lakes TSA study suggest that free-growing stands were meeting expectations, subsequent attack by the mountain pine beetle casts doubt on this conclusion. However, early results from similar studies in the Okanagan TSA and Headwaters Forest District, suggest that many free-growing stands may not be meeting expectations, largely due to forest health factors. This may be an example of free-growing stands, only 10 to 20 years beyond the free-growing declaration, that are no longer on the anticipated growth and yield trajectory. Timber supply reviews throughout the province base predictions of managed stand productivity, in large part, on the assumptions associated with free-growing designations. Therefore, the policy of free-growing remains a benchmark in stand development, but the impacts of climate change on forest health indicate a need for a policy to monitor post-free-growing stands.

The FREP post free-growing studies indicate possible shortcomings associated with our current policy of free-growing. The management choices made to achieve a cost-effective, minimum number of preferred species above a minimum height may not necessarily be the same choices that would be made in order to create a resilient, adaptable stand capable of coping with the effects of climate change. Rather than specifying minimum standards for stocking density of preferred and acceptable species, an attempt should be made to address whether a variety of species, stocking levels and stand structures maintained across the landscape would provide stand resilience in light of a changing climate.

The Future Forest Ecosystem Initiative (FFEI) has an objective to adapt the forest and range management framework to maintain and enhance ecological resilience and ecosystem services, products and benefits under changing ecological conditions. Accordingly, the FFEI initiative is an opportunity to review and recommend changes to forest regeneration policy including free-growing that would align its definition, assumptions and purpose better with the realities of climate change-induced forest health issues.



Models cannot provide the certainty we would like. However, modeling can provide qualitative insights on the magnitude and direction of changes; give focus to monitoring program requirements, and aid in the evaluation of management strategies.

RECOMMENDATIONS

We present nine recommendations of equal importance that, overall, request of the ministry greater recognition of the primary role that insects and disease will play as forest ecosystems are impacted by climate change. In all aspects of forest management – from research and policy formulation through to planning and operations – climate-change-induced, forest health issues must receive greater attention. The unprecedented and concurrent outbreaks of insects and diseases in BC emphasize the need to expedite an action plan on the following recommendations.

MONITORING

1. Mandate expanded forest health monitoring for forest health agents at the landscape, watershed and stand level, as a component of ministry responsibility.

Rationale: The anticipated increases in forest insect and disease occurrences will challenge our management and operational capacity, but early and aggressive intervention will mitigate and possibly delay impacts. Improved monitoring will be essential if we are to continue to manage our forests in a way that achieves a sustainable flow of multiple products and values. The current aerial overview survey captures insect and disease occurrences at medium to large scales, yet many of our forest health interventions are best applied at the incipient stage. For this reason, monitoring for insect and disease occurrences at a finer scale than that of our overview survey is essential. Although surveys and reports serve well to detect and quantify the severity and extent of disturbances, monitoring focuses on the long-term, widespread, unexpected and sometimes subtle changes that provide early indication of changing stand health. Monitoring programs need to be coordinated across spatial scales, providing long-term records that can be effectively used in landscape management. Landscape level management generally involves tactics designed to modify existing high hazard ecosystems and to reduce future hazard.

One of the greatest effects that climate change will have on forest management is that it will increase the level of uncertainty surrounding future forest productivity and the anticipated increases in insect and disease impacts.

Forest health monitoring needs to be mandated as a core ministry responsibility, and would include stewardship monitoring protocols such as the FREP Resource Stewardship Monitoring of post free-growing stands currently being implemented. Links between this FREP monitoring system and the inventory system that feeds timber supply reviews must be clearly articulated.

FORECASTING

2. Build a forest health research section to identify key forest pests and to investigate interactions with their hosts and changing population dynamics.
3. Implement modelling projects to predict future forest health impacts and to evaluate different management circumstances (physiologically based models like BioSim), and incorporate the results into timber supply reviews.

Rationale: Forest pests and their host plants have co-evolved over thousands of years. Climate change is disrupting these co-evolved relationships in substantial and often unpredictable ways. In many areas, changing climate regimes will prompt stress responses from trees as their environments become increasingly sub-optimal. Additional research is needed to better understand the interactions between pests and their hosts, and how physiological changes induced by climate change will affect these interactions.

One of the greatest effects that climate change will have on forest management is that it will increase the level of uncertainty surrounding future forest productivity and the anticipated increases in insect and disease impacts. Models cannot provide the certainty we would like to have when making management decisions today to achieve some desired future forest condition. However, modeling can provide qualitative insights on the magnitude and direction of these changes; give focus to monitoring program requirements, and aid in the evaluation and adaptation of management strategies.

