Silvicultural Techniques and Guidelines for the Management of Major Insects and Diseases of Spruce, Pine and Aspen in Eastern Canada

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Canada

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Preface

This report provides silvicultural techniques and guidelines for reducing the impact of insects and diseases in stands of spruce, pine and aspen in eastern Canada. It is directed primarily at forest managers and forest policy staff.

> *This report provides forest management guidelines for minimizing the impact of insects and diseases in stands of spruce, pine and aspen in eastern Canada.*

In Section 1, we introduce the major insect and disease pests and discuss the role of silviculture in mitigating insect and disease pest losses. It is our experience that the majority of forest practitioners will be most interested in knowing what will affect the forests that they manage. Thus in Section 2, we discuss the major insect and disease pests by working group and provide a general overview of how silviculture can increase or decrease insect and disease problems. In Section 3, we describe the insect and disease pests in greater detail. For each pest, we describe the distribution, hosts, host damage and habitat in order to provide background to the main feature, which are the guidelines to reduce losses from the pest.

In eastern Canada, there are hundreds of insects and diseases that attack trees; fortunately few of them are pests and even fewer are chronic, common and cause severe enough damage to warrant preventative or remedial action. These few are pests because they reduce growth and yield, form, and survival of the tree to below an economic threshold. It makes sense that if we make significant financial investments in a forest, we should be willing to make an effort to protect these investments from serious losses. High value wood requires high quality trees that are free from stem defects or produce wood fibre rapidly. Thus, insects and diseases that affect these qualities become of greater concern to the forest manager. Moreover, as the need for (or value of) wood intensifies, insects and diseases previously considered acceptable or inconsequential might become "pests" even though absolute populations have not changed.

Any silvicultural treatment that you use to encourage tree growth and survival, or to alter stand composition and structure, may influence the susceptibility of the stand to attack from insect and disease pests and its vulnerability to damage. Susceptibility is the probability that a forest will be attacked. Vulnerability is the probability that damage (e.g., relative growth rate and amount of mortality) will result from attack. As a forest manager, it is essential that you consider the possible consequences while planning your silvicultural treatments. The consequences may be beneficial (reduced susceptibility and vulnerability) or detrimental (unacceptable economic loss).

Our knowledge of the impact of silviculture on pests is incomplete and rudimentary. There are no long-term definitive studies that can accurately predict and quantify the expected benefits or impact of a silvicultural treatment on pest populations. The changing and complex dynamics of a forest ecosystem, the long growing period, and changes in silvicultural practices are just a few of the formidable challenges. Can we

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afford to wait until the best answers come in, or do we proceed with imperfect knowledge, learn, and make adjustments along the way? If you expect simple, definitive and detailed prescriptions, you need not read any further - the answers are not here - or anywhere else. If you are prepared to follow general prescriptions based on current knowledge, experience and some common sense based on an understanding of insect and disease ecology, then we think you will find this report of value to you.

Acknowledgments

Section I:

Intensive Forest Management and Associated Pest Problems:

An Introduction

Growing a forest from seed to maturity not only requires a long time but also a long-term view and commitment. Things to be considered range in scale from the autecology of the species and site characteristics to the larger picture including societal, economic and ecological values and products. It is seldom easy finding a balance that satisfies everyone.

In response to historical land use conflicts, and to meet economic, ecological, and sociological needs, zoning the land base into intensive timber production, integrated zones, and protected areas has been proposed in many areas of the world, including Canada.

Although having areas where timber production has been designated as the primary purpose may help ease some of the conflicts and simplify some of the forest management practices, intensive forest management causes new problems of its own. One of these potential concerns is how insects and diseases will be affected by silvicultural practices.

The accessibility of a forest stand, its productivity and ecological conditions, as well as prevailing ecological, social and economic values determine in large measure the intensity of forest management and consequently the importance of insect and disease pests. The most logical sites for direct enhanced forest productivity are on accessible sites with potential for high productivity.

Insects and diseases occur throughout the life of the forest. Some pests attack seedlings, others affect the sapling stage, usually before crown closure, while others attack mature or over-mature trees. Most plantations are established one-to-three years after harvesting. Cut conifer stumps and logging slash left on-site after harvesting are attractive to adult **root collar weevils** (*Hylobius* spp.), which use this material for breeding. These insects girdle the root collar and main lateral root of young trees resulting in tree mortality, or they cause fluted root collars, which leave the trees susceptible to windthrow or secondary insects. The **white pine weevil** (*Pissodes strobi*) damages the central shoot (leader) of a tree and affects stem form and quality. Repeated infestations may reduce the tree to a subdominant one, which may become suppressed and die prematurely. This insect is typically found in young open-grown stands. The **yellowheaded spruce sawfly** (*Pikonema alaskensis*) and **redheaded pine sawfly** (*Neodiprion lecontei*) feed on the foliage of young open-grown trees causing severe defoliation and reducing tree growth or killing the tree.

White pine weevil damage

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The **spruce budworm** (*Choristoneura fumiferana*), the **jack pine budworm** (*Choristoneura pinus pinus*) and the **forest tent caterpillar** (*Malacosoma disstria*) are typically associated with mature trees and have historically been important in the dynamics of forest succession, renewal and nutrient cycling. These insects occur in widespread outbreaks (sometimes affecting millions of hectares), and are responsible for major wood losses. When these outbreaks happen, younger and more vigorous trees can also be vulnerable to damage.

Unlike insects, diseases are generally more chronic and less extensive, and more focused on individual trees or groups of trees rather than entire stands. However, diseases, including decays and rots, are responsible for losses in merchantable timber that normally exceed the total annual harvest. These losses are caused in large part by the mature nature of northern forests. Decays, which infect wounds, are responsible for the majority of lost fiber in natural forest. Root diseases such as **Armillaria** (*Armillaria* spp.) and **tomentosus root rot** (*Inonotus tomentosus*), while causing mortality to newly planted trees, are also responsible for mortality and growth loss to older trees, and make trees susceptible to windthrow. Diseases such as the European race of **scleroderris canker** (*Gremeniella abietina*), and **white pine blister rust** (*Cronartium* ribicola) can cause mortality of young trees, and are particularly successful in plantation environments.

Prior to the widespread use of synthetic chemical insecticides, silvicultural methods of pest control were widely advocated and

Armillaria root rot damage

were often the only method that could offer some relief from pests. In recent years there has been a resurgence in the use of silviculture to manage insects. Silvicultural techniques for pest management can normally be integrated with forest management and therefore they are appealing. Many are just good silviculture - plain and simple. A silvicultural approach for pest management is also attractive in the sense that it is much less controversial than pesticides and many approaches are environmentally benign.

Silvicultural techniques in pest management manipulate the host or the environment so that they are or become less favorable to the insects or diseases deemed to be pests. Typically, populations or the amount of innoculum are reduced, sometimes substantially. The goal is to create a forest stand that is less susceptible and

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vulnerable to attack by pests and still economically sustainable. Within this goal is the fundamental concept that we attempt to reduce the pest problem, which is reasonable, but do not eliminate it, which is often untenable. Silvicultural approaches can be quite beneficial against some pests, less so with others. Another important consideration is that silviculture is one part of the pest management toolbox. Other methods of pest management, including the application or conservation of natural enemies such as parasites, predators or pathogens may be needed to achieve a desired level of pest management.

Many insects and diseases infest trees that are suffering in vigor, or ability to resist attack, because they were planted off-site, or because improper silvicultural methods were used. Silviculture aims to maintain and enhance the productivity of the forest. Sometimes, however, practices that are silviculturally sound and necessary (e.g., thinning) result in an increase in insect and disease problems. Here the forest manager must make a trade-off, but at least it will be an informed choice. Another trade-off that sometimes has to be made occurs when a silvicultural practice to reduce one pest promotes an increase in another pest. Again the best one can do is to make an informed choice.

A very important caveat in the use of silviculture for pest management (and this can not be overemphasized enough) is that for many pests we are working with incomplete knowledge and working hypotheses rather than time-tested practices. Almost all of the silvicultural guidelines described here have had limited development and testing in terms of geographic area, tree species, site characteristics, equipment and time, and cost.

It is also important that we dispel the notion that silvicultural treatments can fully, and independently, solve pest problems. They can't. What they can do is reduce the likelihood of trees being susceptible to attack or vulnerable to serious damage. They are used best when combined into an integrated forest pest management strategy that uses various approaches to maintain insects and diseases at acceptable levels. This is not to say that silvicultural techniques can not be powerful tools for pest management. At times, avoiding a certain practice will mitigate pest damage (such as not planting in areas where fresh stumps and logging debris will provide food for **root collar weevils** in high hazard areas). In other situations, using one silvicultural method over another (where this is possible) will lessen the impact of pests; for example, planting white spruce under an aspen canopy to reduce the impact of the **yellowheaded pine sawfly**.

A word of caution is in order. In our effort to condense, synthesize, and rationalize the existing knowledge into succinct and readable guidelines, we have had to generalize. Generalization always comes at the expense of ignoring some exceptions, smoothing over gaps in our knowledge, and worst, making things seem simple when they aren't. But in the spirit that a good plan now is better than a better plan too late, we present these guidelines. Furthermore, in the interest of keeping the reader with us, we have avoided an exhaustive and academic review of the literature. We surveyed the literature as abstracted to late 2002 and generally concentrated on and referenced the most recent and relevant work.

Section II:

*General Considerations
for Forest Management
of the Major Insects and
Diseases by
Tree Species
Working Group*

The purpose of this section is to introduce the major insects and diseases of black and white spruce; jack, red and white pine; and aspen, and to present some general forest management guidelines. More detailed information is provided in the section III describing each insect and disease.

Black spruce (*Picea mariana*)

The spruce budworm (*Choristoneura fumiferana*), yellowheaded spruce sawfly (*Pikonema alaskensis*), and white pine weevil (*Pissodes strobi*) are occasionally pests of black spruce. During an outbreak of spruce budworm, upland black spruce growing with balsam fir can suffer some growth loss. Open-grown spruce is susceptible to the weevil and sawfly, but they are only infrequently a serious problem on these trees. Standard silvicultural practices of planting, spacing, and stand improvement seldom result in serious insect problems and generally, silvicultural intervention is rarely needed or practical for black spruce.

Black spruce has few significant disease problems. Numerous minor problems such as needle rusts and mistletoes exist, but they normally cause minimal impact in terms of mortality and growth loss. Root and butt rots caused by Armillaria (*Armillaria* spp.) and tomentosus root rot (*Inonotus tomentosus*) are common in black spruce stands. They can cause significant mortality to young trees in newly established stands and result in poorly stocked stands or ones with large openings. Typically, these rots are more serious on mature trees and are a major contributing factor in growth loss and to blow down. Tomentosus, while affecting all conifer species is most serious on spruces more than 30 years of age, particularly on well-drained sites. Early harvest should be considered if the disease is well established. The area should be replanted with a less susceptible pine species if the site is appropriate.

White spruce (*Picea glauca*)

The major insect pests of white spruce are the spruce budworm (*Choristoneura fumiferana*), yellowheaded spruce sawfly (*Pikonema alaskensis*), and white pine weevil (*Pissodes strobi*). Spruce budworm is particularly troublesome where white spruce is mixed with balsam fir. Both the weevil and the sawfly are pests of young open-grown trees. Establishing closely spaced plantations, promoting rapid tree growth, planting white spruce under a hardwood overstory, or delaying stand spacing until trees are at least 20 years old and/or 5 m tall will help reduce the impact of the white pine weevil and the yellowheaded spruce sawfly. Healthy, vigorously growing white spruce can tolerate several years of defoliation by the spruce budworm. Management of the spruce budworm on white spruce may require the reduction or removal of mature balsam fir in mixed conifer stands, breaking up large areas of mature forests and avoiding creating large single species plantations. Presalvage of forest stands, as a pre-emptive measure should be considered where white spruce is most vulnerable to damage.

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Armillaria root rot (*Armillaria* spp.) and Tomentosus root rot (*Inonotus tomentosus*) can be problems for young white spruce that are planted on former hardwood sites. Direct control procedures for root rots are usually neither practical nor economic. Avoidance and early detection are the best strategies in plantation management. Stem decays are normally a problem with older trees in natural forests. However, damage caused to young and semi-mature trees during thinning operations makes pre-mature decay increasingly likely in managed stands.

Jack pine
(*Pinus banksiana*)

The jack pine budworm (*Choristoneura pinus pinus*) and the white pine weevil (*Pissodes strobi*) are the most serious insect pests of jack pine. Jack pine budworm is primarily a pest of mature jack pine, whereas the weevil is a pest of young open-grown stands. Bark beetles (*Ips* spp.) can be a problem where trees are stressed due to nutrient deficiencies, drought, wet soil, storm damage, defoliation caused by other insects or where logging or thinning have occurred recently and slash has not been removed. Root collar weevils are occasionally problems on extreme nitrogen-deficient soils, and where jack pine is established near Scots pine stands.

