# BIOLOGY, DAMAGE AND MANAGEMENT OF SEED ORCHARD PESTS

# BIOLOGIE ET IMPACT DES RAVAGEURS DES VERGERS À GRAINES ET OPTIONS DE LUTTE

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## PREFACE

This information report documents the proceedings of a workshop held in Sault Ste. Marie, Ontario, on 29 September 1993, during the Joint Annual Meeting of the Entomological Society of Ontario and the Entomological Society of Canada. The purpose of this workshop was to consolidate the latest information on the theoretical and practical implications of pest management in seed orchards, and to share it with the managers of Ontario seed orchards.

We have organized the contributed papers around the basic components of an integrated pest management system, i.e., pest biology, impact prediction and control options. Thus, the first three manuscripts discuss the biology of pests affecting seed production and seed orchard trees. The need and ability to predict crop abundance and pest impact are subjects dealt within papers 4, 5 and 6. The status and future directions of preventative and suppressive control are discussed in papers 6 and 7. The last manuscript provides an update of Ontario's tree improvement program.

We are grateful to K. Jamieson for editing the final version of these proceedings and to V. Santana for design and layout. Special thanks to L. Panneton for translating the abstracts, A. Lavallée for editing the French text and to all authors for their timely contributions.

## AVANT-PROPOS

Ce rapport d'information présente les travaux d'un atelier qui s'est tenu à Sault Ste-Marie (Ontario), le 29 septembre 1993, à l'occasion de la réunion annuelle conjointe de la Société d'entomologie de l'Ontario et de la Société d'entomologie du Canada. L'atelier avait pour but de réunir l'information la plus récente sur les conséquences théoriques et pratiques de la lutte antiparasitaire dans les vergers à graines, et de la partager avec les gestionnaires des vergers à graines de l'Ontario.

Nous avons agencé les documents présentés en fonction des éléments fondamentaux d'un système de lutte antiparasitaire intégrée, c'est-à-dire la biologie des ravageurs, la prévision de l'impact et les options de lutte. Les trois premiers documents traitent donc de la biologie des ravageurs qui influent sur la production de graines et sur les arbres des vergers à graines. Le besoin et la capacité de prévoir l'abondance des récoltes et l'impact des ravageurs sont abordés dans les documents 4, 5 et 6. L'état et les orientations futures des mesures de prévention et d'élimination des ravageurs sont discutés dans les documents 6 et 7. Le dernier document fait le point sur le programme d'amélioration des arbres de l'Ontario.

Nous remercions K. Jamieson pour la révision linguistique du présent rapport et V. Santana pour la conception graphique et la mise en page. Nous remercions également L. Panneton pour la traduction des résumés, et A. Lavallée pour leur révision linguistique, et finalement tous les auteurs pour leurs efforts.

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# CONE AND SEED INSECTS OF PINES, SPRUCES AND WESTERN LARCH

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## ABSTRACT

With over 80 intensively managed orchards established for 12 coniferous species, the British Columbia (BC) seed orchard program is a major, expanding component of the provincial reforestation strategy. Spruce, pine, and larch account for half of the orchards. A seed pest management unit in the BC Ministry of Forests provides services to orchardists and natural stand cone collectors confronted with insect and other pest problems. A great diversity of insects are associated with conifer cones but only a few attain pest status or are otherwise of interest in seed production because of their facultative or obligate cone and/or seed feeding habits. About two dozen insect species in the orders Hemiptera (seed bugs), Homoptera (aphids and gall aphids), Coleoptera (cone beetles), Lepidoptera (budworms, seedworms, and coneworms), Diptera (cone maggots), and Hymenoptera (seed chalcids) are responsible for the major problems encountered in BC spruce, pine, and larch seed orchards.

## RÉSUMÉ

Avec plus de 80 vergers où 12 espèces de conifères sont cultivées par des méthodes intensives, le programme des vergers à graines de la Colombie-Britannique (C-B) représente un élément majeur, d'une importance grandissante, dans la stratégie de reboisement de la province. La moitié des vergers servent à la production de graines d'épinette, de pin et de mélèze. Au ministère des Forêts de la C-B, un service s'occupe d'aider les exploitants des vergers et des peuplements naturels à lutter contre les insectes et les autres ravageurs. De nombreuses espèces d'insectes sont associées aux cônes de conifères, mais seulement quelques-unes d'entre elles sont considérées comme des ravageurs ou ont une influence sur la production de graines parce qu'elles sont facultatives ou obligatoires. Dans les vergers à graines d'épinettes, de pins et de mélèzes de la C-B, les plus grands problèmes causés par des insectes sont dûs à environ deux douzaines d'espèces réparties entre 6 ordres (hémiptères, homoptères, coléoptères, lépidoptères, diptères et hyménoptères).

## INTRODUCTION

Cone and seed insects of pines, spruces and western larch are serious forest pests in British Columbia (BC) where reforestation is big business. Presently, an average of over 200 million seedlings of about 20 species and varieties of trees are planted annually in the province (Table 1). About 10% of these seedlings (ranging from 2-71% for seven species) are grown from "A" Class seed produced in orchards. By the year 2000, seed orchards in BC are expected to supply 50% of the annual provincial seed requirements.

