Extension Note

BC Journal of Ecosystems and Management

Characterizing the effects of dwarf mistletoe and other diseases for sustainable forest management

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Abstract

Many insects, fungi, and plants in forest ecosystems can damage trees and forests, depending on stand and environmental conditions. Natural disturbances, harvesting, and other forest practices can retard or increase the spread and the effects of dwarf mistletoe and other diseases on tree growth. To monitor the effects of diseases, certification and monitoring programs typically use incidence and severity of infestations as criteria and indicators. However, these are often insufficient to characterize the impact of the disease or to measure the effects of new management practices, such as variable retention silviculture, on sustainability. Long-term observations and models of stand development are advocated as better methods for characterizing disease effects. For dwarf mistletoe (*Arceuthobium tsugense*), we are designing and monitoring installations in infested stands of western hemlock (*Tsuga heterophylla*) and constructing a spatial and life history model of stand and disease development. Disease spread and effects are influenced by several factors including site quality, stand density, and the spatial arrangement of infected trees, which are sources of mistletoe spread into new stands. Potentially, these factors could be manipulated to either reduce or encourage the spread and the effects of dwarf mistletoe.

KEYWORDS: Arceuthobium tsugense, *forest tree disease impacts, disease forecast models, forest health monitoring.*

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Introduction

In forest ecosystems, a diverse group of fungi and plants, including dwarf mistletoes (*Arceuthobium* spp.), affect forest sustainability by causing tree diseases and major damage to forest ecosystems. These organisms are prevalent and often damaging in old-growth forests, including those in British Columbia that are reserved or managed for timber, wildlife, recreation, and water objectives. However, disease infestations can also create desired features. These include damaged, dying, and (or) dead trees that provide habitat for wildlife, and canopy gaps that promote the establishment of a variety of tree species and vegetation (Lundquist and Beatty 2002). In young managed forests, therefore, it could be appropriate to encourage development of some attributes associated with disease infestations. The challenge is to determine which management practices will encourage or suppress infestations or their effects without unduly affecting forest productivity, and where and when such practices should be applied.

Maintaining healthy forests is an important objective of recent initiatives geared to ensuring sustainability of forest resources and good performance by industry and government. National forestry monitoring and reporting programs, and most programs developed to certify sustainable forest management practices, include indicators of forest health and ecosystem condition. These indicators usually measure occurrence (incidence) and severity of damage caused by insects and diseases (Canadian Council of Forest Ministers 2000). Although traditionally used for insect infestations, these measures are insufficient to characterize many effects, including stress caused by abiotic agents (Innes and Karnosky 2001). Many recent or proposed changes to forest practices, notably variable retention harvesting and silvicultural practices (Beese *et al*. 2003), could exacerbate disease damage and create substantial uncertainty about certification programs developed to track and ensure the sustainability of forest ecosystems. Unfortunately, very few data or tools are available to analyze the effects of current or future disease infestations. To describe these issues and suggest possible solutions, we briefly review several important factors related to monitoring the effects of disease, and outline an approach for modelling the effects of hemlock dwarf mistletoe (*Arceuthobium tsugense*) (Figure 1), which is a widespread parasite of western hemlock (*Tsuga heterophylla*) in western coastal North America.

FIGURE 1. Young hemlock dwarf mistletoe infection with aerial shoots.

Criteria and Indicators for Monitoring Effects of Diseases

Attributes of incidence and severity are appropriate for monitoring and reporting occurrences of defoliating insects and bark beetles. Generally, the effects of these insects are relatively well known and current measures of occurrence and damage are important components of decision making in management programs. For example, insect damage is readily determined by annual aerial and ground surveys, usually over extensive areas. In many instances, long-term data or observations are available to determine historical trends, recurrent cycles, and recent changes in insect disturbances.

However, measures of incidence and severity are not always adequate to characterize tree diseases and pathogens. Signs and symptoms of disease may be cryptic or unrelated to the potential for pathogen increase and tree damage. Many diseases develop slowly but are persistent and, therefore, the duration of an infection and its cumulative effects are often important.

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Significant differences are also apparent in the impacts related to pathogen life history, mode of disease spread and intensification, and type of host tissue infected. These lead to differing approaches for measuring the effects of major disease groups (e.g., foliar diseases, stem diseases, root diseases, wood decay, and dwarf mistletoes [Henigman *et al.* 2001]).

Foliar diseases are similar to infestations of defoliating insects in that they directly affect current or successive annual growth. Incidence and severity of infestation can be reasonably well correlated with effects on tree mortality and stand growth (e.g., Shaw and Toes 1977; Maguire *et al.* 2002). Foliar disease surveys can be conducted annually in early summer to determine the extent and severity of damage. Unfortunately, few or no treatments are available for foliar diseases in forests, except to plant trees with higher levels of genetic resistance (Wu and Ying 1998). Although foliar diseases generally cause only limited or sporadic damage, in some instances they are extremely damaging or even lethal (Woods 2001).