Silvicultural prescriptions for jack pine budworm are based on the need to develop jack pine stands that are less susceptible to attack and vulnerable to damage by reducing the abundance of male staminate flowers, and by promoting tree and stand vigor. Prescriptions to reduce stand susceptibility and vulnerability include managing jack pine to a predetermined rotation to avoid overmature stands, maintaining proper stocking, avoiding creating uneven-aged or two-storied stands and encouraging age class and species diversity across the landscape. Managing the white pine weevil in jack pine stands is difficult because the option of providing overhead or side shade to a shade intolerant species like jack pine is not desirable. The alternative prescription of planting at a close spacing to promote crown closure and to delay thinning until trees have reached 5 m (if trees are grown for lumber production) is more feasible. The pine engraver beetle, *Ips pini*, is best managed by managing the slash left behind after logging. Slash less than 8 cm in diameter can be left because beetles seldom develop large populations in this material. Larger slash can be scattered to encourage rapid deterioration of the phloem or left in large deep piles to provide a food source and divert them away from standing trees left after thinning. Root collar weevils can become serious pests of young regeneration. Preventative measures include a delay in planting, removal of infested trees, planting jack pine with non-susceptible species, maintaining stocking standards and delaying thinning.

Scleroderris canker (*Gremmeniella abientina*) is a serious disease of jack pine but rarely kills trees over 2 m tall. It is typically a problem in frost pockets where it can result in significant mortality. Armillaria root rot (*Armillaria* spp.) can be a problem on jack pine, but pines are normally more resistant to root rots. Dwarf mistletoe has proven to be a serious problem of jack pine and once established requires a significant effort for eradication. However, due to forest fire history this disease is presently absent from Ontario, even though it is prevalent

in Manitoba. Gall rust (*Endocronartium harknessii*) and stem rusts (*Cronartium* spp.) can also be serious problems in individual plantations. During thinning operations trees with serious levels of rust should be removed. These rusts are primarily a problem during the early years of plantation establishment.

Red pine (*Pinus resinosa*)

The major insect pest of red pine in the Great Lakes – St. Lawrence and transition boreal forest regions is the redheaded pine sawfly (*Neodiprion lecontei*). The sawfly is a problem in young open-grown stands. Bark beetles (*Ips* spp.) can be a problem where trees are stressed due to nutrient deficiencies, drought, wet soil, storm damage, defoliation caused by other insects or where logging or thinning have occurred recently and slash has not been removed. Root collar weevils occasionally become a problem.

Selecting the right site for a red pine plantation is probably the most important consideration for managing the sawfly because it is generally a problem where red pine is growing under stress. Other considerations include reducing competition from hardwoods, not planting red and jack pine in mixtures, and planting at a close spacing to encourage early crown closure. Managing the pine engraver beetle and root collar weevils in red pine is similar to that of jack pine.

Scleroderris canker (*Gremmeniella abientina*), Armillaria root rot (*Armillaria* spp.) and fomes root rot (*Heterobasidium annosum*) are the major diseases of red pine. Diplodia tip blight (*Sphaeropis sapineai*) and sirococcus shoot blight (*Sirococcus strobilinus*) are occasionally problems. The European strain of Scleroderris is found in Canada. It can cause extensive mortality, but has been restricted to south central Ontario. Where the North American strain is a problem, the disease can be controlled through pruning until canopy closure is reached. Armillaria root rot can be a problem where red pine is established on sites where the disease was previously common. Fomes root rot is the most significant disease problem of red pine and causes mortality to all ages of pines. However, the disease is restricted by climate to southern Ontario and southwestern Quebec. Avoidance and early identification are the best control strategies for control of Fomes. Areas known to be affected should be harvested and replanted to hardwoods. More recently some biological control agents have shown some potential.

White pine
(*Pinus strobus*)

The white pine weevil (*Pissodes strobi*) is the major insect problem of white pine. The weevil is a pest of open-grown trees. There are two key approaches to managing the white pine weevil in white pine stands. The first is to provide overhead or side shade to reduce the amount of favorable habitat for the weevils. This can be accomplished through uniform shelterwood, underplanting or nurse crops. Providing side shade is a variant of the shelterwood system and is technically more difficult to use to manage the weevil. The other option is to grow white pine quickly to crown closure, again to reduce the amount of favorable habitat in a stand for the weevil.

White pine blister rust (*Cronartium ribicola*) is the major disease problem of white pine. This introduced disease can cause mortality of young white pine that are typically 8 m or less in height. Together with the white pine weevil, this disease has severely hampered the regeneration of white pine. This disease can be managed by observing hazard zones and avoiding planting where infection is most likely. Silvicultural treatments such as pruning infected branches and growing under shelterwood help to reduce loss to the rust. If resistant stock is available, its use, together with increasing stand density in high hazard zones are also options. As always, the use of a non-host should be considered when rust limits the planting of white pine.

As with other conifers, Armillaria root rot (*Armillaria* spp.) can be a problem for young white pine, although pines are generally less susceptible than spruces and Armillaria is not usually limiting.

Trembling Aspen
(*Populus tremuloides*)

The forest tent caterpillar (*Malacosoma disstria*) and the large aspen tortrix (*Choristoneura conflictana*) are the major insect pests of trembling aspen. Aspen stands that are at high risk to the forest tent caterpillar are found on poorly drained and drought-prone soils. Using forest management and silviculture for these insects is difficult and to date no prescriptions have been developed, except the suggestion to discourage fragmenting the forest into blocks of less than 100 hectares.

The major diseases of aspen are Hypoxylon canker (*Entoleuca mammatum*), Armillaria root rot and stem decays such as the white root rot (*Phellinus tremulae*). Hypoxylon canker is common in low-density stands and on stressed trees with stem and branch injuries. Trembling aspen is about five times more susceptible than large-tooth aspen to the canker. There is no direct control measure but removal of infected trees is recommended during stand improvement. The disease is also more prevalent in pure stands of aspen. White root rot is typically found in aspen over 40 years old and like all decays is more common in stands where wounding has occurred through storm damage or poor silvicultural practices. Reducing the length of stand rotation is probably the most effective way to manage the disease.

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Section III:

*Forest Management
Guidelines and
Recommendations*

Insects

Spruce budworm *Choristoneura fumiferana* (Clemens)

Spruce budworm larva

Spruce budworm damage

Distribution: The spruce budworm is found throughout Canada and the northern United States. It is a native insect, defoliating spruce-fir forests in eastern North America from Newfoundland southward to Virginia and westward through Canada's boreal forests to British Columbia.

Hosts: The principal hosts of spruce budworm are balsam fir, and white and red spruce. Mature balsam fir is the preferred host. Other conifers attacked include black spruce, eastern hemlock, tamarack, and eastern white pine particularly when these trees are growing along with the favored food source (Rose et al. 1994).

Host Damage: Spruce budworm larvae consume needles. In the spring, the newly emerged larvae mine needles of the previous year's growth, unopened buds, and male flowers if present. As the larvae grow, they attack new needles and expanding buds, moving back to old needles as the supply of new growth diminishes. The larvae form feeding tunnels joining a few shoots

together with silk. The top of the tree is the first to show damage, as transport of water and nutrients is affected. After heavy feeding, the tree appears "scorched".

Tree mortality and growth loss are functions of the timing, duration and intensity of defoliation. Attacks over consecutive years result in a decline in the tree's capacity for production and storage of food and metabolites. Cone and seed mortality, losses in radial and height growth and rootlet death occur. Stress and reduced vigor of trees will predispose them to attack by secondary insects and pathogens. Up to 90% reduction in tree growth as a result of loss of current year's foliage has been reported (Steinman and MacLean 1994). Young trees are usually able to regenerate new rootlets and live, but more mature trees often cannot and succumb. If more than 75% of the foliage is lost in a mature tree, death usually follows (Hudak and Raske 1982). Top-kill of balsam

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fir may begin after 2-3 years of heavy defoliation. Balsam fir mortality may begin after 3-5 years depending on tree vigor. All of these events can result in significant volume loss in stands. Budworm defoliation also results in seed loss, which can influence the composition of future stands (Schmitt et al. 1984). Other impacts, in addition to economic losses, include wildlife changes, increased vulnerability to forest fires and loss of recreation and aesthetics.

Habitat: The spruce budworm is generally an insect of mature trees. Outbreaks frequently occur in areas with many mature and overmature stands (especially with large components of mature balsam fir) but can "spill-over" to younger trees. Studies of the population dynamics of spruce budworm have demonstrated that outbreak collapse is due to a variety of parasites and predators working together to increase larval mortality and reduce adult fecundity (Royama 1992).

Forest Management Guidelines and Recommendations

There is a large, diverse, and at times conflicting and contentious literature on the use of silviculture to manage the impact of the spruce budworm. During the late 1970s and 1980s there was a flurry of research activity and several valuable reviews and extension publications were produced. Flexner et al. (1983), Blum (1985), Blum and MacLean (1984, 1985) and MacLean (1996) have synthesized the extensive literature and provided sensible and practical guidelines to follow. Miller and Rusnock (1993) provide an interesting history of the use, discussion and criticism of silvicultural methods for spruce budworm.

In the following sections, some general principles and caveats are provided as a background to the consideration of the use of silviculture to manage spruce budworm.

General principles

Before examining how silviculture might be used to mitigate spruce budworm damage, it is important that the concepts of susceptibility and vulnerability are understood. Susceptibility is the probability that a forest will be attacked. Susceptibility (to spruce budworm) may be quantified as the amount of defoliation that occurs (MacLean and MacKinnon 1997). Vulnerability is the probability that damage (e.g., relative growth rate and amount of mortality) will result from attack. The concepts are interrelated insofar as susceptibility determines the severity of attack and potential damage (Blum 1985). Differences in vulnerability among tree species, trees and stands are central to the use of silviculture to manage the spruce budworm.

Tree species, stand age, and hardwood content all influence the amount of mortality during a spruce budworm outbreak. Stand condition variables have been quite consistent over time and among geographic locations (Blum and MacLean 1984; MacLean 1996).

Balsam fir is the most vulnerable to damage by the spruce budworm. Balsam fir usually dies after 5 to 7 years of severe attack; mortality in mature or overmature stands can reach 100%. Mortality of fir in immature stands or when mixed with spruce is generally less (MacLean 1980). White spruce is considered the next most vulnerable species.

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Spruce budworm induced mortality

Because white spruce produces larger and more shoots than balsam fir (thus providing more food for larvae) damage is generally less severe than on balsam fir. Black spruce is less vulnerable than white spruce and balsam fir. This reduced vulnerability is primarily a function of later opening buds (typically 9 days after white spruce and 13 days after balsam fir) and because black spruce foliage is less suitable for young larvae (Greenbank 1963).

Stands with large amounts of mature or overmature fir tend to have consistently high mortality whereas immature spruce stands have low mortality (MacLean 1980, 1996). Although immature trees are less vulnerable than mature trees they are not immune to damage. The presence of staminate flowers on overmature dominant trees and those growing under unfavorable conditions increases the susceptibility and vulnerability to the spruce budworm (Greenbank 1963). Maturity is also accompanied by reduced growth and vigor of the trees. Stand size may be important because the mortality of dispersing larvae is likely lower in large continuous stands of mature forests.

Vulnerability is further decreased as the proportion of non-host trees in the stand increases, or where hardwoods overtop a conifer understory. MacLean (1980) and Osawa et al. (1986) found that balsam fir forests with more than 20% hardwoods sustained less mortality than pure stands. Stands with at least 50% of the basal area in conifers are the most vulnerable (Flexner et al. 1983). If the spruce and fir are in a subordinate crown position, vulnerability is further increased.

Site quality and growing conditions are also important. Generally trees and stands of low vigor and that show reduced growth rate and poor crown development are more vulnerable to damage.

Several studies have shown that vulnerability tends to increase as stand density increases. This may be related to lack of vigor of the closely spaced trees or poorly developed foliage or decreased larval mortality during dispersal. But in a few cases, spaced stands can be severely defoliated and damaged (Blum and MacLean 1985), thus spacing of a stand isn't always going to result in lowered vulnerability.

Until recently, abnormally wet or dry sites were considered more vulnerable to damage than more mesic sites. Balsam fir sustained, on average, 18% more mortality from spruce budworm on poorly drained than well-drained sites (Hix et al. 1987) and black spruce mortality was about 25% more on excessively dry than on poorly drained sites (Osawa 1989). Dupont et al. (1991) found balsam fir mortality of 85, 75, 45 and 27% on xeric, hydric, mesic and subhygric drainage classes, respectively.

On the other hand, MacLean and Ostaff (1989), Bergeron et al. (1995) and MacLean and MacKinnon (1997) did not find a strong or consistent relationship between soil drainage and budworm-caused tree mortality, and recommended that the past emphasis on soil drainage class and surficial deposit as predictors of stand vulnerability be re-evaluated.

In short, silvicultural prescriptions aimed at reducing the impact of spruce budworm include: 1) reducing the amount of balsam fir (especially mature and overmature trees) in a stand; 2) increasing the amount of less vulnerable host species (such as spruce) or non host species in a stand; 3) using a short rotation; and 4) maintaining vigorous trees with high growth rates. In broader terms, forest management would change the species composition of the forests, change the age class structure and change the spatial arrangement of stands. Achieving these goals should provide a general reduction in stand vulnerability for future budworm outbreaks.