British Columbia is divided into 24 seed planning zones based on long term provenance (seed source) and progeny testing and provincial biogeoclimatic data. Individual seed orchards are designed to produce seed adapted to conditions within particular seed planning zones. A planning zone may have more than one orchard to address its seed needs. For example, there are two Central Plateau zone interior spruce (*Picea glauca* x *P. engelmannii*) orchards — one for higher and one for lower elevations within the zone. Seed orchards in BC are agroecosystems

**Table 1. British Columbia provincial sowing requests (000's of seedlings) in 1993**

| SPECIES | NUMBER REQUESTED | A CLASS (Seed Orchard) | A CLASS % of Total |
|---|---|---|---|
| Lodgepole pine (interior) | 93,647.9 | 2,317.1 | 2 |
| Interior spruce | 84,497.5 | 9,299.5 | 11 |
| Western red-cedar | 10,815.8 | 4,219.0 | 39 |
| Western hemlock | 7,928.4 | 2,664.4 | 34 |
| Douglas-fir (coast) | 7,584.7 | 5,397.2 | 71 |
| Douglas-fir (interior) | 7,297.8 | -- | -- |
| Pacific silver fir | 3,640.8 | 0.0 | 0 |
| Western larch | 3,068.0 | 0.0 | 0 |
| Interior x Sitka spruce | 1,715.0 | -- | -- |
| Sitka spruce | 1,581.7 | 795.7 | 50 |
| Sub-alpine fir | 1,147.5 | -- | -- |
| Lodgepole pine (coastal) | 990.1 | -- | -- |
| Ponderosa pine | 928.2 | -- | -- |
| Yellow-cedar | 613.0 | 0.0 | 0 |
| White pine | 385.4 | 48.0 | 12 |
| Grand fir | 198.2 | 0.0 | 0 |
| Mountain hemlock | 62.6 | -- | -- |
| Red alder | 32.0 | -- | -- |
| Noble fir | 29.0 | -- | -- |
| Siberian larch | 27.0 | -- | -- |
| Paper birch | 16.6 | -- | -- |
| Eastern larch | 15.0 | -- | -- |
| **TOTAL** | **226,222.2** | **24,740.9** | **11** |

**Table 2. Number of orchards, size (ha), and number of trees in the British Columbia seed orchard program as of 1 June 1993**

| | FOREST SERVICE | | | INDUSTRY | | | TOTAL | | |
|---|---|---|---|---|---|---|---|---|---|
| **SPECIES** | **Orchards (No.)** | **Size (ha)** | **Trees (No.)** | **Orchards (No.)** | **Size (ha)** | **Trees (No.)** | **Orchards (No.)** | **Size (ha)** | **Trees (No.)** |
| COAST | | | | | | | | | |
| Douglas-fir | 6 | 31 | 5,666 | 10 | 37 | 6,112 | 16 | 68 | 11,778 |
| western hemlock | 1 | 4 | 1,753 | 10 | 20 | 9,878 | 11 | 24 | 11,.631 |
| Sitka spruce | 0 | 0 | 0 | 4 | 4.5 | 2,655 | 4 | 4.5 | 2,655 |
| western red cedar | 0 | 0 | 0 | 5 | 3 | 1,719 | 5 | 3 | 1,719 |
| yellow-cedar | 0 | 0 | 0 | 3 | 2 | 1,206 | 3 | 2 | 1,206 |
| pacific silver fir | 1 | 3 | 270 | 3 | 10 | 4,554 | 4 | 13 | 4,824 |
| grand fir | 0 | 0 | 0 | 1 | 1 | 672 | 1 | 1 | 672 |
| white pine | 0 | 0 | 0 | 2 | n/a | n/a | 2 | n/a | n/a |
| Englemann spruce | 1 | 4 | 1,440 | 0 | 0 | 0 | 1 | 4 | 1,440 |
| **Sub-total (Coast)** | **9** | **42** | **9,129** | **38** | **77.5** | **26,796** | **47** | **119.5** | **35,925** |
| INTERIOR | | | | | | | | | |
| spruce[a] | 18 | 35 | 18,936 | 3 | 14 | 8,156 | 21 | 49 | 27,092 |
| lodgepole pine | 9 | 29 | 9,471 | 1 | 3 | 1,200 | 10 | 32 | 10,671 |
| western larch | 2 | 4 | 3,800 | 0 | 0 | 0 | 2 | 4 | 3,800 |
| white pine | 2 | 2 | 1,234 | 0 | 0 | 0 | 2 | 2 | 1,234 |
| **Sub-total (Interior)** | **31** | **70** | **33,441** | **4** | **17** | **9,356** | **35** | **87** | **42,797** |
| **TOTAL (All Orchards)** | **40** | **112** | **42,570** | **42** | **94.5** | **36,152** | **82** | **206.5** | **78,722** |

[a] Englemann spruce, white spruce, Englemann x white spruce

intensively managed by permanent, full time staff on a year-round basis to produce regular and frequent cone crops.

Presently, there are more than 80 established orchards in the BC seed orchard program covering over 200 hectares at over 20 private and government sites (Table 2). The majority of these are located on southern Vancouver Island and in the Okanagan Valley. The dry, warm climate of these areas is more conducive to frequent, controlled cone production than the climate elsewhere in the province.

For many years after its inception in 1963, the program was dominated by the coastal variety of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco. There are now 12 coniferous species being grown in orchards (Table 2), about half of which are spruce (*Picea* spp., especially interior spruce), and pine (*Pinus* spp., especially lodgepole pine, *P. contorta* Douglas). Western larch, *Larix occidentalis* Nuttall, is new to the program with two orchards established and nearing production.