PLANNING

4. Maintain forest health strategies for the province, regions and individual TSAs with linkages to Forest Stewardship Plans (FSP) and the Timber Supply Review (TSR). Develop and incorporate forest health risk assessments associated with climate change within TSA strategies.
5. Review and revise legislation and existing policy to explicitly identify foreseeable forest health risks and associated prevention and mitigation strategies within each FSP.
6. Institute resource planning at the landscape level to proactively address forest health issues, as well as other forest values.
7. Implement insect and disease hazard- and risk-rating systems to manage pests and to plan and prioritize harvesting and regeneration activities.

Large scale, pest-caused forest decline and mortality will have long-term environmental and economic consequences. Timber supplies as well as other forest resources will be impacted.

Rationale: We believe that strategic planning for forest health is imperative and will become even more important as the effects of climate change increase. This planning is required at the provincial, regional, TSA and landscape scales and will inform resource management at all levels. Incorporation of forest health risks associated with climate change into TSA strategic planning will assist TSRs and, as outlined below, would guide the development of FSPs.

Currently licensees are required to assess long-term forest health risks associated with stocking standards; however, they are not required under the *Forest and Range Practices Act* (FRPA) to address forest health issues elsewhere within the FSP. This requirement was a component of the previous forest legislation, and is a gap within current legislation. Current legislation is an artefact of the Defined Forest Area Management (DFAM) initiative. Planned legislation for forest health under FRPA was removed to allow DFAM to be implemented. However, DFAM did not materialize for forest health. Consequently, responsibilities for forest health were returned to the ministry without supporting laws and regulations. Repatriation of forest health responsibilities to the ministry, considering current pest conditions and anticipated increases in future forest health issues make a review of forest health legislation and policy necessary. Forest health risks and strategies within FSPs should be evaluated annually against the landscape conditions and the occurrence of forest health agents. A forest health related result and strategy under the timber objective could provide a mechanism for this. There must also be linkages to forest health strategies at the TSA and provincial level.

Long-term forest health risks that are relevant to species selection must be considered in the development of stocking standards associated with FSPs. Recognizing that it is difficult to forecast future conditions, we suggest that the risks associated with climate change be included in these risk assessments both in terms of the suitability of stocking standards to future climates and to likely risks of damage from insects and pathogens. District Managers would need to be satisfied that these risk assessments are adequate (see FPPR Section 26).

Forest health strategies are a critical vehicle for informing the forest health test in stocking standards.

Forest management at the landscape level is necessary to proactively address a variety of issues, including forest health, but is difficult to implement when strategic resource planning at this level is limited. As an example, preventative strategies for bark beetles, such as developing age class and tree species mosaics, and prioritizing high hazard stands for harvest or modification, need to be implemented at the landscape level. These are strategies that have to be implemented by multiple forest licensees operating within a given area, however, even major licensees are not obliged to consider such strategies. Under FRPA, licensees are not required to specify a result or strategy for the timber objective. As a result, landscape level strategies for forest resource management in BC are limited. A result and strategy established under the timber objective would allow for the prioritization of harvests based on forest health risks.

While proactive management of forest ecosystems for resilience to insect and disease impacts should be a primary focus of forest management, the need for a greater range of direct control options remains.

Hazard and risk-rating systems are integral components of forest health plans and should be in place, and applied, in advance of insect and disease outbreaks. However, for many insects and pathogens, these rating systems either require refinement to account for climate change or have not been developed. As these systems have proven to be useful when attempting to forecast future pest impacts due to climate change, they are a priority for forest health research and development. Relating historical occurrence with biogeoclimatic zone variants can be helpful in the interim.

Prevention and Mitigation

8. Implement changes to tree species selection and stocking standard guidance designed to manage both intra- and inter-specific variation within stands and across the landscape. Facilitate the migration of tree species to correspond with future climates.
9. Enable the research and development of products and tactics for the treatment of forest insects and diseases. Do this in collaboration with the Canadian Forest Service and other research agencies.

Rationale: The establishment and maintenance of diverse and resilient stands are good general strategies to prevent or limit impacts from pests. Many of our standards for stand establishment are currently being re-evaluated to ensure that they will achieve resiliency within stands and across landscapes (e.g., Species Selection and Seed Zone Transfer working groups). We believe this is a necessary proactive strategy to initiate and will help reduce susceptibilities to forest pests.