Caveats

The recommendations for the use of silviculture to manage the spruce budworm have largely been based on retrospective analyses of outbreaks. Baskerville (1976), Blum and MacLean (1984, 1985) and several other authors, before and since, have cautioned that even the best of the suggestions to reduce vulnerability of a forest to spruce budworm have not been adequately tested over sufficient area, over sufficient time and over sufficient stand conditions to be considered anything but conceptual. Particularly vexing is the inability to predict the effectiveness of a treatment, that is, to establish a quantitative relationship between the treatment and the reduction of vulnerability. To quote Blum and MacLean (1984) "The real issue here is what specific actions, taken at what specific levels, at what specific times, in what specific forest and budworm conditions, will render future outbreaks less potent by what specific amounts." Because spruce budworm outbreaks can occur over a large geographic area and last many years, and further, because we have many different forest types, stand, site and age conditions, climatic conditions, absolute population sizes, and many arrays of natural enemy complexes – not to mention different forest management objectives, policies and directives – it is easy to see why this is a daunting task. It would take 50-100 years to restructure the forest, and areas of more than 1 000 000 ha would require treatment (Baskerville 1976).

In the absence of "hard data", we can either simply wait until the research is complete or proceed on the basis that the concepts, although unproven, are logical and appear ecologically sound. Given the time frame involved and the significant damage the spruce budworm can cause, it is prudent not to wait but to attempt to potentially reduce the vulnerability and economic impact of the spruce budworm. One thing that seems virtually certain is that if we do nothing the spruce budworm will continue to be a major competitor with us for the forest resources.

There are no simple solutions to the spruce budworm problem. Silviculture and forest management alone will not protect forests from the spruce budworm because there are many other factors such as climate and natural enemies that are part of the

population dynamics of this insect. The key to the use of silviculture is to reduce vulnerability (loss of growth, mortality) more than to reduce susceptibility (the probability of attack), which is largely unavoidable. Finally, remember that silviculture is only part of the pest management toolbox: this toolbox includes the use of direct control agents such as microbial and natural insecticides, and natural enemies. Including silviculture as part of the pest management plan can decrease the need for direct control with a longer time interval between direct control programs (Mott 1980; Dimond et al. 1984). As Baskerville (1975) noted "Since we cannot eliminate the problem [spruce budworm] we must be realistic in our expectations of forest management techniques and recognize that our aim is to compete with the budworm at a tolerable level of ecological disturbance."

Tactics

The overall strategy in using the various tactics outlined below is to prevent outbreak populations of spruce budworm from developing. At one time, more than 50 years ago, the selection system of silviculture, which maintains an uneven-aged forest stand, was widely promoted as a method to manage the spruce budworm. Because this system of silviculture maintains an open almost mature crown with abundant sun, foliage and flowering, which are ideal for the spruce budworm, this method is no longer advocated for spruce budworm management (Baskerville 1975, 1976). In Ontario, black and white spruce are managed under an even-aged silvicultural system either through clearcutting or shelterwood (OMNR 1997, 1998). The tactics described below focus on individual stands. Because spruce budworm outbreaks can cover large geographic areas, regional strategies are essential, but they should be stand-oriented. On a regional basis, various combinations of these tactics should be considered where practical and appropriate.

Plant less vulnerable species. Reforestation (or afforestation) of sites with species such as black spruce and to a lesser extent white spruce, which are less vulnerable than balsam fir, may be appropriate under certain ecological and economic scenarios. In essence, this is stand conversion. Establishing extensive areas of single species plantations may have some serious drawbacks. First, is the potential for increased vulnerability to other pests. White spruce plantations have had serious problems with the spruce budmoth (in New Brunswick and Quebec), the yellow-headed spruce sawfly, and the white pine weevil. White spruce is typically a mixedwood species and pure natural stands of white spruce are less common. Mixed-species plantations or growing white spruce under aspen can reduce insect problems. Black spruce on the other hand occurs naturally in 'monocultures' and generally, plantations have fewer insect problems. Although much less vulnerable than balsam fir, black spruce is not immune to the budworm. Secondly, expensive and intensive site preparation and control of competing vegetation may be needed, especially on productive sites. Thirdly, the overall effect of stand conversion on local and regional wildlife habitat and food sources must be considered.

Promote natural regeneration of less vulnerable species. Winter harvest stands mixed with aspen to encourage aspen

reproduction to either convert it to an aspen stand or create a mixed stand. Aspen will provide protection for understory fir and spruce during an outbreak. Promote spruce regeneration through partial cutting, whenever possible. If shelterwood is to be used, do so in stands with more than 50% spruce or non-host trees and where the residual trees are wind-firm and vigorous. If shelterwood is done during an outbreak, then the residual trees may need to be protected through direct control to reduce infestation of the developing regeneration.

Reduce the amount of balsam fir in a stand. If natural regeneration is used to restock an area, it is frequently difficult to control the amount of balsam fir regeneration because it is an aggressive species that out-competes most species and tolerates a wide variety of growing conditions. One way to reduce the vulnerability of the stand is to preferentially remove balsam fir when thinning mixed fir-spruce or mixed fir-hardwood stands. Do not release balsam fir from a hardwood overstory, especially during a budworm outbreak or if one is anticipated in the near future. Batzer et al. (1987) observed that in balsam fir - aspen stands where all the aspen had been removed at age 36 or age 47, the balsam fir was much more vulnerable to damage than those stands thinned from above or below. Similarly, Crook et al. (1979) observed that thinning balsam fir in a mixed stand increased damage to balsam fir when some of the hardwoods (aspen and white birch) were removed but thinning balsam fir stands did not increase defoliation.

Encourage mixed balsam fir-hardwood stand management. Recent work by Su et al. (1996) has demonstrated that as the amount of hardwood content in a hardwood-balsam fir stand increased, the amount of defoliation by spruce budworm decreased. Their work suggests that a hardwood content of 40% or more would substantially reduce losses during spruce budworm outbreaks. Although the underlying mechanism for this reduction remains unknown it is hypothesized that the greater amount of hardwood in the forest increases the diversity of populations of natural enemies such as parasitoids and birds. Needham et al. (1999) examined the relationship between hardwood and balsam fir content further and concluded that mixed stand management can potentially reduce balsam fir volume losses during a budworm outbreak. They also explore the application of these results under various forest management objectives such as reduction in pesticide use, production of balsam and/or hardwoods. It is of merit that they note again the complexities of managing forests for spruce budworm in context of the different forest management objectives, constraints, and opportunities superimposed by the variable landscape.

Manage balsam fir stands on a rotation age of 40 to 60 years. Mature and over-mature trees suffer the most severe damage, therefore shorten the rotation so that these species are less susceptible to attack and vulnerable to damage. A 40 to 60 year rotation would also reduce losses of volume due to rot and decay.

Thinning of stands. Where pure stands of balsam fir are present, thinning should be considered to promote vigor and therefore reduce vulnerability. One potential drawback to thinning pure balsam fir stands has been the increase of damage from the

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balsam fir sawfly (*Neodiprion abietis*) (Piene et al. 2001). Although the spruce budworm was more damaging in spaced than in unspaced balsam fir stands, tree mortality was statistically the same (MacLean and Piene 1995). Piene and MacLean (1999) note that spacing did contribute to a rapid individual-tree recovery after spruce budworm defoliation.

Break up areas of large areas of mature susceptible forests. Harvest by patch or block cuts to break up the continuity of large areas of susceptible forests. This harvest method prevents stands from reaching maturity simultaneously over large areas. Higher dispersal losses of young larvae and adults should occur when the forest is fragmented because of the increased spatial diversity of different even-aged stands. Diversity in species compositions on a landscape scale is also required. For this to be a potentially effective tactic, the entire budworm-susceptible forest of a large region must be involved in such a program, which requires sustained and extensive co-ordination among different owners and political jurisdictions.

Presalvage forests identified as the most vulnerable. This is a pre-emptive measure to dampen the impact of outbreaks and to use the wood before the budworm renders it useless. Vulnerable forests include those that are severely defoliated and those that are mature or overmature. Stands will need to be ranked according to their damage potential when scheduling the harvest. Stands with a large mature balsam fir component, growing on poor sites or ones with a high volume of sound wood should be harvested first. The publications by Dimond et al. (1984) and

Blum and MacLean (1984) provide useful guidelines on how to set salvage priorities.

Maintain a good road system. A good road system allows access to the sites to conduct stand improvement measures and also to pre-salvage or salvage the sites when needed.

Some final thoughts.

The spruce budworm and the spruce-fir forests have evolved together in ecological succession whereby spruce-fir replaces spruce-fir and the budworm act as the causal agent for this replacement (MacLean 1982). Forest management alone will not be a panacea for managing the spruce budworm. Although it cannot be said with certainty that any of the above forest management guidelines will be effective, it is likely that planting less susceptible species and encouraging spatial age-class and spatial diversity over a large landscape will help reduce the impact of the spruce budworm.

Well-managed and vigorous stands should respond well to direct control efforts that may be needed at some time in the rotation. Having a good portion of the forest in a less vulnerable condition should allow more time between control programs, decrease the need for control at the early stages of the infestation, and should allow more time for shifting salvage operations to the most vulnerable stands as the infestation progresses (Blum 1985). Forest management practices to reduce the impact of the spruce budworm must be considered a long-term strategy.

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Jack pine budworm *Choristoneura pinus* pinus Freeman

Jack pine budworm larva

Distribution: Jack pine budworm is found throughout the areas where jack pine grows, from Alberta to New Brunswick and in the Great Lakes States. It is particularly common in the Great Lakes States, Manitoba and Ontario.

Host: Jack pine is the preferred host. Eastern white, red and Scots pine are sometimes attacked but usually only when they are growing adjacent to or in the same stand as jack pine.

Host damage: The larvae of jack pine budworm are defoliators. In the spring, young larvae begin feeding on pollen cones, moving to the current year's needles as the latter develop. They consume the basal portion of the needles, webbing shoots together to form feeding shelters. The larvae feed on one-and two-year-old needles after the supply of the current year's needles diminishes. Desiccation of clipped and webbed foliage causes it to turn brown. Because feeding takes place first in the tops of trees, top kill and deformities (crooks and multiple leaders) are common.

Jack pine budworm is considered by many to be the most important insect pest of jack pine, causing substantial tree mortality in some areas, particularly where trees are drought-stressed (Ives and Wong 1988; Hopkin and Howse 1995; McCullough

Jack pine defoliation

2000). Outbreaks in Ontario generally persist for 2 to 4 years occurring roughly every decade (Hopkin and Howse 1995). An excellent review of the ecology and factors that affect the population dynamics can be found in McCullough (2000). Hopkin and Howse (1995) and Gross et al. (1996) reviewed the many studies on the impact of jack pine budworm in Ontario. Severe defoliation rarely occurs for more than one year in a stand (McCullough et al. 1996). The impact of only one year of moderate defoliation is not great. Defoliation for more than one year at moderate to severe levels will cause a significant growth loss and mortality. Cumulative growth losses range from 40 to 240% and are evident 3-6 years after the

onset of defoliation. Trees with 50% or more defoliation are more likely to have dead tops and recover more slowly to pre-infestation growth rates. An average of 15-20% of trees can be top-killed during a single outbreak (Conway et al. 1999; Hopkin and Howse 1995). Whole tree mortality ranges from 13 to 60% and is most evident among the intermediate to suppressed trees. On average, about 15% of the trees died following recent outbreaks in Canada and the United States (Conway et al. 1999; Hopkin and Howse 1995). A high degree of variability in defoliation, growth loss and mortality within and among stands is frequently encountered. When dead and top-killed trees build up in the forest and wildfires occur, conditions for subsequent jack pine regeneration are provided (McCullough 2000).

Habitat. Jack pine budworm is typically a pest of mature trees. Poorly stocked or overstocked stands, stands that are over-mature, and stands with low vigor trees are the most susceptible to attack and vulnerable to damage. All of these types of stand conditions typically have trees with abundant pollen cones, which are very critical to the survival of young budworm larvae (Nealis and Lomic 1994; Nealis 1995). Mallett and Volney (1990) found no clear indication that infection by root pathogens (e.g., Armillaria) determines the extent to which trees are damaged by the jack pine budworm or whether repeated defoliation by the budworm predisposes trees to root pathogen attack. Gross et al. (1996), note that where Armillaria was present in jack pine (not common), it was associated with an increase in mortality and overall growth loss in jack pine budworm defoliated stands.

Forest Management Guidelines and Recommendations

Many of the important caveats outlined for spruce budworm apply for the jack pine budworm. Again, long term, quantitative studies on how forest structure and forest management affect populations of jack pine budworm are lacking. And again, until these studies are done, we can only proceed on the basis of what appears to make sense based on the knowledge of insect ecology and a retrospective analysis of past outbreaks.

The overall strategy to dampen the impact of jack pine budworm outbreaks is to develop jack pine stands that are less susceptible to being attacked and less vulnerable to significant mortality and topkill. The two key components of a forest management strategy for jack pine budworm are to reduce the amount of pollen cones (staminate or male flowers) in an area, and to promote tree vigor so that the trees are less vulnerable to damage and death. Many of the approaches to do this have been described by Hodson and Zehngraff (1946), Jones and Campbell (1986), McCullough et al. (1994), Albers et al. (1995), and Weber (1986, 1995). Recent studies by McCullough et al. (1996), Kouki et al. (1997), Conway et al. (1999) and Radeloff et al. (2000) have refined general forest management approaches. The recommendations outlined below have been drawn largely from these sources.