**Table 3. Classification of pine, spruce, and larch insects of importance to British Columbia seed orchards**

| ORDER | FAMILY | SPECIES |
|---|---|---|
| Coleoptera | Curculionidae | *Pissodes* spp. |
| Diptera | Anthomyiidae | *Strobilomyia neanthracina* |
| Hemiptera | Coreidae | *Leptoglossus occidentalis* |
| Homoptera | Aphididae | *Elatobium abietinum*<br>*Mindarus* spp. |
| | Adelgidae | *Adelges* spp.<br>*Pineus* spp. |
| Hymenoptera | Torymidae | *Megastigmus* spp. |
| Lepidoptera | Coleophoridae<br>Tortricidae<br>Pyralidae | *Coleophora laricella*<br>*Choristoneura occidentalis*<br>*Dioryctria* spp. |

As with any intensively managed agroecosystem, pest management is a major component of the BC seed orchard program. The Silviculture Branch of the BC Ministry of Forests (BCFS) maintains a Seed Pest Management program designed to aid all provincial seed orchard staff, as well as natural stand cone collectors, in the protection of cone and seed crops from insects, diseases, and competition from other animals and weeds. The program is run by three permanent staff biologists and a variable number of seasonal employees. The bulk of their work deals with the assessment of damage by, and the identification, monitoring, and control of, cone and seed insects and other insects causing damage to seed orchard trees. There is currently no directed, long term basic research program on cone and seed insects in place in BC.

## CONE AND SEED PROBLEMS OF PINES, SPRUCES AND WESTERN LARCH

A very large number of species of insects are associated with seed cones as herbivores, scavengers, parasites, and predators (Miller 1986). Only a relatively small component of the herbivorous community is of major interest in seed production; these species may be obligate cone and seed insects (cones and/or seeds are critical to completion of their life cycle) such as cone maggots, *Strobilomyia* spp., or facultative (insects that may feed upon cones and/or seeds but are not dependent upon them) such as budworms, *Choristoneura* spp. Another community of insect species indirectly affects seed production through feeding on branches, stems, foliage (e.g., most gall aphids: *Pineus* spp., *Adelges* spp.).

**Table 4. Other cone and seed insects of importance to spruce and pine seed production in British Columbia**

| ORDER | FAMILY | SPECIES |
|---|---|---|
| Coleoptera | Anobiidae | *Ernobius punctulatus* |
| | Scolytidae | *Conophthorus ponderosae* |
| Diptera | Cecidomyiidae | *Kaltenbachiola* spp. |
| | | *Mayetiola carpophaga* |
| | | *Resseliella* spp. |
| | Lonchaeidae | *Earomyia barbara* |
| Lepidoptera | Tortricidae | *Eucosma* spp. |
| | | *Cydia* spp. |
| | | *Rhyaciona* spp. |

In BC about two dozen species in the orders Hemiptera (seed bugs), Homoptera (aphids, gall aphids), Coleoptera (beetles), Lepidoptera (moths), Diptera (flies), and Hymenoptera (seed chalcids) are of immediate concern to spruce, pine, and larch seed orchardists (Table 3). Other species in the orders Coleoptera, Lepidoptera, and Diptera are normally problems only in natural seed production stands (Table 4), either because their host species are not grown yet in seed orchards or these insects are not usually found in seed orchards.

The following insects are the most important ones of those listed in Tables 3 and 4. They (and most of the others) have been well-described in various field guides and scientific papers. For illustrations and more detailed information consult the references at the end of this article (see especially Baker 1972; Furniss and Carolin 1977; Hedlin 1974; Hedlin *et al.* 1980; Turgeon and de Groot 1992 — much of the following has been gleaned from these works).

WESTERN CONIFER SEED BUG (*Leptoglossus occidentalis* Heidemann) This bug is primarily a problem for Douglas-fir seed production in BC, but feeds on most conifers and is commonly found in spruce and pine seed orchards. Originally an insect of the western U.S. and adjacent regions of Canada, it has become well established in Ontario (Marshall 1991) and is probably now generally distributed across central North America.

This distinctive insect feeds on seeds by inserting its long needle-like beak through individual cone scales and into seeds. Secreted salivary enzymes dissolve seed contents, which are then sucked up. Seed contents may be partially to completely consumed. Both nymphs and adults damage seeds. Damage is very difficult to assess as there is little external evidence on the cone of feeding activity and seed bug damaged seed is nearly indistinguishable from other unfilled seed in radiographs. Seed losses of up to 26 and 41% in western white pine, *Pinus monticola* Douglas, and Douglas-fir, respectively, have been attributed to western conifer seed bug (Hedlin *et al.* 1980).

The life cycle is completed in one year. Adults overwinter in protected places, often in open cones or in buildings. Oblong, cylindrical eggs are laid in single lines on needles through the late spring and early summer. These hatch in less than two weeks; nymphs congregate and feed upon developing cones and have usually matured by late summer. The BCFS Seed Pest Management group believes this insect is a facultative cone and seed insect that feeds (and probably develops) on foliage as well as seeds, especially when cones are in short supply.