The facilitated migration of tree species may be one of the most effective and least expensive forest management adaptation strategies to address climate change. It provides an opportunity to increase stand resiliency and reduce susceptibility to pests. However the current 5 percent tolerance of deviation from the *Chief Forester's Standards for Seed Use* is the only means at present for licensees to utilize non-local species or seedlots, and was not intended for that purpose and does not appreciably enable facilitated migration. We suggest that this level of deviation be reassessed. Given the series of pathogenic and entomological attacks that we have already experienced and that we forecast will continue, and given that the area available for planting comprises a very small percentage of the total forested landbase, we suggest that a benefit from facilitated migration could come about from a substantial (i.e., five-fold) increase in the allowable deviation from the Chief Forester's standards for seed use. The development of a climate based seed transfer and species selection system would address this issue but may take several more years to implement at a provincial scale.

The management of forest lands has clearly become more challenging as a result of climate change. We believe that our current forest management paradigm could be improved to better cope with a highly uncertain future created by climate change.

While proactive management of forest ecosystems for resilience to insect and disease impacts should be a primary focus of forest management, the need for a greater range of direct control options remains. Availability of adequate and effective tools will be especially critical where an invasive species, such as the Asian longhorned beetle or Sudden Oak Death, is introduced. The province should convince the Canadian Forest Service to re-instate its research capacity in the area of knowledge and information development. In addition, the province should increase its financial support for research at universities.

CONCLUSIONS

It is difficult to predict the future and it is difficult to be specific and provide detail about future insect, disease and decline impacts. However, we are confident that the overall impact of these factors will increase over the next two decades, and beyond, as a result of climate change. Timber supply and other resource values will be significantly affected through tree mortality, changes in stand structures or from pressure to conserve larger areas. We also believe that in many areas, pests will function as major agents of change as ecosystems begin to show the effects of climate change. They will accelerate changes by removing specific tree species from landscapes and by reducing the health and growth rates of many remaining species.

The management of forest lands has clearly become more challenging as a result of rapid climate change. We believe that our current static forest management paradigm could be improved to better cope with a highly uncertain future created by climate change. Forest management needs to respond and adapt to accommodate the diverse and innovative practices we will require to manage our forests into the future. The risks associated with trying to maintain the *status quo* far exceed those associated with implementing changes that provide for a broader spectrum of future forest conditions. An uncertain future can be best addressed with approaches that offer institutional flexibility and that include risk-taking, an ability to reassess conditions frequently, and a facility to change direction as conditions require.

It is likely that the value-ranking of our multiple forest resources will soon change, with management of our landscape for water resources or carbon sequestration becoming more important than timber harvesting. Regardless of what future uses are chosen, effective management of forest insects and diseases will be crucial to the maintenance of a range of forest ecosystem values.

The task for the next decade is to understand better how climate affects biotic and abiotic disturbances and how forests respond to them. Improved monitoring programs and analytic tools are needed to develop this understanding. Ultimately, this knowledge should lead to better ways to predict and cope with disturbance-induced changes in forests.

Regardless of what future uses are chosen, effective management of forest insects and diseases will be crucial to the maintenance of a range of forest ecosystem values.

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Appendix – Terms of Reference

Terms of Reference

**FOREST HEALTH AND CLIMATE CHANGE:
A BRIEF TO THE CHIEF FORESTER**

Background

The chief forester has tasked the forest health specialists within the British Columbia Ministry of Forests and Range to investigate and report on those areas of his responsibilities that may be affected by forest health factors as a result of forecasted climate changes.

The intent is to compile and synthesize current information and knowledge to inform the chief forester in the short term within the scope of his stewardship responsibilities. The resulting report and summaries are to be forest health focused, short and concise. It will be important to include indications of risk (consequences and likelihood) and to provide options for changes to policy or procedures, where this is possible.

The general topic of climate change contains many unknowns and much uncertainty. It is therefore acknowledged that the various issues that the working group will encounter are unlikely to be solved by this initiative; however it is intended that the working group members will turn their minds to them and determine what advice can be provided. This is the primary purpose of this exercise. This exercise is not intended to specifically chart a direction for the Forest Health program to deal with a changing climate; a separate initiative is planned for this.

The recent report by Dave Spittlehouse (2007), Climate Change, Impacts and Adaptation Scenarios, will be used to form the climate change scenario for this work.

Numerous other related initiatives are underway within the ministry: Future Forest Strategies, Future Forest Ecosystems Initiative, Forest Genetics Council's strategic development, Tree Species Selection Project, and the Chief Foresters Stewardship Vision and Framework. This forest health/climate change project will be consistent with, and inform, these other initiatives. Two related workshops were held recently, Forest Pest and Climate Change Symposium (Dunsmuir Lodge) and the Forest, Insects and Pathogens and Climate Change workshop (Portland). The reports from these workshops will be referred to for guidance.