Pre-outbreak stands:

To reduce the susceptibility of attack and vulnerability to damage, before outbreaks occur, consider the following.

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Manage to a predetermined rotation age to avoid overmature stands. Stand age is the most important factor to be considered in the management of jack pine budworm, because operationally forest managers have more control over rotation ages than site quality or stand density (Conway et al. 1999). Overmature stands have trees of low vigor and ones that are less tolerant of budworm damage. Moreover, older stands damaged by budworm are more likely to become attacked by secondary pests such as the pine engraver beetle, *Ips pini*, Armillaria root disease, and blowdown. McCullough et al. (1996) observed that once stands in northern Michigan reached about 50-55 years, vulnerability to budworm-related mortality increased rapidly with stand age. A rough rule of thumb would be to determine first when a stand typically begins to stagnate and deteriorate in the area and then to set the harvest date about 5 years before this happens. Shortening the rotation age reduces the vulnerability of the forest to budworm damage. Annual harvests should be allocated to those stands at greatest risk. Albers et al. (1995), Jones and Campbell (1986), McCullough et al. (1994), and Weber (1986, 1995) have consistently supported this recommendation.

Maintain proper stocking. Optimal stocking will encourage stand vigor and reduce the number of staminate flowers in a stand. Overstocked stands contain many suppressed trees, which can contain numerous pollen cones. Also, trees with short, narrow crowns that have little needle biomass are typically found in overstocked stands and can be quickly defoliated and killed in budworm outbreaks. In under-

Healthy jack pine stand

stocked stands, top kill is usually greater especially in mature to overmature stands. For the Lake States region, Albers et al. (1995) and Weber (1986, 1995) suggest that stocking should be maintained between 16 to 25-35 m^2/ha of basal area.

The conventional wisdom is to remove "wolf trees" from stands because they have full and large crowns typically with abundant pollen cones. These trees are thought to act as budworm reservoirs during outbreaks increasing the overall vulnerability of the stand. McCullough et al. (1996) however found no strong evidence that wolf trees increased stand vulnerability to tree mortality. Priority should be given to maintaining optimal stocking levels. The removal of wolf trees may be considered optional if there is a market for the trees.

Thinning good quality stands to remove suppressed, intermediate and wolf trees has been suggested to reduce the impact of the budworm. Recent studies by Conway et al. (1999) however, have shown that the presence of suppressed trees does not appear to adversely affect the volume or value in

a stand. These authors suggest that pre-commercial thinning from below should be given low priority as a forest management technique to reduce the impact of jack pine budworm. Studies designed to compare the susceptibility and vulnerability of thinned stands (either pre-commercial or commercial) and unthinned stands are lacking. Researchers have speculated that thinned stands would produce more pollen cones and thus make them more vulnerable to damage. This hypothesis needs to be tested. Ultimately the forest manager must weigh the balance between producing greater wood volume through thinning and the possible risk of increased damage by the budworm.

Avoid creating uneven-aged or two-storied stands. In situations where stands have a well-stocked understory but a second older under-stocked overstory, attempt to remove the overstory trees as soon as possible. During a budworm outbreak, these overstory trees, which typically have abundant pollen cones, can support large populations of budworm. These budworms can spin down or get blown down to the smaller trees and soon defoliate and kill them. Regenerate jack pine by clearcutting. Standing dead trees, hardwoods or less susceptible species such as eastern white pine can be left to promote diversity.

Site quality. Low quality sites were once thought intuitively to be inappropriate for jack pine stands. McCullough et al. (1996) and Kouki et al. (1997) observed, contrary to expectations, that mortality was lower on poor sites with low site index values than on better sites with higher site index values. Defoliation and site index were not correlated and thus differences in defoliation alone did not explain why mortality was highest on relatively good sites (Kouki et

al.1997). Conway et al. (1999) suggest that trees growing on low quality sites may have increased tolerance to stress, or conversely that trees growing on higher quality sites have higher foliar nitrogen levels, which are positively associated with larval survival.

Encourage age class diversity across the landscape. Whenever possible, promote age class diversity in large jack pine areas to reduce the overall susceptibility and vulnerability to jack pine budworm at any one time and in any one area. Large, contiguous areas of mature and overmature jack pine should be avoided. Where there are large natural stands or plantations of jack pine of the same age that are close to rotation age, stagger three clear-cuts over a 10-year period to break-up (diversify) the area.

Weber (1986, 1995) advised that when block- or patch-cutting jack pine stands, the amount of edge created should be kept to a minimum. Jack pine trees left at the edge tend to respond with profuse crops of pollen cones. The best shapes of harvest areas are large squares, broad rectangles, or broad ovals. Avoid thin strip cuts; aesthetic leave strips or islands, especially during a budworm outbreak. Avoid leaving trees along a roadside during an outbreak because they typically succumb to death within a few years and must be harvested later to "improve aesthetics" or reduce hazards.

Kouki et al. (1997) and Radeloff et al. (2000) examined the significance of stand edges. Kouki et al. (1997) observed that young stands adjacent to older stands (5 years older or more) increased the level of defoliation in the older stands. They speculated that the young stands had increased amounts of pollen

cones because of a greater exposure to light. This finding therefore appears to contradict the recommendation to encourage the break up of age classes across the landscape. The authors do caution that additional studies are needed to verify these results before general recommendations can be made.

Radeloff et al. (2000) found that edge had both a negative and positive effect and that this change in direction was related to the different phases of the outbreak. Up to the peak of the outbreak, edge density of budworm populations was positively correlated thus possibly supporting the hypothesis that pollen cones along the edge provided better food habitat for the budworm. After the outbreak peak, edge density was negatively correlated; that is, the edge helped decrease the populations of budworm. It is known that predators respond with a time lag to more abundant prey, and that higher numbers of predators occur along stand edges. Radeloff et al. (2000) concluded that edge was not significantly related to budworm populations and that the positive and negative effects seem to counteract each other over the course of the outbreak.

So where does this leave us, in terms of management recommendations for edges and age structure? On balance, and in the absence of additional research, it seems prudent at this time to attempt to minimize edges to reduce the production of pollen cones. The relationship between pollen cones and the survival of young jack pine budworm is clear and unequivocal. It therefore makes sense that if we wish to reduce the susceptibility of jack pine stands to the budworm at the beginning of an outbreak that we reduce

the amount of pollen and the edge, which encourage pollen cone production through increased light. Increasing the age-class diversity across the landscape also makes sense in that the evidence strongly suggests that as the age of the stand increases so does the susceptibility to attack and vulnerability to damage. Therefore reducing the amount of forest that is susceptible at any one time may reduce the overall impact and volume of wood that needs to be salvaged. Increasing age and species diversity (see below) across the landscape also has broader ecological benefits to species diversity.

Promote species diversity across the landscape. Wherever possible, establish less susceptible species to reduce the overall impact of the jack pine budworm on the forested landscape. Red pine is not a favored host of the budworm and often can be established on many sandy jack pine sites. On better quality sites, consider establishing white pine or trembling aspen. As a rule of thumb, aim to maintain about half of the area in non-host or less susceptible tree species.

Post-outbreak stands:

When severe defoliation has occurred or is expected to occur, pre-salvage and salvage of affected stands will reduce the impact and preserve most of the value of the wood. Harvest high-hazard stands and areas of heavy defoliation first. Overstocked stands should be given high priority for salvage (Conway et al. 1999).

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White pine weevil *Pissodes strobi* (Peck)

White pine weevil adult

Distribution: The white pine weevil is found throughout Canada and the northern United States.

Hosts: Eastern white pine is the most common and preferred host in eastern Canada. Other hosts include jack, lodgepole, pitch, Scotch and occasionally red pine; and, black, blue, red, white, Sitka, Engelmann and Norway spruce (Wallace and Sullivan 1985).

Host Damage: In the spring, adults feed on the previous years' terminal shoot and lay eggs in the feeding punctures. The larvae feed on the phloem and progress downward on the leader eventually forming a "feeding ring" and girdling the stem. The terminal withers, reddens and eventually dies, forming a "shepherd's crook." Weevils often kill two years of growth and sometimes as much as three to four years of growth in a single year. Leader damage results in loss of height growth and deformed main stems. Typically, one of the lateral branches assumes dominance, with a resulting crook where the lateral joins the main stem. Occasionally, two laterals may compete equally for some time and a fork is formed. Acute branch

White pine weevil damage

angles (often encased in bark) are common. Repeated attacks may result in suppressed trees, which are prone to being killed by competing vegetation.

The overall impact of the weevil depends on: how many trees are affected in the stand; the number of weevil injuries per tree; how well the tree recovers stem form and maintains height growth; and, ultimately on the target products (e.g., pulpwood, sawlogs, veneer). Over time, and as the tree increases its radial growth, damage to the terminal becomes less apparent. Many mature trees have internal evidence of weevil attack but do not have an obvious stem crook. Loss estimates vary widely and reflect in part the local conditions of the stand (open-grown trees are much more heavily attacked than those grown in partial shade), geographic location, sawmilling standards, tree size

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and rotation age. For eastern white pine, achieving a defect-free 5 m first log is a common goal. There is a considerable body of literature on the impact of the weevil on eastern white pine in eastern North America and on Sitka and interior spruce in western North America, but virtually none on the remaining host species.

Habitat: The weevil is most prevalent on young open-grown stands. Once crown closure is achieved, it is seldom a problem. Weevils attacking eastern white pine generally prefer fast growing trees, with leaders that are greater than 4.0 mm in diameter and have bark thicker than 0.8 mm (Sullivan 1961; Wallace and Sullivan 1985). Weevils also prefer long, upright terminal stems (Vandersar and Borden 1977).

Open-grown trees suffer considerable damage. Increasing the amount of overhead shade reduces injury from the weevil (e.g., (Peck 1817; Graham 1918, 1926; Peirson 1922). Sullivan (1961) noted that when isolation is reduced by just 25-50%, weevil damage is reduced by about 10%.

Shady conditions reduce ambient temperature and heat accumulation in the stand. Studies by Sullivan (1961) demonstrated that weevils in shaded stands feed and oviposit in an irregular pattern on as many as 4 to 5 years' growth (normally one years' growth in open stands). Under shaded conditions, females fail to deposit a sufficient number of eggs in a localized area of the main stem to provide enough larvae to form a feeding ring. Without this feeding ring, isolated larvae or small groups of larvae are insufficient in number to overcome the resin flow in the leader and

are eventually drowned or trapped in the resin. Furthermore, the leaders in shaded areas are often too small (they are less than 4 mm wide and have less than 0.8 mm of bark) to be attractive for oviposition and do not provide sufficient food for weevil larvae. The lower temperature of shaded leaders also retards larval development resulting in longer exposure to natural enemies (Wallace and Sullivan 1985). Weevils that hibernate within shaded areas have higher mortality during the winter (Wallace and Sullivan 1985).

Forest Management Guidelines and Recommendations

Silvicultural practices to reduce the impact of the weevil are aimed at providing shaded conditions that make the habitat unsuitable for the weevil (Sullivan 1961; Wallace and Sullivan 1985). Shade can be provided by: i) growing the trees underneath a canopy (overhead shade); ii) growing trees adjacent to taller trees (side shade); or, iii) establishing crown closure quickly.

Provide overhead shade

Overhead shade can be provided by using a uniform shelterwood, underplanting, or by using a nurse crop. Each particular system for regeneration has its merits reflecting the silvics of the species, the current site and stand conditions, available resources, and the need to consider wildlife, genetic, cultural and economic values.

Uniform shelterwood. As the name implies, shelterwood provides a shelter or habitat that is favorable to the growth and development of the tree. In Ontario, eastern white pine is managed predominately under the uniform shelterwood system and less

frequently under the clearcut system (Pinto 1992). White spruce can also be managed under uniform shelterwood.

Growing trees in shade requires a trade-off between survival and overall growth (Katovich and Morse 1992). Overstory trees may also create a physical barrier to the leaders of the understory eastern white pine and subsequently damage them. The balancing act that foresters must do when growing eastern white pine in an understory is to provide enough sunlight to allow adequate growth of the leaders, yet enough shade to create unfavorable conditions for the weevil.

In a shelterwood system, the existing stand provides both a seed source and shade for regeneration (Stiell 1985). In a uniform shelterwood system for eastern white pine, an initial preparatory cut is done to open the mature stand, and promote crown expansion, seed production and stem volume. A regeneration or seeding cut is done next to favour germination and provide space for seedlings and finally a removal cut takes the remaining trees after the regeneration is well-established (Stiell 1985). In the preparatory cut, trees are ideally spaced at 25-30% of their height; in the seeding cut the residual trees are spaced at about 40% of their height (Pinto 1992). (The goal should be to maintain a 50% canopy cover after the seeding cut). Methods to estimate this are provided by Bentley (1996). To ensure high quality first logs, the removal cut should wait until the eastern white pine regeneration is at least 5 m tall. These 3-cut shelterwood cuts appear to work well in Ontario in providing good regeneration and weevil control (Szuba and

Pinto 1991). The removal cut may also be done twice (4-cut shelterwood), once when the white pine regeneration is less than 6 m and again when the regeneration is beyond 6 m (Pinto 1992).