GREEN SPRUCE APHID [*Elatobium abietinum* (Walker)] This is the only aphid that causes major damage to BC seed orchards. It provides a good example of an insect having an indirect effect on seed production. It severely defoliates and weakens coastal seed orchard spruce trees. Without appropriate monitoring and control severely infested trees lose most of their old foliage.

The green spruce aphid feeds on sap extracted by inserting its mouthparts into needles. Affected foliage becomes mottled and yellow and eventually falls off. Populations expand rapidly in mid-winter and have usually gone through several generations and peaked by the end of March or early April. By the onset of bud flush, populations have crashed to barely detectable levels (but have occasionally remained high until early June) and consequently damage is almost entirely restricted to older foliage.

In North America this species reproduces asexually and most adults are wingless. Its biology is not well understood and its actual effect on seed production has not been documented. It is not known if this species migrates to an alternate summer host as do many other aphids. Other than ongoing control trials, there is no research currently being directed at *E. abietinum*.

GALL APHIDS (*Adelges* spp., *Pineus* spp.) Nearly a dozen species of gall aphids are known to occur in BC forests. Most have a complex two host life cycle. Sexual reproduction and species specific gall formation occur on spruce, the primary host. The secondary host, some other specific conifer species, supports a population of asexually reproducing, "woolly" females.

In BC, four gall aphid species are common and can be major problems in spruce, white pine, and western larch seed orchards. *Adelges cooleyi* (Gillette) is the best known gall aphid in BC. It alternates between various spruce species and Douglas-fir.

*Adelges lariciatus* (Patch) is relatively new to BC and switches between interior spruce and western larch. *Pineus pinifoliae* (Fitch) occurs on western white pine and interior spruce (usually). *Pineus similis* (Gillette) is not known to occur on a secondary host but cycles quite adequately on several spruce species.

Gall aphids do not usually cause direct damage to spruce cone and seed crops. Progeny of overwintering females develop in galls formed on flushing buds and indirect effects to seed production are caused by the destruction of these sites for future cone production. Galling is occasionally severe in some locations and subsequent cone production is reduced until new, ungalled branchlets can be grown. Sometimes galls will form on conelets (especially during heavy infestations). Seed from these cones is difficult to extract and galled cones are discarded during cone collections.

Damage to secondary hosts is usually limited to foliage. *Pineus pinifoliae* can severely defoliate young western white pines in seed orchards. Other, more familiar examples of major gall aphid damage to secondary hosts are balsam woolly aphid, *Adelges piceae* (Ratzeburg), on true firs (*Abies* spp.) in eastern and western North America and hemlock woolly aphid, *Adelges tsugae* Annand, on eastern hemlock, *Tsuga canadensis* (L.) Carrière. *Adelges lariciatus* may be the only North American obligate cone-feeding gall aphid. Its life cycle is presented below because of its direct association with larch seed production and as an example of basic gall aphid natural history.

On western larch in BC, immature females overwinter at the bases of buds mostly on two-year-old branches. They mature in early spring, before bud flush, and begin to produce large numbers of eggs asexually. Before the end of April these hatch into nymphal females, which rapidly move to conelets where they attach to scales and bracts and feed on plant fluids. Within two to three weeks of hatching most of the nymphs have matured into winged adults which fly to suitable spruce trees and produce a generation of sexual offspring. These mate and produce female offspring which overwinter at the base of new spruce buds. The gall aphids remaining in the larch cones become wingless females. They and their progeny continue to infest cone scales and bracts through the summer but have disappeared from cones by the time seeds are mature.

On spruce the overwintering nymphs mature and produce female progeny early in the spring. Feeding activity induces the formation of a pineapple-like gall around the progeny on an expanding bud. Winged adults form in chambers within the galls. By mid-summer the galls have dried out and opened, releasing the females to fly to larch trees. The young progeny of these females then wait out the winter at the base of older buds.

In spite of heavy infestations on some larch cones there is no evidence yet that

*A. lariciatus* seriously affects seed production. Some preliminary work by seed orchard staff suggests that *A. lariciatus* may not affect filled seed per cone but may cause difficulties in seed extraction due to excessively gummed cones. In 1994, BCFS research on this insect will focus on control options, effect on seed production, and its life history. Gall aphid surveys are conducted annually in all spruce orchards in BC.

CONE BEETLES (*Conophthorus* spp.) Cone beetles can significantly affect seed production, but are not a major problem in BC seed orchards. In contrast to most other cone and seed insects where feeding by immature forms is the primary cause of damage, destruction by cone beetles is attributable entirely to adult females.

About a dozen species of bark beetles in the genus *Conophthorus* are obligate cone feeders (with one exception) in pines across North America and Mexico. Some species can be very destructive to host seed crops. *Conophthorus ponderosae* Hopkins, occurs on ponderosa pine, *P. ponderosa* Lawson, western white, and lodgepole pine in BC as a minor cone pest. Elsewhere in Canada *C. coniperda* (Schwarz), can severely damage eastern white pine, *P. strobus* Linnaeus, cone crops and *C. resinosae* Hopkins is very destructive to cones of red, *P. resinosa* Aiton, and jack pine, *P. banksiana* Lambert.

Cone beetles go through one generation annually. Life cycles for most species are similar. Adults overwinter, usually in the cones in which they developed, but also in shoots or conelets. In late spring and early summer females emerge and bore into the bases of second year cones, killing them in the process. Attacked cones may remain on the tree or fall to the ground. Males enter the cones and mate with the females. Eggs are laid along a gallery and develop into adults over the summer.