Stem disease incidence and severity are often highly variable within stands and between regions, depending on genetic resistance, weather, and local factors (Wu and Ying 1998; Woods *et al.* 2000). During ground-level surveys, stem cankers and rusts can be well characterized by measuring incidence and severity. On small trees, infections may cause mortality within one or two years, whereas on older trees infections may take several years to girdle and kill a tree, which results in reduced tree growth over the infection period. Stem infections may persist for many years, but in some instances may increase or accumulate for one to two decades, or longer. Trees planted in ecosystem zones where the species does not commonly grow may be severely and repeatedly infected.

Root diseases have widespread, long-term, and pronounced effects on forest ecosystems, but these effects are not well characterized by measures of incidence and severity. Individual infected trees, or centres of dead and dying trees, can be measured using aerial and ground surveys. However, critical aspects (e.g., below-ground infection of live roots and persistent infection of dead tree roots) are not detectable by usual operational surveys (Morrison *et al.* 2000). Detailed excavations and sectioning of roots and stems are necessary to determine the true extent of infection and the severity of root disease activities, but these methods are not practical for forestry surveys. Root diseases also cause a substantial long-term reduction in tree growth that can be measured on individual trees (Cruickshank 2002), but effects may be confounded or obscured by other factors affecting growth, such as tree age, site quality, species composition, and stand density. Selective cutting may also exacerbate Armillaria root disease mortality and growth losses (Morrison *et al.* 2001).

Several fungi, including root disease fungi, can infect live trees and cause wood decay (B.C. Ministry of Forests and B.C. Ministry of Environment 1997). This often leads to structural weaknesses in live trees that may result in tree collapse or increased vulnerability to windthrow (Wallis *et al.* 1992). It may also result in the post-harvest rejection of logs or a lowering of lumber quality and value. Wood decay is common in old-growth forests, but is generally not believed to be a problem in young stands. However, without proper care and attention, thinning or partial cutting can increase the incidence of tree wounding, which may lead to increases in wood decay of the residual trees (Vasiliauskas 2001). Consequently, wood decay will likely become an increasingly important issue in both immature and mature trees, particularly in variable retention silviculture systems. Although measuring decay in live trees is possible using non-destructive techniques such as analyzing sound waves (Lawday and Hodges 2000), usually trees must be felled and sectioned (Jones and Ostry 1998). These methods are not feasible for most forestry surveys. Residual trees are usually rated for soundness and (or) stability using external indicators of decay, such as wounds and fungal fruiting bodies or conks (Wallis *et al.* 1992).

Incidence and severity ratings can generally be used to characterize dwarf mistletoe infections (Muir and Moody 2002). Severely infected stands can be detected by aerial surveys (Brandt *et al.* 1998), but incidence and severity usually must be determined by ground surveys or inventory sampling (Muir and Moody 2002). In young trees, dwarf mistletoe incidence and severity can be low; however, effects on tree growth are slow to develop and can be highly variable, depending on stand density and other environmental conditions. Dwarf mistletoes are readily controlled by clear-cut harvesting or sanitation cutting, which removes all residual infected trees; however, recent initiatives to retain live trees in harvested areas and limit clearcutting can be expected to substantially increase the effects of dwarf mistletoe on stands.

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Approaches to Develop Improved Measures of Diseases

Given the prevalence and wide influence of diseases and pathogens in forest ecosystems, and the limitations of existing measures of incidence and severity to indicate their impact, a more comprehensive approach is needed to characterize the effects of diseases on natural resource sustainability (Muir *et al.* 2002). We suggest two components:

1. establish experimentally designed installations in conjunction with monitoring programs to determine disease effects and treatment efficacy, and
2. develop disease forecast models to predict disease effects under a wide range of forest types and ecological conditions.

Forest tree diseases are extremely variable in their nature, occurrence, and impacts. For each important ecosystem, we need to determine the effects of major tree diseases under selected management regimes for major tree species. Establishing an experimental design is essential to ensure representative, unbiased sampling of levels of disease occurrence and provide sufficient replication to enable forecasts over a range of ecosystems. Whenever possible, installations should incorporate existing trials, experiments, and long-term inventory growth plots (where these have been properly selected), and include sufficient measurements to characterize diseases. Designs must also include both conventional forest practices and new regimes such as variable retention silviculture. However, it is evident that data will always be limited in applicability because of continuing changes in forest practices.

We also recommend the development of disease forecast models to determine the impact of diseases and to extend the usefulness of existing data. Models for each disease or pathogen should be linked to inventory data and tree growth models. These models can then be used to:

- determine disease effects under a wide range of stand and environmental conditions at various tree ages and under different management regimes;
- visualize disease effects and resolve debates and differences in opinion about these effects and the impacts of new management regimes;
- predict stand yields as part of the timber supply analysis process (e.g., Woods *et al.* 2000); and
- identify gaps in knowledge and suggest new experiments.

However, relatively few disease models exist, and several difficulties hinder their development or application.