Underplanting. Underplanting of eastern white pine under hardwood canopies has been successful in some areas in Ontario (Szuba and Pinto 1991). However, underplanting under a conifer or mixed conifer stand is likely to provide more shade early in the spring when weevils first become active than would intolerant hardwoods, which begin leaf flush around the same time. When using this technique to reduce the impact of the white pine weevil, the key is to provide enough sunlight for adequate growth of the tree and yet enough shade to create unfavorable conditions for the weevil. This tradeoff is the same as the shelterwood system. Because eastern white pine seedlings can obtain maximum height growth in as

Underplanting

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little as 45% of full sunlight (Logan 1966; Stiell 1985; Messier et al. 1999), one should probably aim for a maximum of 40-50% full sunlight in the understory. A rule of thumb for 8-15 year-old eastern white pine is that they should grow about 40 cm per year. If they are growing less, they probably require more light (Katovich and Mielke 1993). The same advice would apply if a shelterwood system was being used. Under-planted eastern white pine should be protected until trees reach at least 5 m in height. An alternative to underplanting under the entire canopy is removal of the overstory in 3-m wide strips, planting therein, and leaving 5-m bands between the cut-strips (Messier et al. 1999).

Periodic release will be required and competition may be needed to ensure adequate survival of the under-planted trees. Katovich and Morse (1992) examined the growth response of young understory white pine (about 2 m tall), and incidence of weevil to four levels of canopy removal (about 0, 7, 11, and 16 m^2 of basal area (BA) per ha). They found that maintaining about 7-11 m^2 BA appeared to be a good compromise between increasing growth and mitigating weevil damage. In other words, removing too much of the overstory resulted in increased damage by the weevil, but not removing enough resulted in reduced leader growth. Messier et al. (1999) suggest two approaches for releasing white pine planted underneath a hardwood story: i) a low intensity thinning that allows at least 10% of photosynthetic photon flux density (PPFD, i.e., above-canopy light) followed by a more intensive thinning, or ii) a higher intensity thinning initially (30-40% PPFD, followed a few years later by understory brushing.

Nurse crops. An alternative to a high-density single species plantation (see below) is the establishment of a mixed species stand where one species grows faster than the other and serves as a "nurse crop". Nurse crops are established at the same time as the other tree species. Nurse crops could be hardwood species or other conifer species that are less susceptible to the weevil. Hardwood nurse crops could work well for eastern white pine and white spruce, which can tolerate some shade. (Struik 1978) recommends that white pine always be established with a nurse crop. Szuba and Pinto (1991) cautioned that it is important to carefully evaluate the site when planning to grow eastern white pine with a nurse crop such as aspen. For example, aspen grown on poor quality sites (e.g., dry, rapidly drained sites) may not grow fast enough to provide sufficient shade and protect eastern white pine from the weevil. It is very important to ensure that the nurse crop grows at least as fast as the desired species to provide shade during the first 20 years or so.

Planting white pine with another conifer (usually in alternate rows) has been advocated for some time (e.g., Peirson 1922), but has produced mixed results (Peirson 1922; MacAloney 1943; Belyea and Sullivan 1956). The main objective is to have the less susceptible alternate species out-top the highly susceptible white pine thus providing shade and the associated unfavorable condition for the weevil. To be effective, field observations suggest that the alternate conifers should be at least 60 cm above the canopy when white pine are 2 m or less and at least 1 m when white pine are more than 2 m (Peirson 1922). In most cases the alternate species may need to be planted before white

pine to gain the height advantage, in which case it would be considered underplanting rather than a nurse crop.

Struik (1978) suggests a maximum of 50% of sunlight is the most practical compromise for seedling growth and weevil management when using nurse crops for eastern white pine. Stand density and light intensity must be carefully regulated for the first 20 years of the plantation, which is best achieved through release treatments (gradual or every 5 years) that selectively remove individual stems. The timing of the release treatment is very critical and should be done when the leader shows a gradual reduction in growth (as a result of suppression) but is still vigourous enough to respond to release (Struik 1978). Tending white pine on fertile soils may be futile, because costs will be high to manage the competing vegetation. Working with white spruce in the interior of British Columbia, Taylor et al. (1996) demonstrated that the number of trees attacked by the weevil diminished as the percent of overtopping crown cover increased. They noted that measuring crown cover (in 19% classes) gave as good or better relationship between current weevil attack and leader length as the more complex light-interception measurements. Removal of the overstory should first be done in areas where the weevil infestation is light followed by areas where the infestation is heavier.

Provide side shade

Another variant of the shelterwood system is the strip shelterwood where narrow parallel clearcuts are seeded by the residual stand, which also provides side shade (Stiell 1985). (Stiell and Berry 1985) examined the incidence of weevils in clearcut strips that

would admit nominal values of 25, 50, 75 and 100% of full sunlight. The incidence of weevil attack diminished with decreasing amounts of sunlight. Stiell and Berry (1985) concluded that strips cut in a north-south direction, and with a strip width to stand ratio of 0.66 to 1.0 (50-75% of full light), resulted in an adequate number of white pine trees to reach 5 m free from weevil damage. The regeneration established in strips would require release to reduce mortality from suppression. Strip shelterwood was not effective in hardwood stands because the hardwoods were leafless early in the spring when the weevils were active. Better results might have been obtained if the strips had been aligned to minimize exposure to direct sunlight (Stiell and Berry 1985). (Taylor and Cozens 1994) found that alternating strips of overstory shade (5 m wide) and no shade (7m wide) oriented in an east-west direction, reduced weevil attacks by 2-6% on interior white spruce. Attack rates were low (< 2%) when the treatments were started and had the attack rates been higher (e.g., 15-20%), larger differences among the treatments may have been possible (Taylor and Cozens 1994). Taylor and Cozens (1994) observed that it took at least three full growing seasons before overhead or side shade treatments had a noticeable reduction of weevil damage.

Grow trees quickly to crown closure

Shade intolerant species like jack pine and black spruce are managed under the clearcut system and are typically established as single species stands from seed (natural or artificial) or seedlings (OMNR 1997, 1998). Plantations of eastern white pine

may be used on these clearcut sites to restore areas where it is formerly was present, where stand conversion is planned, or to afforest old fields (OMNR 1998). White pine may also be used where competition with advanced reproduction, such as on shallow tills of the Canadian Shield, would be very severe.

Planting eastern white pine in dense plantations has been advocated and investigated for some time (e.g., Peirson 1922; Graham 1926). The main objective for weevil management is to grow the trees as quickly as possible to crown closure to create shaded conditions, which are unsuited to the weevil. This technique is not failsafe because weevils will attack trees before shading reaches a level that is unsuitable for the weevil. Weevil populations typically take several years to develop to high levels, thus the sooner the plantation reaches crown closure the lower the levels of weevil damage. Maintaining high levels of stocking and tree vigor are essential for this technique to have success (MacAloney 1943).

Trees in high density plantations (less than 2 m by 2 m spacing) tend to have better form of the main stem because the close spacing forces the weevilled trees to grow in height ("correcting themselves") rather than laterally. The trade off with rapid height growth is that diameter growth of the leader is reduced. Graham (1926) suggests that if a density of 2960 (about 1.8 by 1. 8 m spacing) to 3700 trees per hectare (about 1.6 by 1.6 m spacing) is maintained through the first 20-25 years of the plantation, losses from the weevil will be minimal. (Alfaro and Omule 1990) found Sitka spruce (*Picea sitchensis*) spaced at 2.7 by 2.7 m had less weevil damage than trees spaced 3.6 or 4.6 m apart. Close spacing

reduces, but does not eliminate damage from the weevil (Graham 1926; Alfaro and Omule 1990). High-density plantations of eastern white pine should not be established in high-hazard white pine blister rust zones.

A high density of trees becomes a liability in plantations if they are not tended. Untended stands have very slow diameter growth and high natural mortality, especially in the lower crown classes. Stiell (1979) observed that untended stands of eastern white pine do not produce a sufficient number of healthy, uninfested trees without weevil damage at harvest. The fate of untended spruce or jack pine plantations that were weevilled is unknown, but it is very likely that these species will have fewer weevilled trees because they are less preferred than eastern white pine. The threshold for economic loss for spruce and jack pine in eastern Canada is unknown.

Pre-commercial thinning is required in high-density stands to promote survival and growth of trees. The earliest thinning for eastern white pine should be scheduled when the crop trees reach 5 m in height (1 log length), leaving about 370 undamaged stems per hectare (Stiell 1979, 1985). First release thinning could be delayed until there are only about 370 crop trees per hectare, which would allow commercial thinning and diminish risk of sun scorch. The drawbacks the delayed thinning include slow growth response of the remaining trees because of short crowns and possibly an unsatisfactory distribution of undamaged trees within the stand (Stiell 1979). Alfaro and Omule (1990) recommended close spacing of Sitka spruce with precommercial thinning at age 25 to allow a first log of good quality.

Similarly, Maclauchlan and Borden (1996) recommended delaying pre-commercial thinning of lodgepole pine attacked by the closely related terminal weevil (*P. terminalis*) until the trees are at least 15 years old or until the base of the crown has lifted above the top of the first log. Although no specific prescriptions for thinning weevilled stands of white or black spruce and jack pine have been developed, the guiding principle of waiting to do a precommercial thinning until one log length has been produced appears reasonable.

Even in the weevil-preferred eastern white pine stands, some trees will escape attack and become suitable crop trees. Retaining weevil-free and usually smaller trees in eastern white pine plantations while removing the more vigourous, heavily weevilled trees does not result in selection against rapid growth (Ledig and Smith 1981). In Ontario, high density eastern white pine plantations show low levels of weevil damage and probably work the best on good sites where trees are vigourous enough to grow well (Szuba and Pinto 1991).

In a survey of 30- to 80-year-old eastern white pine growing in well-stocked and unsuppressed plantations in Wisconsin, Pubanz et al. (1999) found at least one weevil injury in 87% of the crop trees examined. The average volume deduction due to crook in the first log (5 m) was only 1.3%. If eastern white pine is to be established in plantations, Pubanz et al. (1999) make five important recommendations: 1) maintain good stocking; 2) promote vigor (good crown development and diameter growth); 3) thorough selective thinning of unthrifty and heavily weevilled trees; 4) prune trees to improve the lumber grade recovery of crop trees or to move non crop trees to crop tree status; and, 5) focus on the number of crop trees in a stand rather than how many non crop trees are present.

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Root Collar Weevils

Pine root collar weevil *Hylobius radicis* Buchanan

Pine root collar weevil adult

Pine root collar weevil damage

Distribution: The weevil is native to eastern North America and is found from Newfoundland, southward to Virginia and northwestward through the United States and Canada to Minnesota and Manitoba (Wilson and Millers 1983).

Hosts: The pine root collar weevil attacks several species of native and exotic pines. Jack and red pine are more susceptible than eastern white pine. Among the various species of pines planted together or located near each other, the frequency of attack by larvae on the root collar is high on Scotch, moderate on red and jack pine and rare on eastern white pine. The order of shoot preference by adult weevils, however, is eastern white, Scotch, jack and red pine (Wilson and Millers 1983).

Host Damage: The larvae of the root collar weevil inflict the major damage to the tree, feeding on the inner bark at the base of the tree (the root collar) and roots. An area of pitch-soaked soil adjacent to the tree base indicates larval feeding. Badly damaged trees exhibit changes in the color of their foliage, progressing from yellow to red before the needles drop off. If enough tissue is killed, the tree dies or is weakened and breaks over.

Habitat: Trees growing in light sandy soils on dry sites are preferred by the pine root collar weevil. However, heavy attacks and mortality can also occur in stands near swamps and on loamy or clay soils. Infestations tend to be more severe in pine plantations and windbreaks than natural stands. Planted pines typically have a larger root collar at the soil surface and below the soil than naturally growing pines. Stands that have dense canopies following crown closure have fewer insects than poorly stocked open-grown stands. In closed stands the temperature is lower and humidity is higher, which are conditions less favorable to the weevils (Wilson and Millers 1983).

Forest Management Guidelines and Recommendations

Wilson and Millers (1983) summarized the literature on the pine root collar weevil and provided guidelines to manage this weevil. The prescriptions outlined here are based on those guidelines.

Before planting, evaluate the site for weevil hazard. High-risk plantations occur where summers and winters are relatively mild, where jack, red or Scots pine stands nearby are heavily infested and are dying from the weevil, and where the planting is a mixture of closely related pine species or different ages of the same species. Risk drops rapidly when the infestation source is more than 1.5 km away, the climate is cooler, and where pines are planted in small monocultures or in mixtures with spruce or hardwoods. Consider planting less susceptible white pine rather than the more susceptible red and jack pine when planting in high hazard areas. Ignoring a nearby infestation source will eventually lead to serious damage and costly control treatments six to 15 years after planting.

Weevil-infested brood trees that are on or adjacent to a planting site cause an infestation of the young trees 3 to 4 years after planting. Brood trees include residual trees left from logging, seed trees, windbreak trees, wolf trees, or any other tree that is infested and left on site. Choose uninfested trees as seed trees and remove infested trees whenever possible.