BUDWORMS (*Choristoneura* spp.) Three species of budworms are common in BC primarily on Douglas-fir, spruces, and true firs: two-year budworm, *C. biennis* Freeman, eastern spruce budworm, *C. fumiferana* (Clemens), and western spruce budworm, *C. occidentalis* Freeman. Of these, the western spruce budworm causes the most destruction to cones, especially in Douglas-fir, spruce, and larch. *Choristoneura fumiferana*, the budworm of northeastern BC, is found in spruce-fir forests across the continent and is a major problem in conifer seed production in eastern Canada.

Budworms are facultative cone feeders and are most often associated with defoliation. However, especially when populations are high, flowers and conelets will be seriously damaged by the external grazing activities of the caterpillars. If left undisturbed, a western spruce budworm caterpillar will usually damage only one bud, cone, or clump of cones. However, they respond readily to any disturbance by dropping from their feeding positions on silk threads. They can then land on other sites or be blown easily to other trees. Interior spruce seed orchard damage is often caused by budworm caterpillars blown in from off-site.

Most budworms have a one year life cycle. In western spruce budworm, early instar larvae overwinter in small silk hibernacula among needles of the host. In early spring they begin mining in needles or buds. As they grow they exit these sites to graze on shoots and conelets. Larvae pupate in mid-summer; adults emerge shortly after, mate, and lay eggs in clumps on host needles. Eggs hatch and the young larvae construct their overwintering hibernacula. Larvae do not begin to feed until the following spring.

Western spruce budworm populations are monitored annually by BCFS Seed Pest Management staff in interior spruce seed orchards.

SEEDWORMS AND SEED MOTHS (*Cydia* spp.) About a dozen species of seedworms and seed moths occur in North America as obligate feeders on conifer seeds. Two species are common in BC: the spruce seed moth, *C. strobilella* Linnaeus, and the ponderosa pine seedworm, *C. piperana* (Kearfott) are major problems in spruce (particularly natural stands) and ponderosa pine seed production, respectively. The former occurs throughout the range of spruce in Canada. The eastern pine seedworm, *Cydia toreuta* (Groté), is common in jack, red, and other pines across eastern North America. This species and *C. strobilella* can be very destructive cone and seed insects.

Seedworm caterpillars develop entirely within cones and leave no external evidence of their feeding activity. Normally only one or a few are found in the cone feeding on seeds. Three seedworms are usually sufficient to destroy most of the seeds in a cone.

Seedworms can complete their life cycle in one year but they may undergo extended diapause for an extra year or two. Adult seedworms emerge from brood cones in early spring, mate, and lay eggs between the scales of female flowers in spruce or on the surface of second year cones in pine. Young larvae are enclosed within the developing spruce conelet or bore into the pine cone and feed on seeds through the summer. When cones are mature the larvae migrate to the cone axis to overwinter. In the spring, the larvae pupate; about two weeks later adults emerge.

CONEWORMS (*Dioryctria* spp.) Coneworms are the most important cone and seed Lepidoptera in North America. At least five species of *Dioryctria* are known in BC. Two of these, the fir coneworm, *D. abietivorella* (Groté), and the spruce coneworm, *D. reniculelloides* Mutuura and Munroe, have transcontinental distributions and feed on species of at least six genera of conifers.

A prominent pest wherever it occurs, fir coneworm is most troublesome in BC seed orchards on Douglas-fir and spruce but also occurs regularly on pine, larch, and other conifers. The spruce coneworm is not usually a problem in seed production in BC, but populations can be high in years of heavy western spruce budworm infestation.The ponderosa coneworm, *D. auranticella* (Groté), occasionally reaches high levels in ponderosa pine cones. In eastern Canada, the webbing coneworm, *D. disclusa* Heinrich, can cause major damage to jack and red pine cone crops.

All above ground portions of all ages of trees are susceptible to attack by coneworms: cones, foliage, leaders, branches, and stems. Woody tissue is usually invaded secondarily through lesions produced by regular seed orchard management techniques (grafts, pruning, bore holes, induction treatments, etc.), other mechanical injury, or damage from other insects or disease. Cones and seeds can be seriously affected (50 to 100% have been destroyed at certain sites) and stems can break as a result of coneworm damage. Cone damage is usually easily identified by obvious webbing and coarse frass on the cone surface. One larva can destroy an entire cone.

The basic biology and life cycle of the fir and most other coneworms is variable and not well known. In general, coneworms appear to have a one year life cycle but in several species there appears to be an overlap of generations. There may be two flights of adult fir coneworms, one in the spring and another in the fall. Fir coneworm may be a complex of two or more species. Larvae are active in cones from late spring to late summer.

CONE MAGGOTS (*Strobilomyia* spp.) Several species of *Strobilomyia* are of major concern in seed production in Canada. In BC, the white spruce cone maggot, *S. neanthracina* Michelsen, is probably the most important cone and seed insect in spruce, especially interior spruce. This pest is found throughout the range of spruce in Canada. Elsewhere in Canada, the larch cone maggot, *S. laricis* Michelsen, and the tamarack cone maggot, *S. viaria* (Huckett), are important problems for eastern larch, *Larix laricina* (Du Roi) K. Koch, seed production.