We are currently developing a detailed spread and tree growth model for hemlock dwarf mistletoe in coastal western hemlock forests in British Columbia (Muir 2003). This model includes a statistical spread module for dwarf mistletoe that could also be used or adapted for other dwarf mistletoes in other regions (Robinson *et al.* 2002). The spread module incorporates research results from many areas in the Pacific Northwest and projects the effects of dwarf mistletoe for individual trees, and for stand- and forest-level conditions. The growth module is the B.C. Ministry of Forests' Tree and Stand Simulator (TASS), recently augmented to include detailed stem, branch, and foliage biomass measures for western hemlock (B.C. Ministry of Forests 2002). Sample trees will be felled and detailed measurements taken to determine effects of dwarf mistletoe on these attributes. Dwarf mistletoe effects will also be used in the University of British Columbia forest level model, FORCEE, to determine impacts on non-timber forest-level characteristics and forest succession or dynamics (J.P. Kimmins, University of British Columbia, pers. comm., 2003).

Hemlock mistletoe is extremely variable in incidence and severity (presumably in response to a wide range of climatic and stand conditions; Figure 2), and we are analyzing factors that could affect spread or severity of infection. Survival and spread of dwarf mistletoes are substantially affected by disturbance events, such as fires,

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windstorms (Trummer *et al.* 1998), or logging, and are correlated with the numbers and spatial distribution of surviving mature infected trees.

In young regenerating stands, mistletoe seed production can be vigorous and result in extensive infection and spread of the parasite, but subsequent effects depend on the density and growth of the young stands. Where stands remain relatively open, mistletoe infection is able to keep up with tree height growth and trees become severely infected. Where stands are dense and height growth is rapid (e.g., approximately 50 cm or more per year is typical on medium to good sites), trees can grow faster in height than the mistletoe can spread upwards. In dense stands, where the production of mistletoe shoots and seeds is suppressed by shading, dwarf mistletoe is excluded from upper tree crowns and effects remain limited. However, even a low incidence of infection in young stands can pose the threat of future damage after thinning or partial cutting. Individual mistletoe infections on the stems or lower branches of living trees can survive in a quiescent state for several decades or more and then resume vigorous seed production after a new disturbance.

FIGURE 2. Hemlock dwarf mistletoe witches' brooms.

We have been incorporating these phenomena of disease spread into the detailed model. Several outputs support hypotheses that disease effects are strongly influenced by the number and spatial distribution of infected trees and the proportion of less-susceptible or non-susceptible tree species. We are acquiring more field measurements and long-term tree growth data to test these possibilities.

We hope that a model will assist foresters and others to determine the tolerable or acceptable levels of dwarf mistletoe damage under various environmental conditions or forest practices. For example, practitioners may wish to know the levels of dwarf mistletoe incidence and severity of damage that would indicate significant effects on stand growth. On an individual tree basis, reductions of 15–30% of annual growth rates are statistically significant at a mistletoe severity rating of 3–4. However, a tolerable average severity rating for a particular stand could be much higher or lower depending on several factors and management objectives. Hopefully these questions will be resolved by further model development and design of monitoring programs to include dwarf mistletoe effects.

Discussion and Conclusions

Forest tree diseases are integral components of forest ecosystems and often have major effects—both detrimental and desirable—on natural resource sustainability. Recent forest legislation for harvesting, regenerating, and managing immature forests includes regulations and forest practices to prevent or reduce current or future damage from diseases. However, existing measures of incidence and severity are insufficient to characterize many disease effects or the overall impact of diseases on forest ecosystems. Even where measures are feasible and appropriate, data on incidence and severity must be qualified because most diseases have decreasing effects as trees grow in size, as trees age, or at higher rates of tree growth. Nevertheless, trees on good sites are generally able to tolerate more disease or damage with less effect on growth or survival. Another reason why existing measures are inadequate is that many disease effects are inconspicuous and difficult to measure. Unlike insect outbreaks that occur for only one or a few years, many disease effects are manifested slowly and accumulate over several decades. Damage, therefore, becomes most severe

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and apparent in older immature or mature stands. Forest ecosystem characteristics, such as species composition and stand density, can influence the course and effect of many diseases. Further, many diseases are substantially affected by, or interact with, forest practices.

Apparently, the adequacy of proposed criteria and indicators for diseases has received little critical examination, and there is little research to develop better indicators of the effects of diseases. Criteria and indicators developed to monitor forest health and ecosystem condition should incorporate more specific measures of disease, including effects on long-term tree growth and ecosystem attributes. Existing long-term data on disease effects are very limited. We suggest that disease effects should be determined by experimentally designed, long-term measurement plots, preferably established in conjunction with certification monitoring programs. We also recommend the development of growth impact models for each important disease. A model under development for hemlock dwarf mistletoe shows promise in extending the usefulness of existing data to new ecosystems. It will also aid in predicting disease effects and the impacts of new retention management regimes over a range of environmental and ecosystem features.

Acknowledgements

The abstract of an earlier version of this paper was published in the proceedings of the XII World Forestry Congress, Quebec City, Canada, September 2003. Funding for development of the spatial statistical dwarf mistletoe model was provided by the Methods Application Group, U.S. Department of Agriculture Forest Service, Ft. Collins, Colorado. Further model development funding was provided by the British Columbia Ministry of Forests, Forest Renewal BC, and Forestry Innovation Investment Ltd.

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