When establishing a new plantation, plant at a 1.8 by 1.8 m spacing to encourage early crown closure because weevil populations in these stands will drop before tree mortality occurs. Maintain stocking standards by replanting open areas caused by planting failures. The severity of damage tends to increase as planting depth increases so plant as shallowly as possible – about 10-13 cm in high hazard areas. If possible, plant trees in small solid blocks of 2.5 to 5.0 ha separated by buffers of non-host species. If large blocks are planted, then mix (e.g., alternate rows) pine with spruce or tamarack or other compatible non-host trees to reduce the risk. (Cerezke 1994)

Work to keep the trees vigorous because healthy trees are better able to resist attack by the weevil. Plant on good sites whenever possible, especially when the risk of weevil injury is high. On good sites pines tend to outgrow the weevil injury. On the other hand, trees that are weak and dying not only encourage weevil populations to build up but they also attract secondary insects such as bark beetles, especially in dry years when the trees are under greater stress. Remove dead and dying trees from a plantation.

Survey plantations regularly during the susceptible period of tree growth (1-5 m tall) to determine the level of damage by the weevil. Monitoring plantations occasionally (once every 2 or 3 years) where the risk is high will usually reveal problems before they become too serious. If the amount of injury is unacceptable, consider pruning the lower branches (up to 1 m above the ground) and scraping the litter and about 5 cm of the topsoil out to 15 cm from the tree stem. The removal of the litter destroys the habitat necessary for adults; pruning the lower branches decreases moisture and increases temperatures and air circulation.

Warren root collar weevil *Hylobius warreni* Wood

Warren root collar weevil damage

Warren root collar weevil stand damage

Completely girdled trees die. In partially girdled trees, the open wounds may provide portals of entry for secondary pathogens and insect pests. Mature trees subjected to repeated attacks show some loss of growth in height and radial increment and are subject to blow down (Ives and Wong 1988).

Distribution: The warren root collar weevil is a common pest in coniferous forests of North America, particularly in the boreal forests of Canada. It is found from Newfoundland to British Columbia, and in southern sections of the Northwest Territories (Cerezke 1994).

Hosts: Jack pine and white spruce are common hosts. In Ontario, the weevil will also attack eastern white, red, and Scots pine, and black and Norway spruce (Cerezke 1994).

Host Damage: The larvae of warren root collar weevil feed on the inner bark of the root collar and roots at and below the surface of the duff, causing complete or partial girdling of the stem and roots and open wounds in the root collar area. Profuse resin flows are associated with the larval wounds. Adult weevils ascend the tree at night to feed on needles, branches and twigs (Cerezke 1994).

Habitat: The presence of the weevil correlates well with site conditions. This weevil prefers trees growing on moist to wet soil and humus conditions and a humus or organic duff layer that is relatively deep, which often includes mosses around the base of the tree (Rose et al. 1994; Cerezke 1994). In Ontario, jack pine stands that are rated as fresh and moist and which support twinflower, lily-of-the-valley, bunchberry, bracken fern, Labrador tea, and leather leaf are likely to be the most susceptible to the weevil. Generally, the abundance of weevils increases with stand age and tree size.

Forest Management Guidelines and Recommendations

Cerezke (1994) summarized the literature on the Warren root collar weevil and provided guidelines to manage this weevil. The prescriptions outlined here are based on those guidelines.

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Before planting, evaluate the site for weevil hazard. Site conditions rated from intermediate to moist and with moderate to high productivity in white spruce and jack pine have the highest risk for damage by the weevil. Use site-specific plant association information before harvesting and planting. Assessment of the risk to young regeneration may require a pre-harvest survey.

Weevil infested trees left after harvesting will provide a source of weevils for the new plantation. These brood trees include residual trees left from logging, seed trees, windbreak trees, wolf trees, or any other tree that is infested and left on site. Choose uninfested trees as seed trees and remove infested trees whenever possible. If the pre-harvest weevil density is high, a 2 to 3 year post-harvest delay before replanting may reduce weevil damage.

Although field studies are lacking, there is good evidence to support the logic of scarifying or burning an area within a year of clear-cut harvesting to increase the mortality of larvae and pupae remaining in cut stumps and adults remaining in the harvested area. Larvae are able to continue their development in stumps for 2 years after cutting. These treatments should also retard the re-invasion and spread of adults for several years after harvest within young stands.

Mixtures of conifers with non-host conifer species (e.g., Tamarack) or deciduous species may retard the invasion of the weevil but again, field experiments to investigate this are lacking. Mixing susceptible species (e.g., jack pine) with less susceptible species (e.g., upland black spruce) is not recommended because the weevils attack the more susceptible species first and, as the populations build up, they attack the less susceptible species in greater numbers than usual.

Where the weevil is present, pre-commercial thinning or spacing should be delayed beyond 15-20 years to minimize weevil-caused mortality and growth loss. Thinning of sites where Armillaria root rot and the weevil are present should be delayed as long as possible or they should not be thinned at all.

If direct control is deemed necessary, then consider pruning the lower branches (up to 1 m above the ground) and scraping the litter and about 5 cm of the topsoil out to 15 cm of the tree stem to reduce the habitat favorable for the weevil. This practice should be done when trees are between 5 and 15 years old.

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Pine engraver *Ips pini* (Say)

Pine engraver adult
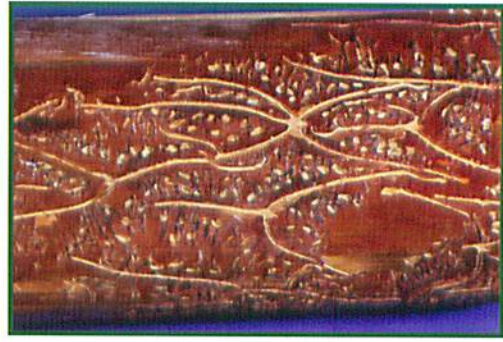
Pine engraver damage

Distribution: The pine engraver is one of the most common and widely distributed bark beetles (Scolytidae) in North America. It occurs throughout Canada and across the northern United States in the east from the southern Appalachian Mountains northward and in the west along the Rocky mountains to northern Mexico.

Hosts: In eastern Canada and the United States, the principal hosts include jack, red and eastern white pines. In western Canada and United States, ponderosa, lodgepole, jack, shore and Jeffrey pines are attacked. Other species of pine are attacked less frequently; and probably any species of pine could be a host at some time.

Host damage: Adult male beetles initiate attack by boring into the outer bark of the tree and excavating a chamber, called a nuptial chamber. The males release a pheromone to attract an average of three females and after mating, the females bore a gallery in the phloem layer to deposit their eggs. After hatching, the larvae mine the phloem laterally from the egg gallery. The larval galleries essentially girdle the tree causing a reduction in nutrient and water flow. The foliage of infested trees eventually fades and the trees that were living prior to attack, die.

Habitat: The engraver is seldom a tree killer. Typically, the engraver beetle attacks logging slash, wind-thrown trees, or trees broken by wind, snow or freezing rain. Unthrifty and stagnant stands are particularly susceptible to attack and vulnerable to damage. Populations can build up in slash, and because the beetle often has two or more generations per year (two is normal for Ontario), subsequent populations can attack standing green trees. The tops of standing green trees may be killed while others may suffer complete mortality.

Forest Management Guidelines and Recommendations:

The following recommendations are based on the publications by Thomas (1957), Kegley et al. (1997) and Overhulser (1999).

Maintaining vigorous and healthy forests and sanitation are the keys to preventing tree damage. Slash or weakened trees attract

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beetles and provide suitable conditions for populations to establish, build up and potentially damage or kill standing green trees. The diameter of the slash and the time it is produced are important considerations. Slash less than 8 cm in diameter can be left behind because it usually dries out rapidly and seldom produces large beetle populations. For slash larger than 8 cm in diameter, the time of cutting is important. Slash created in late summer to late fall, before snowfall, will usually dry out to the point that it is unsuitable for the pine engraver the following year. However, logging slash created from early winter through late spring provide an ideal habitat for the engraver beetle. If possible, avoid cutting during this period but if this is impractical then implement one of the following precautions:

1) Scatter the slash into open areas to accelerate drying, or crush the slash with heavy equipment. Chipping the slash into small pieces will also reduce the amount of breeding material for the beetles, or,

2) Produce a continuous supply of fresh slash during July and August (the time when the second generation of adults are searching for sites to lay eggs). New slash should be produced when the first generation adults are in the pupal stage. Producing a continuous supply of new slash, called a "green chain" diverts the beetles away from the remaining "leave" trees. An alternative to the "green chain" is to create large piles of slash in the spring before beetle flight. These slash piles should be at least 3m long and 3m high; leave them in the thinned stand. The pieces in the interior of the pile remain fresh and attractive long enough for the second generation beetles and again divert them away from the standing trees.

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Yellowheaded spruce sawfly *Pikonema alaskensis* (Rohwer)

Yellowheaded spruce sawfly

Distribution: Yellowheaded spruce sawfly occurs across Canada and the northern United States and follows the distribution of spruce throughout North America.

Hosts: The sawfly feeds on all spruces native to North America, including white, black and red and on the exotic - Norway spruce. There appears to be geographical variation in host preference, which may be associated with the synchrony between bud burst and emergence of females (Pointing 1957). White spruce buds burst about 10 days before black spruce (Blais 1957). In Ontario, the sawfly may select one species over the other in areas where both are present (Pointing 1957), whereas in Minnesota, in spite of the abundance of black spruce, white spruce is the common host (Houseweart and Kulman 1976).

Host damage: Early instar larvae skeletonize new needles; as the larvae grow, they consume whole needles. Late instar larvae may attack foliage from previous years (Wilson 1971).

The yellowheaded spruce sawfly causes severe defoliation of young spruce trees

Yellowheaded spruce sawfly damage

grown in plantations and in open areas. The susceptible period is usually from three to five years after planting until crown closure (Kulman 1971). While severe feeding injury may result in the death of branches and whole trees, some trees have been observed to withstand 100 percent defoliation. Mortality in white spruce plantations in Minnesota was 2.3 to 2.7 percent as a result of defoliation by the sawfly, with pockets where mortality reached 15% (Morse and Kulman 1984b).

The major economic losses are attributable to reduced growth. Terminal and shoot lengths are shortened relative to the degree of defoliation. Kulman (1971) reported that a single defoliation of 80% or more on 1.5 to 2.5 m tall trees caused about 60% reduction in terminal shoot elongation in the first and 50% in the second year. Two years of similar

defoliation caused about an 80% reduction in growth. Long term effects of defoliation have not been examined.

Habitat: Young, open-grown trees are preferred (typically 1 to 6 m tall and 5 to 9 years old), especially those in plantations, shelterbelts, and urban ornamental plantings (Wilson 1971; Rose et al. 1994). Population outbreaks often occur on south facing slopes before crown closure (Morse and Kulman 1986). Once trees reach crown closure, sawflies are seldom a problem. Trees grown under an overstory (often aspen) or those in dense stands are generally not susceptible to the sawfly.

Forest Management Guidelines and Recommendations

Because the sawfly prefers open-grown trees, once crown closure has been achieved in the stand, sawflies are seldom a problem. Therefore silvicultural practices to manage the yellowheaded spruce sawfly should involve full stand stocking, early crown closure, or using nurse crops to provide shade.

It is always best to grow spruce on sites appropriate for the species. Insect problems are usually more frequent and more severe when tree species are planted "off-site". Avoid establishing white spruce plantations on south-facing slopes where trees are under greater stress and often have higher insect populations (Morse and Kulman 1986). Also avoid sites for white spruce that have poor drainage or heavy clay soils (Cook 1976 in Katovich et al. 1995).

During site preparation, attempt to minimize the loss of soil organic matter and nutrients from planting sites because trees growing on nutrient poor sites are more likely to sustain significant damage if defoliated (Katovich et al. 1995). Site disturbance may also reduce populations of small mammals and insects that feed on sawfly cocoons and keep populations at low levels (Katovich et al. 1995). Therefore, allow some woody material to remain on the site to provide habitat for them.

Consider growing white spruce under a light overstory or "nurse" crop because these trees are less susceptible to damage by the sawfly (Morse and Kulman 1984a). A nurse canopy of aspen or white birch, which reduces full sunlight by 25 to 30 percent, not only permits maximum height growth of young spruce but also protects them against spring frost damage (Rauscher 1984). If possible, keep a light overstory of aspen or other species, until trees are about 3 to 4 m tall.

Plant at a 2 m by 2 m spacing to encourage early crown closure. If the initial survival in the plantation is poor, then replant to fill in the spaces to promote early crown closure. Avoid overstocking; it may result in slower growth or reduce the ability of the trees to recover from defoliation or other induced stress. Pre-commercial spacing, which opens up the stand, may encourage the reestablishment of sawfly populations.

Be careful with release treatments. Morse and Kulman (1984a) released white spruce from a 70% overstory that was predominantly aspen and observed a six-fold increase in the amount of defoliation by the sawfly the following year compared to the unreleased control. However, Kostyk et al. (1997) did

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not find an increase in defoliation of black or white spruce by the sawfly after mechanical and chemical conifer release treatments. They noted, however, that even though the vegetation cover was significantly lower in the treatment areas, even a small amount of cover left on the site may deter the sawfly from laying eggs in the released areas.

Little is known about the effects of fertilization on yellowheaded spruce sawfly. Popp et al. (1986) fertilized white spruce at 0, 224 or 448 kg/ha of ammonium nitrate and observed that the highest survival of sawfly larvae occurred at 224 kg/ha. This result seems to suggest that there is an optimal level of nitrogen that maximizes the larval survival.