In eastern Canada, what has been known as *S. neanthracina* is actually two species with distinct host preferences (Turgeon and Sweeney 1993). *Strobilomyia neanthracina* is limited to white spruce, *Picea glauca* (Moench) Voss, while the black spruce cone maggot, *S. appalachensis* Michelsen, attacks black, *P. mariana* (Mill.) B.S.P., and red spruce, *P. rubens* Sargent. *Strobilomyia appalachensis* has not yet been shown to occur in BC.

Damage is caused by the cone maggot larvae tunneling around the cone axis and feeding on seeds. The larvae are obligate seed feeders and the spiral shaped tunnel is diagnostic of attack. Entire crops have been destroyed by infestations of cone maggots; one larva is usually sufficient to destroy most seeds in a cone.

The life cycle is similar for all species. Adults emerge around the time of bud elongation in the spring. Typically, most females lay single eggs on or near ovuliferous scales around the time of pollination. Eggs hatch within two weeks and larvae immediately begin tunneling through the maturing cone, feeding on developing seeds. In mid-summer, larvae bore to the surface of the cone and drop to the ground to pupate and overwinter in the litter.

The BCFS Seed Pest Management group intensively monitors interior spruce cone crops every spring for the presence of white spruce cone maggot eggs.

## OTHER INSECTS OF MINOR IMPORTANCE

CONE BEETLES Anobiid beetle larvae of *Ernobius punctulatus* (LeConte) may be found in mature or dead ponderosa pine cones in BC. Normally, they are scavengers in cones (mature or killed by other insects or disease) but can cause damage to scales and seeds. Populations can become established in debris where cones are stored or processed and can infest new crops being brought in. The presence of legs on the larvae of *Ernobius* distinguish them from the legless larvae of other cone beetles (*Conophthorus*).

PINE CONE BORERS Two species of pine cone borers (*Eucosma* spp.) are obligate cone feeders of minor importance to seed production in BC: western pine cone borer, *E. ponderosa* Powell, feeds on ponderosa pine and the lodgepole pine cone borer, *E. recissoriana* Heinrich, occurs on lodgepole and western white pine. Cone borers have an annual life cycle with adults emerging in early summer. Pupation and overwintering occur in the soil. In eastern Canada, red pine cone borer, *E. monitorana* Heinrich (on red and jack pine), and white pine cone borer, *E. tocullionana* Heinrich (on eastern white pine), can be very serious pests in seed production.

PINE NEEDLE SHEATH MINER Larvae of *Zellaria haimbachi* Busck mine in the needles of lodgepole and ponderosa pine in southern BC and sometimes cause extensive defoliation to seed orchard trees. Seed production could be affected, although it has not been documented. The life cycle is completed in a year, with larvae overwintering in needles and chewing needles off at the base and webbing up fascicles through the spring. Pupation occurs in mid-summer with adults emerging and ovipositing in late summer.

EUROPEAN PINE SHOOT MOTH *Rhyacionia buoliana* (Schiffermüller) is primarily a foliage feeder on hard pines. It affects seed production by damaging reproductive buds. In southern BC, it is sometimes a problem on lodgepole and ponderosa pine. In eastern Canada, red pine is this insect's usual host. European pine shoot moth has an annual life cycle: larvae overwinter in buds, pupation occurs in late spring, and adults emerge and lay eggs in early summer.

GALL AND AXIS MIDGES A number of species of *Kaltenbachiola* can be common in spruce seed cones in Canada. They feed on scale tissue and rarely damage the seed. The life cycle is annual. Larvae of *K. canadensis* (Felt) form galls in cone scales of white, black, and red spruce. Galls may impede seed extraction. Larvae overwinter in the galls. Most spruce species support populations of *K. rachiphaga* (Tripp). Larvae of this midge overwinter in the cone axis after spending the spring and early summer feeding on scale tissue (one larva per scale).

SPRUCE SEED MIDGE *Mayetiola carpophaga* (Tripp) is widespread across the range of spruce in North America. Damage is usually slight except when populations are high. The life cycle is completed in one year. Larvae develop singly within seeds and destroy one seed each. Each larva overwinters in a cocoon within a seed and pupates in early spring. Adults emerge in spring about the time of bud burst and lay eggs near the ovules of conelets.

CONE SCALE MIDGES Scale midge larvae (*Resseliella* spp.) often cause concern to cone collectors or seed processing technicians when they drop from stored cone sacks in large numbers. A number of species are found feeding on cone scales in spruce, pine, and larch. They often occur in considerable numbers (and in conjunction with other cone and seed pests, especially maggots) with up to half a dozen larvae or more on one scale. Damage is usually restricted to scales but seeds and sometimes cones can be killed. The life cycle is annual.

SEED MAGGOTS Most lonchaeid flies are scavengers or predators but some species of the genus *Earomyia* are commonly found in conifer cones across North America. None is considered a serious pest of seed production. *Earomyia barbara* McAlpine is found in spruce, pine, and other conifers in BC. This species may also be a predator of other cone insects but seeds are destroyed as its larvae bore through cones. Larvae drop to the soil in late summer and overwinter there as pupae.