Don Heppner will lead a small working group of forest health specialists (Harry Kope, Peter Hall, Lorraine Maclauchlan, Alex Woods, Jennifer Burleigh). The working group will draw upon subject experts as required (e.g., FFEI: Kristine Weese; forest ecology: Elizabeth Campbell; forest genetics: Alvin Yanchuk; species selection: Brian Raymer; timber analysis: Christine Fletcher; biodiversity: Andy MacKinnon; seed transfer: Greg O'Neill). Jim Snetsinger and Craig Sutherland will be executive sponsors of the report.

Timeframe: completion by the end of May, 2008.

Objectives

1. To inform the chief forester, the deputy chief forester and the deputy minister about forest health related implications of climate change. This information will be formulated relative to the chief forester's responsibilities regarding AAC determination, species selection and the standards for seed use and will include indications of probability and severity with consequences and options for changing policy or procedures.

2. This information will inform other related ministry initiatives (Future Forest Strategies, FFEI, Forest Genetics Council's strategic development, Tree Species Selection Project) about forest health related implications of climate change.

3. Identify options for forest health-related changes to the forest inventory, timber supply models and key forest management policies.

Investigate and report on the following items:

4. Current forest health/pest occurrences that have been attributed to climate change:
Examples:
- Mountain pine beetle;
- Dothistroma;
- Yellow cedar decline;
- Fir engraver beetle in grand fir in the CDF;
- Drought impacts;

5. Anticipated future pest occurrences and environmental impacts as a result of climate change (including the chance of unanticipated occurrences) and where they may occur (e.g., margins of BEC zones, margins of tree distribution range). Include information concerning the likelihood of occurrence, and an assessment of risks, consequences and priorities.
Examples:
- Declines – yellow cedar, red cedar, birch, etc.;
- Rusts – sensitive to changes in disease and host phenology;
- Foliar Diseases – intensification of previously obscure pathogens;
- More chronic budworm outbreaks and outbreaks in new habitats;
- Increasing proportions of univoltine spruce beetle populations;
- Exotics – new introductions and possible expansion of existing introductions (that may currently be 'under the radar').

6. Anticipated future impacts of forest health factors on the timber supply and AAC determination as a result of climate change (descriptive rather than quantitative):
   - Mortality – losses to standing inventory;
   - Impacts on growth rates (OAFs);
   - Impact on re-establishment (regen delays, NSR, post-free growing failures);
   - Impacts on utilization (waste and breakage, blue stain, etc.);
   - Timber profiles (harvest profiles);
   - Unsalvaged losses;
   - Impacts on old growth strategies, ecosystem representation and wildlife habitat.

7. The potential need for changes to tree species selection for reforestation to deal with a changing climate:
    - Consider removing the "filter" categories of primary, secondary and tertiary species rankings but provide their limiting factors and risk assessments.
    - Consider possible objectives for species selections such as managing for a diverse species mix and/or short rotations.
    - Consider linkages from free growing effectiveness evaluations, the management of post-free growing stands and related timber supply implications.

8. Standards for seed use/seed transfer limits:
    - Examine options for modifying seed transfer limits; adjusting elevational and latitudinal transfer limits of tree species will be warranted, but we need to consider the forest health/pest management implications of this.

9. Forest management/pest management policy and procedures: consider the need for changes.

Examples:

- Consider free growing effectiveness evaluations and stand management beyond free growing in a warming climate;
- Consider the importance of landscape level planning to maintain diverse landscape composition and structure to mitigate catastrophic losses;
- Consider the efficacy of current monitoring programs at detecting insects and diseases of concern (intermediate and fine scale monitoring required).

10. Genetic management options:
    - Consider an increase in the development and use of genetically improved material with elevated levels of pest resistance;
    - Consider the importance of research programs that investigate mechanisms of pest resistance that may provide for general tolerance or resistance.

Outcomes

- A brief report of 10 to 15 pages covering items 1 through 7 that will inform the chief forester, the deputy chief forester and the deputy minister about forest health related implications of climate change.
- From the report, a brief summary of options/recommendations for forest inventory, timber supply model and forest management policy amendments;
- From the report, a summary of options/recommendations for improved forest health management to mitigate the effects of anticipated climate change.

Jim Snetsinger, R.P.F.
Chief Forester

Jan 10/08
Date