More work needs to be done to firmly establish this relationship between fertilization with nitrogen and the response of the yellowheaded spruce sawfly. One common observation is that defoliation by the sawfly tends to be higher when soil nutrients are low, particularly nitrogen (Katovich et al. 1995). Insects may compensate for lower quality food (i.e., lower nitrogen levels) by eating more (Mattson and Scriber 1987), which may explain why defoliation is higher on nitrogen-poor soils (Katovich et al. 1995).

No efforts have been made to select spruce that are resistant to or tolerant of damage by this sawfly. Nienstaedt and Teich (1972) observed differences in defoliation among 28 white spruce seed sources from Minnesota when infestations were light, but no differences were observed when the same seed sources were heavily defoliated. Connor et al. (1982) found no significant differences in susceptibility of 25 white spruce seed sources to the sawfly when the sawflies were caged on trees. However, the fact that only three trees per seed source were used in this study make it difficult to detect subtle seed source differences (Katovich et al. 1995).

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Redheaded pine sawfly *Neodiprion lecontei* (Fitch)
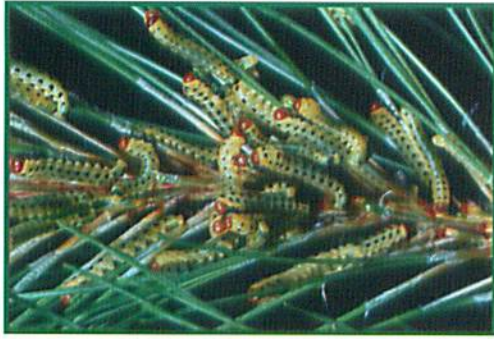
Redheaded pine sawfly larvae

Redheaded pine sawfly damage

Distribution: The redheaded pine sawfly is found throughout most of eastern North America. In Canada, it is found in Ontario, Quebec, and New Brunswick. The sawfly is probably the most serious pest of red pine plantations in southern and central Ontario, and south central Quebec (Rose et al. 1999).

Hosts: In Ontario, jack, red and Scots pine are the principal hosts. Larvae will occasionally be found feeding on eastern white pine, but this is almost always the result of larvae migrating from nearby hard pines. Host preference appears to vary with latitude and the availability and abundance of the different pine species (Wilson et al. 1992). In Ontario, red pine appears to be preferred over jack pine, but in the Lake States, jack pine is preferred over red pine. Controlled experimental studies of host preferences have not been undertaken and so that these apparent regional differences may also be a function of host and site interaction.

Host damage: Young larvae skeletonize the needles and older larvae consume the entire needle. After the older needles have been consumed, feeding continues on the new growth. As foliage becomes scarce, larvae feed on the young bark. When a tree has been completely defoliated, larvae migrate to another tree to continue feeding.

Complete defoliation is usually enough to kill red and jack pine. Heavy defoliation causes top kill and forking while less extensive feeding stunts height and diameter growth. Branches that are completely defoliated often die.

Typically a wide range of defoliation is observed in a single plantation and it is not unusual to see entire trees stripped of foliage.

Habitat: Redheaded pine sawfly typically attacks young open-grown trees up to 6 m tall. It can be found in natural stands, plantations and on ornamentals. Once crown closure occurs, the insect is seldom present or its damage significant.

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Forest Management Guidelines and Recommendations

Selecting the right site for a new plantation is probably the most important silvicultural practice for reducing the impact of the redheaded pine sawfly. The condition of the site affects the condition of the trees, which in turn determines the degree of susceptibility to the sawfly. Averill et al. (1982) examined different site conditions for red pine and developed three site classes for resistance to the sawfly. Based on this classification and other ecological information, Wilson et al. (1992) developed management guidelines for red pine. The recommendations below are largely drawn from these guidelines. Jack pine grown under similar conditions as red pine have not shown similar site resistance classes.

Grow pine on sites that are appropriate for the species. Sawfly problems are usually more frequent and more severe when tree species are planted "off-site". Site conditions that are poor for tree growth are favorable for redheaded pine sawfly. Trees that are stressed show poor height growth, poor form and off-color foliage. Avoid planting red pine in high stress sites such as those where there is competition from bracken fern (*Pteridium aquilinum* (L.) Kuhn) or sod, along edges where there are hardwood roots, or in frost pockets. Also avoid planting where the soils are nutrient poor, fine textured, too shallow, too compacted, too dry or too moist, or on eroded soils. Sites where the pH is neutral or higher tend to be more susceptible. Sites that are too moist can be indicated by the presence of sedges, even during dry periods. Bracken fern and sweetfern (*Comptonia peregrina* (L.) Coult.) stress red pine by competing for moisture thus making them more susceptible to the sawfly. Therefore plant on good sites where competitive species like bracken fern and sweetfern are less than 10% of the ground cover.

In general, pines (like all tree species) should be planted on the best sites for the species to keep them vigorous and as stress-free as possible. Good red pine sites that are highly resistant to redheaded pine sawfly have relatively undisturbed soil and have a visible leaching (Ae) zone. These soils also frequently have a B-horizon, containing textured bands or well-developed color-band (Wilson et al. 1992). Soils should be well-drained, deep, loose loamy sand or gravel and have sufficient water-holding capacity.

Remove hardwoods before planting pine on the site. If this cannot be done, then plant at least 6 m beyond the crowns of hardwoods, reducing the competition from hardwoods for moisture and nutrients. Control of competing vegetation may be required to accelerate crown closure and reduce tree stress.

In the Lake States, the recommendation is to avoid planting red and jack pine mixed in a stand or as adjacent blocks of trees because jack pine appears to be more susceptible than red pine to the sawfly. The sawfly tends to cause much more injury to red pine when it is mixed with, or adjacent to, jack pine stands. In Ontario, the sawfly has been a problem mainly in red pine plantations, predominantly in southern Ontario, but this may be a result of host availability rather than host preference because jack pine is scarcer in southern Ontario than red pine.

Plant at a 2 m by 2 m spacing to encourage early crown closure. If the initial survival in the plantation is poor, then replant to fill in the spaces to promote early crown closure. Avoid overstocking because it may result in slower growth or loss of the ability of the trees to recover from defoliation or other induced stress. Griffiths (1958) found that open-grown red pine was more susceptible to the sawfly than shaded trees, whereas Benjamin (1955) found the reverse for red and jack pine. This apparent contradiction may be more a function of site quality, root competition, or plant stress than overhead shading per se.

Once crown closure has been achieved, the redheaded pine sawfly is seldom a problem. Pre-commercial spacing, which re-opens the stand, may result in the reestablishment of sawfly populations.

No efforts have been made to select trees that are resistant to the sawfly. In Ontario, tree improvement programs are active for jack but not for red pine. Hodson et al. (1982) found variation in the incidence of attack by the sawfly among 30 jack pine seed sources obtained from various locations in Michigan, Wisconsin and Minnesota.

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Forest tent caterpillar *Malacosoma disstria* Hübner

Forest tent caterpillar larvae

Forest tent caterpillar damage

Distribution: The forest tent caterpillar is found from coast to coast across Canada from the tree line to the southern United States (Rose et al. 1997).

Hosts: The caterpillar attacks almost all hardwood trees, with red maple being a notable exception (Rose et al. 1997). Trembling aspen, balsam poplar, white birch and sugar maple are common hosts in the boreal and Great Lakes-St. Lawrence regions of Ontario. It will even eat tamarack during outbreaks.

Host Damage: Forest tent caterpillar larvae feed in clusters on foliage. Larvae begin feeding about the same time as the leaves unfold. As foliage becomes scarce, larvae move around the tree in search of food. When a tree has been completely defoliated, larvae will migrate to another tree or surrounding deciduous vegetation to continue feeding (Rose et al. 1997).

Trees are rarely killed because they can produce a second crop of leaves in midsummer following defoliation. Light defoliation causes little damage but moderate-to-heavy defoliation, especially over two or more years, causes a decrease in radial growth. Vigorous trees can tolerate up to 2-3 years of heavy defoliation without suffering serious growth loss or mortality. Growth recovery to pre–infestation levels may take two to three years after the caterpillar population collapses. Trees heavily defoliated for four or more years, may suffer branch mortality and some trees may die. Trees stressed from drought are less tolerant of defoliation and may die sooner. Defoliation does weaken trees and makes them more susceptible to attack and vulnerable to damage by woodborers, cankers and root rots. Infestations of forest tent caterpillars are widespread and cyclic, occurring every 6-16 years and lasting 4-5 years (Ives and Wong 1988).

Habitat: This insect occurs over a wide variety of habitats because it has a large geographic and host range.

Forest Management Guidelines and Recommendations

The wide host range of the tent caterpillar (all hardwoods except red maple) severely limits forest management options. Typically, growth losses are accepted. After a few years, natural control factors such as weather, starvation, parasites, predators, and disease substantially reduce populations of forest tent caterpillar.

Recent studies by Roland (1993), Roland and Kaupp (1995), Roland and Taylor (1997), Roland et al. (1997, 1998) have examined the effects of forest fragmentation, forest stand size and the dynamics of insects and diseases. Roland (2002, and personal communication, April 2002) recommends that forest managers not fragment the forest, creating stands of less than 100 ha. Distance between stands is less of a factor if the leave blocks are a minimum 100ha, but obviously the closer together large blocks are, the larger the intact forest. Minimizing stand edge would be preferable.

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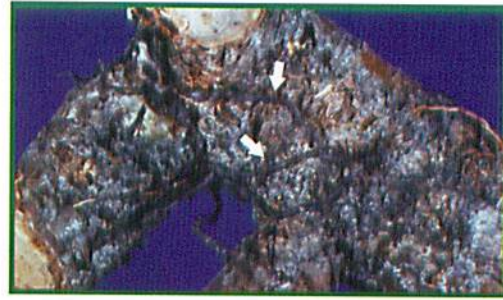
Section III:

*Forest Management
Guidelines and
Recommendations*

Diseases

Armillaria root rot *Armillaria ostoyae* (Romagn.) Herink

Armillaria damage

Armillaria rhizomorphs are shown by white arrows

Distribution: Occurs worldwide in boreal, temperate, and tropical forests (Hood et al. 1991); very common throughout Canada and the United States.

Host: Capable of affecting a wide variety of tree species.

Host Damage: Armillaria consists of a group, or complex of species and strains, that differ in pathogenicity and host preference (Dumas 1988). The fungus normally lives saprophytically on dead woody material but often becomes parasitic when the overall vigor of the host declines as a result of unfavourable environmental conditions, particularly drought. The disease generally causes a rot in the roots and base of the stem (Davis and Meyer 1997), reducing tree vigor and growth rate, but it will also influence forest succession by killing seedlings,

saplings, and sometimes mature trees. Trees die individually or in small circular pockets, especially in monocultural plantations. In mature and over-mature forests the disease may occur over very large areas, and in the plantations that replace these heavily infected sites numerous small disease centers routinely develop.

The first symptoms of infection are yellowing of foliage, loss of old needles, and the death of branches in the upper tree crown. All foliage may die suddenly on smaller trees. White mycelial fans form under the bark of the roots and root collar, and are often associated with basal resinosis. Dark brown to black shoe-string-like structures called rhizomorphs are often found on the stump and roots and in the soil surrounding the infected trees. The rhizomorphs consist of a dark brown outer layer of closely compacted fungus tissue. The disease spreads primarily through root grafts and rhizomorphs, growing outward through the soil from infected roots and penetrating the roots of adjacent trees.

The fungus kills the cambium and outer layers of wood, causing decay. Tree mortality results when the fungus has girdled the

major roots and root collar. Incipient decay is usually yellowish-brown in color and the wood has a water soaked appearance. Advanced decay is yellowish in color, with numerous black zone lines, and is soft and stringy in texture. The disease usually does not progress upward into the stem for more than a meter. Clusters of honey-colored mushrooms are produced at the base of infected trees and stumps in early autumn. Basidiospores are wind-borne and generally infect stumps or dead trees. Occasionally living trees are infected through open wounds at the base of the tree, or on exposed roots.

Forest Management Guidelines and Recommendations

Armillaria root rot is the most serious root disease in Ontario, capable of attacking both deciduous and coniferous trees in natural forests and plantations. Among conifers, pine species are considered more susceptible than spruce, although spruce on upland sites is also affected by this disease (Whitney 1988).

Armillaria root rot is very difficult to control and can persist on logged sites for more than ten years. Roth et al. (1979) and Shaw and Calderon (1977) have reported that Armillaria can cause significant losses in conifer plantations converted from hardwood, although the pre-harvest level of root rot is probably more critical than the pre-harvest tree species. In stands known to have a history of the disease, colonization of stumps can result in significant losses to the future stand. In areas destined to be high-value conifer plantations, a pre-harvest survey to determine the prevalence of root rot is recommended.

Careful site selection and good management practices that maintain a healthy, vigorously growing stands are strongly recommended. When a site is found to have a high source of inoculum, site preparation and stump removal (Morrison and Mallett 1996) should be considered. Stump removal followed by a short fallow period has helped to reduce secondary inoculum, especially on sites that originally consisted of overmature conifers. Although costly, the removal of old, infected stumps, and root raking should be considered, especially if the areas to be replanted are to be used as seed orchards or for high value production Scarification can sometimes exacerbate root disease problems by distributing uninfected material across a site (Ronnberg and Vollbrecht 1999).