SEED CHALCIDS Larvae of nearly a dozen species of seed chalcids (*Megastigmus* spp.) infest conifer seed in North America. Insect larvae detected in seeds by radiography are most often seed chalcids. Adult females insert their ovipositors through the cone scales and lay eggs directly into seeds. One larva develops and pupates per seed. There is no external evidence of its presence until the adult bores a hole in the seed coat and emerges the following year. In BC up to 10 per cent of seeds are often destroyed by seed chalcids (especially in Douglas-fir). Little research is directed at management of seed chalcids presently and in seed production; they are generally viewed as one of the costs of doing business.

## ACKNOWLEDGMENTS

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# INSECTS EXPLOITING SEED CONES OF *LARIX* SPP., *PICEA* SPP. AND *PINUS* SPP.: SPECIES RICHNESS AND PATTERNS OF EXPLOITATION

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## ABSTRACT

Seventy one phytophagous insects exploiting the seed cones of 15 species of *Larix*, *Picea*, and *Pinus* native to Canada were listed together with biological characteristics such as the type of insect seed-cone associations, feeding guild, and life cycle, to provide an overview of the structure and patterns of exploitation of this fauna. The fauna belongs to 6 orders: Lepidoptera (56%), Diptera (17%), Coleoptera (13%), Homoptera (13%), Hymenoptera (4%) and Hemiptera (3%). Approximately 60% of these species are specialists (i.e., feed or develop only in seed cones). Slightly more than 10% of the specialists are spermatophagous; half of the remaining species are conospermatophagous, whereas the remainder are conophagous. The proportion of species that have an exo-or endo-conophytic cycle varies among feeding guilds and host genera. In most cases, congeneric species share the same class of associations with the seed cone, belong to the same feeding guild and exhibit the same type of life cycle. Finally, the faunal uniqueness and similarities between these three conifer genera are presented.

## RÉSUMÉ

La compilation de caractéristiques biologiques telles que les associations insecte-graine, les guildes trophiques et le cycle vital des insectes phytophages exploitant les cônes des 15 espèces de *Larix* spp., *Picea* spp. et *Pinus* spp. indigènes au Canada a permis d'obtenir un aperçu de la structure et des modes d'exploitation de cette faune. La liste contient 71 espèces d'insectes, plus précisément 56% de lépidoptères, 17% de diptères, 13% de coléoptères, 7% d'homoptères, 4% d'hyménoptères et 3% d'hémiptères. Environ 60% de ces insectes sont spécialisés (c'est-à-dire qu'ils ne peuvent trouver leur nourriture ou se développer que dans les cônes) : un peu plus de 10% sont spermatophages, alors que le reste est également divisé entre conospermatophages et conophages. La proportion d'insectes ayant un cycle exo- ou endo-conophytique varient selon les guildes trophiques et les hôtes. Dans la plupart des cas, les espèces du même genre se retrouvent dans la même classe d'association avec la graine et le cône, font partie de la même guilde trophique et ont le même type de cycle biologique. On traite enfin des particularités et des similitudes de la faune entomologique de ces trois genres de conifères.

## INTRODUCTION

Most insects exploiting the seed cones of commercially important conifers native to Canada have already been identified, as surveys over the past 30 years have focused almost entirely on these trees. Conversely, knowledge of the entomofauna of native conifers that are of lesser economic importance is scarce. Because insect communities of host plants, or plant parts, are usually organized in a predictable manner (Price 1984), it should be possible, based on the structure of the fauna of well surveyed conifers, to predict the fauna of those that have received little attention.

Currently, the information available on insects exploiting seed cones of native conifers is limited to descriptions of life stages and cycles, damage or impact and management options; however, a synthesis of the relationships between seed cones and their associated insect fauna is lacking. Knowledge of the structure and the type of habitat exploitation of the insect fauna is essential to establish interrelations of the organisms of the community, to appreciate the relative impact of each species, and to identify patterns that would facilitate prediction of the community composition.

Not all insects that impact on seed cone production do so "directly" by feeding or developing within them. Several species damage or kill seed cones "indirectly" by feeding on cone bearing branches or by weakening the tree. Conversely, not all insects found in seed cones feed on, or destroy, seed cones or seeds. Indeed, conifer seed cones can be inhabited by insects that are **phytophagous** (feed on plants), **mycophagous** (feed on fungi), **saprophagous** (feed on decaying matter) and **entomophagous** (feed on insects, i.e., parasitoids and predators). Furthermore, feeding galleries created by phytophagous insects occasionally serve as hibernating sites for other insects (Roques 1991).

In this paper, I present a list of all phytophagous insects that have been reported to "directly" damage seed cones of all species of larch (*Larix* spp.), spruce (*Picea* spp.), and pine (*Pinus* spp.) native to Canada, together with their association with the seed cone, their feeding guild and type of life cycle. The phytophagous insects associated with seed cones are referred to as either **conophytes** (insects that feed or develop only in seed cones) or **heteroconophytes** (insects that feed or develop in other habitats such as foliage, shoots and twigs, cone bearing twigs and bark, but feed or develop in seed cones when these are available) (Turgeon *et al.* 1994). There are three patterns of habitat exploitation or feeding guilds: **conophages** (insects that feed on cones and bract tissues usually without damaging the seed directly, although some species may damage seeds); **conospermatophages** (insects that consume cone and seed tissues moving from seed to seed in a clear, discriminate pattern); and,