Infection centers within existing plantations are extremely difficult to control. The root systems of adjacent trees around an infection center may already be infected and if these trees are cut down in an attempt to stop the spread, the disease very quickly colonizes their entire root systems causing the epicenter to rapidly expand. Both precommercial and commercial thinning can increase the damage level caused by Armillaria and should be avoided around Armillaria pockets. Stanosz and Patton (1987) noted the potential for Armillaria to accumulate in dead root systems after repeated rotations. Both Armillaria and tomentosus require food bases such as stumps or roots for the fungus to grow and infect other trees (Stanosz and Patton 1990) the long-term effect of shorter rotations with continual planting is unknown. However, the literature would suggest that shorter rotations could seriously increase root rot.

Heavily infected trees experience radial growth loss, butt rot, and are prone to wind throw because of their weakened root systems

Planting these sites with the proper species and healthy stock is probably most important. For example, conifer seedlings are most susceptible to Armillaria during stand establishment, particularly if stressed, or if the roots are deformed by the greenhouse production process or during planting (Livingston 1990). In such instances, seeding might be a cost-effective alternative, which could result in reduced losses. The planting of less susceptible species or using locally adapted seed sources for indigenous species, matching site conditions and type is strongly recommended and will help to avoid economic losses (Haggle and Shaw 1991).

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White pine blister rust *Cronartium ribicola* J.C. Fischer

White pine blister rust fruiting body

White pine blister rust damage

Distribution: The blister rust is widespread in Canada across range of eastern and western white pine.

Host: All native five needle pine, especially eastern (*Pinus strobus*) and western (*Pinus monticola*) white pine; alternate hosts include all domestic and wild currants and gooseberries (*Ribes* spp.).

Host Damage: White pine blister rust is native to Asia, but was first introduced into North America from Europe, in 1906 on German nursery stock. The disease was introduced to British Columbia in 1910, and to Ontario and Quebec in 1911 and is now considered the most damaging disease of eastern white pine in Canada.

White pine blister rust requires two different hosts to complete its life cycle (Ziller 1974). Infection takes place through the needles on the pine host, late in the summer. During the next 12-18 months the fungus grows back along the twig and branch towards the main stem. Yellowish to orange discoloration of the bark tissue of the branch occurs during the second or third year of infection. The spindle-shaped cankers that form eventually girdle the branch or main stem, and everything distal to the canker dies. In the late summer of the third year of infection, honey-colored or brownish droplets of liquid exude from the swelling. The following spring, white blisters, which cover orange coloured spore masses, erupt through the bark, and the aecial spores are dispersed, infecting the leaves of the secondary host, *Ribes* spp. Throughout the summer, uredial spores are produced on the underside of the *Ribes* leaves in yellowish to light orange colored pustules. These uredial spores are only capable of re-infecting other *Ribes* plants. Several generations of these spores are produced in the summer and serve to spread and intensify the infection on the *Ribes* plants. Late in the summer

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or early fall, telial spores are produced on the underside of the *Ribes* leaves in short, brownish, horn-like structures. These spores germinate in place and produce the basidial spores that are released, and re-infect nearby pines (Myren and Laflamme 1994).

Forest Management Guidelines and Recommendations

White pine blister rust has specific temperature and moisture requirements for successful infection (Van Arsel et al. 1956). Based on these criteria, hazard zones have been developed for growing white pine in Ontario and Quebec (Gross 1985; Lavellée 1986). White pine grown in traditional plantations within high hazard zones usually suffer serious mortality during its early years, especially if *Ribes* is in close proximity (Lavellée 1992). However, even within a high hazard area, white pine production is possible. Avoid planting eastern white pine in areas where the alternate host is known to be abundant. Resistant varieties of white pine have been developed and should be used in high risk areas, if suitable stock is available. Van Arsdel (1961) recommends that plantings not occur in areas where cold air collects, such as depressions. Surveys conducted in northeastern Ontario showed that open-grown plantations had much lower infection levels if grown on upper slopes (A. Hopkin unpublished). Some level of control has been achieved by the removal of the alternate host, *Ribes* spp., within 300 m of a pine plantation. Pruning has also been an effective though labor-intensive tool in reducing blister rust incidence. In high value plantations and seed orchards, the disease can be effectively controlled by hand pruning, and destroying infected branches or severely infected trees. Most infection occurs on the lower branches and over time can result in stem cankers if initial infection is within 10-15 cm of the stem. Pruning the lower branches up to two meters from the base of the stem on young trees (age 5-7 yrs) will dramatically reduce infection by the fungus (Hunt 1991). The pruning of lower branches will open the plantation to air movement, drying the site and reducing the germination rate of the infecting spores. Stand density is also important in reducing infection in plantations. Early thinning is known to increase the incidence of this disease (Hungerford et al. 1982). Hagle et al. (1989) recommended thinning at 25-30 years, which allows for a closed canopy and for the natural thinning caused by the rust.

The use of shelterwood systems was suggested by Van Arsdel (1961) as a means of reducing blister rust infection in high hazard areas. The purpose of shelterwood is to maintain drier, and therefore, less conducive conditions for infection on the understory pine. Shultz (1989) describes the use of blister rust tolerant stock in a shelterwood. In the case of white pine blister rust is also affected by spacing when grown on a high hazard area. Maintenance of a closed canopy reduces infection (Van Arsdel 1961). Shelterwood created either by underplanting, or with the use of a fast growing species such as hybrid poplar or birch, will also deliver the advantages of a closed canopy.

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Scleroderris canker *Gremmeniella abietina* (Lagerb.) Morelet

Scleroderris canker damage, North American race

Scleroderris canker damage, European race

Distribution: In North America, two distinct strains of the fungus referred to as the North American and European races (Skilling et al. 1986), are recognized as damaging to pines. The North American race is found in New Brunswick, Ontario and Quebec, north of 45° N latitude. The European race, first appeared in North America in New York State in 1975, where it killed several thousand hectares of semi-mature red and Scots pine (Skilling 1977). In Ontario, this race was first recorded in 1985; it is restricted to central Ontario in the Huntsville and Bancroft areas. It is also found in Newfoundland and New Brunswick, and much of southern Quebec, where it has caused considerable damage (Laflamme and Lachance 1987).

Hosts: The North American race infects primarily Austrian, jack, red, and Scots pine and occasionally eastern white pine. The European race infects primarily red pine. Five needle pines seem to be more resistant than the two and three needle pines.

Host Damage: The North American race of *G. abietina* infects young trees under two meters in height. However, it will infect the lower branches of larger trees, where the fungus may persist and spread to young trees; this race has been associated with numerous planting failures (Dorworth 1970). The European race causes damage to all age and size classes, and with favorable weather conditions, can spread rapidly through the upper crowns of plantation trees.

Both races of scleroderris canker have a similar life history (Skilling et al. 1986). Infective spores are generally dispersed and infect trees during wet periods in the spring and early summer. The North American race produces two types of spores, ascospores, which are capable of long range wind dispersal, and conidia spores, which are dispersed by rain droplets over short

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distances. The European race produces only conidia spores making long-distance dispersal unlikely.

Infection takes place through the base of the needles. The following year, infection symptoms become evident on what are now second year needles. The base of the needles on the tip of infected branches turn red in the early spring. In the North American race the fungus grows back along the branch toward the main stem, usually killing a single internode per year. Once the fungus reaches the main stem, it girdles the stem, killing the tree above the point of infection. If the fungus does not completely girdle the tree, a canker results (Dorworth and Davis 1982). The European race progresses more rapidly, killing entire branches in just one season. Infection occurs at all heights on the tree and when environmental conditions are favorable for this race of the fungus, mortality can result in a single season (Manion 1984). Additional information on the life history and symptomology of this disease is provided by Laflamme (1991) and Myren and Laflamme (1994).

Forest Management Guidelines and Recommendations

Scleroderris canker is climatologically sensitive (Marosy et al. 1989) and does not occur south of 44°30′ (Hopkin and McKenney 1995). On this basis, hazard zones based on climate have been proposed for Ontario (Venier et al. 1998). When grown in a high hazard zone scleroderris can be controlled through pruning and sanitation (Hopkin and Laflamme 1995).

After the disease is detected, and the race verified, the prescribed control method is for on site tree removal and destruction of diseased material, particularly if the European race is present. Pruning trees is an effective control measure if the disease is at low levels (<5% trees infected). To be effective as a control, pruning should be performed on both healthy and diseased trees in affected plantations. Pruning the lower third of the crown for all plantation trees is advisable to prevent or reduce the spread of disease.

Regardless of tree height, if less than 2% of pines have only one or two infected branches, only the infected branches should be removed. This procedure should be repeated the following year if the disease is still evident. In plantations with trees less than 1.5 m high, only infected branches should be cut and destroyed. In the following year the plantation should be inspected and the procedure repeated if necessary. In plantations with trees over 1.5 m in height, where more than 2% of trees are affected, the lower whorls should be removed up to one whorl above the highest infected branch. If more than two thirds of the whorls are infected, the tree should be removed and destroyed. If the majority of the trees in the plantation are infected and more than 25% of the trees are dead or severely infected, consideration should be given to complete destruction of the plantation.

Nursery infections, which are often responsible for disseminating the disease, can be significantly reduced by the removal of infected windbreak trees, or the removal of lower branches of susceptible windbreak trees. Fungicide applications are an effective means of control in nurseries (Hopkin and Laflamme 1995; Skilling et al. 1986) but are not required in nurseries south of the hazard zone.

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Tomentosus root rot *Inonotus tomenetosus* (Fr.:Fr.) Teng

Tomentosus root rot fruiting bodies

Tomentosus root rot damage

Distribution: Associated with spruce-pine forests throughout Canada and the United States.

Host: The primary hosts are white, black, and Norway spruce and occasionally eastern white, jack, and red pine, fir, hemlock, and larch.

Host Damage: Tomentosus root rot is a native pathogen that infects trees through root grafts and airborne spores. The fungus slowly grows through the roots of the tree towards the stem and eventually kills the tree (Myren and Laflamme 1994). The rot can extend up to 3 m into the main stem of the tree, resulting in significant volume loss in the butt log. Infected trees first show signs of reduced vigor, reduced leader growth, thinning of foliage, and stressed cone crops. The incipient stage of the disease causes a reddish-brown stain in the central portion of the root wood. Advanced decay consists of the development of pockets in the wood tissue filled with either white or yellow fibers.

Infected trees may appear healthy but actually have extensive amounts of advanced decay throughout the base of the stump and butt log and can live for 15 or more years before death occurs. As the disease advances in the larger structural roots of the tree, they become weakened, and the tree becomes prone to windthrow and blowdown. Stumps of infected trees remain as an inoculum source for several years following harvesting and become a serious problem in second-growth stands (Whitney 1962).

It is estimated that approximately 15% of all living white and black spruce in natural stands, greater than 30 years in age, are infected with tomentous root rot (Whitney 1977). The spread of the disease is enhanced in pure spruce plantations by the presence of the continuous susceptible root mat. Whitney (1993) noted that higher proportions of trees were infected in pure white spruce plantations than in natural stands. A survey conducted in a 64-year-old white spruce plantation that was clear cut in 1989, revealed that 58% of the stumps showed evidence of tomentosus root rot and an additional 20% were infected but the disease had not yet reached stump height. In naturally occurring mixedwood stands in the same vicinity only 13% of similar age white spruce were affected and only 10% of these showed any evidence of the decay at stump height.

The disease is most prevalent on upland sites with highly acidic soils. A deep duff layer that favors *Hylobious* root weevils also favors the spread of the disease due to the

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increase in root wounds (Whitney 1961). Once established, the disease spreads from tree to tree primarily through root grafts. Diseased trees often occur in groups or pockets, resulting in the formation of stand openings. Tan to yellowish-brown fruiting structures, with a velvet-like upper surface, develop on the ground above infected roots or on the trunk of the host in late summer or early fall. The spores from these are wind-borne and can be carried to new areas where infections occur at root or stem wounds.

Forest Management Guidelines and Recommendations

Damage and volume loss caused by tomentosus root rot increase as stands age, due to the increase in infection sites over time. Once a small pocket of the disease has started, additional damage can be expected within 5 years. Whitney (1993) has suggested that thinning can be a useful tool in reducing this disease. The literature on the effect of thinning on root rots is mixed. Thinning can be used to improve stand vigor and hence reduce root rot under normal conditions; however, Morrison (1981) recommends that thinning should not be conducted in heavily damaged stands. Alternatively, Whitney (1993) reported that the incidence of tomentosus root rot was reduced in white spruce plantations through thinning.

Guidelines for control are provided by Whitney (2000). Early harvesting can reduce losses to this disease and should be considered when losses are unacceptable. Cutting only the trees with above ground symptoms will not stop or prevent the spread of the disease to remaining trees. Heavily infected stands, with one or more stand openings per hectare, should be clear cut and regenerated with a less susceptible species, such as hardwoods or pines. If the site is to be replanted to spruce, stump removal and root raking the site should be considered. Site selection is important, moist or alkaline sites pose little risk of Tomentosus. Planting pure stands of spruce on gravelly, sandy or silty soils should be avoided. On upland sites planting stock carefully to avoid root damage is important in disease avoidance. Maintain a good general overall health by preventing additional stress on the host by other agents, whether it is an insect, disease, or a human activity.

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