**Table 1.** **Biological characteristics of the phytophagous insects exploiting seed-cones of the *Larix* spp., *Picea* spp. and *Pinus* spp. native to Canada**

| Order / Family / Species | Host genus | Association[a] | Feeding guild[b] | Life cycle[c] | References |
|---|---|---|---|---|---|
| **Coleoptera** | | | | | |
| Anobiidae | | | | | |
| *Ernobius bicolor* | *Picea* | C | Cp | En | Schooley 1981; Sweeney *et al.* 1993 |
| *Ernobius nigrans* | *Pinus* | C | Cp | ? | Hedlin *et al.* 1980 |
| *Ernobius pallitarsis* | *Pinus* | C | Cp | ? | Hedlin *et al.* 1980 |
| *Ernobius punctulatus* | *Pinus* | C | Cp | En | Hedlin *et al.* 1980 |
| *Ernobius schedli* | *Picea* | C | Cp | En | Sweeney *et al.* 1993 |
| Scolitydae | | | | | |
| *Conophthorus coniperda* | *Pinus* | C | Cp | En | Hedlin *et al.* 1980 |
| *Conophthorus ponderosae* | *Pinus* | C | Cp | En | Hedlin *et al.* 1980 |
| *Conophthorus resinosae* | *Pinus* | C | Cp | Ex | Hedlin *et al.* 1980; de Groot 1991 |
| Trogositidae | | | | | |
| *Tenebroides* sp. | *Picea* | H | Cp | - | Prévost 1986 |
| **Diptera** | | | | | |
| Anthomyiidae | | | | | |
| *Strobilomyia appalachensis* | *Picea* | C | Csp | Ex | Michelsen 1988; Turgeon & Sweeney 1993 |
| *Strobilomyia laricis* | *Larix* | C | Csp | Ex | Michelsen 1988 |
| *Strobilomyia macalpinei* | *Larix* | C | Csp | Ex | Michelsen 1988 |
| *Strobilomyia neanthracina* | *Picea* | C | Csp | Ex | Michelsen 1988; Turgeon & Sweeney 1993 |
| *Strobilomyia viaria* | *Larix* | C | Csp | Ex | Michelsen 1988 |
| Cecidomyiidae | | | | | |
| *Asynapta hopkinsi* | *Pinus* | C | Cp | Ex | Hedlin *et al.* 1980; Gagné 1989 |
| *Kaltenbachiola canadensis* | *Picea* | C | Cp | En | Hedlin *et al.* 1980; Gagné 1989 |
| *Kaltenbachiola rachiphaga* | *Picea* | C | Cp | En | Hedlin *et al.* 1980; Prévost 1986;Gagné 1989 |
| *Mayetiola carpophaga* | *Picea* | C | Sp | En | Hedlin *et al.* 1980; Gagné 1989 |
| *Plemeliella* sp. | *Picea* | C | Sp | En | Gagné 1989; Turgeon (unpuplished data) |
| *Resseliella* sp. | *Larix, Picea, Pinus* | C | Cp | Ex | Hedlin *et al.* 1980; Gagné 1989 |
| Lonchaeidae | | | | | |
| *Earomyia aquilonia* | *Larix* | C | Csp | Ex | Hedlin *et al.* 1980; Amirault 1989 |
| **Hemiptera** | | | | | |
| Coreidae | | | | | |
| *Leptoglossus occidentalis* | *Pinus* | H | P | - | Hedlin *et al.* 1980 |
| Scutellaridae | | | | | |
| *Tetyra bipunctata* | *Pinus* | H | P | - | Hedlin *et al.* 1980; Turgeon & de Groot 1992 |
| **Homoptera** | | | | | |
| Aphididae | | | | | |
| *Mindarus abietinus* | *Picea* | H | Cp | - | Prévost 1986 |
| *Mindarus* sp. | *Picea* | H | Cp | - | Sweeney (pers. comm.) |
| Phylloxeridae | | | | | |
| *Adelges cooleyi* | *Picea* | H | Cp | - | Hedlin *et al.* 1980 |
| *Adelges lariciatus* | *Larix* | H | Cp | - | Hedlin *et al.* 1980 |
| *Adelges laricis* | *Larix* | H | Cp | - | Hedlin *et al.* 1980 |
| **Hymenoptera** | | | | | |
| Torymidae | | | | | |
| *Megastigmus albifrons* | *Pinus* | C | Sp | En | Hedlin *et al.* 1980 |
| *Megastigmus atedius* | *Picea, Pinus* | C | Sp | En | Hedlin *et al.* 1980 |
| *Megastigmus laricis* | *Larix* | C | Sp | En | Hedlin *et al.* 1980 |

**Table 1. Cont'd**

| Order<br>Family<br>Species | Host genus | Association[a] | Feeding guild[b] | Life cycle[c] | References |
|---|---|---|---|---|---|
| **Lepidoptera** | | | | | |
| Blastobasidae | | | | | |
| *Holcocerina immaculella* | *Larix, Picea, Pinus* | C | Cp | En | Amirault 1984; Hedlin *et al.* 1980; Prévost 1986; Ruth 1980 |
| Cochylidae | | | | | |
| *Henricus fuscodorsanus* | *Larix, Picea* | C | Csp | Ex | Hedlin *et al.* 1980 |
| Coleophoridae | | | | | |
| *Coleophora laricella* | *Larix* | H | Cp | - | Prévost 1994 |
| Gelechiidae | | | | | |
| *Coleotechnites atrupictela* | *Picea* | H | Cp | - | Prévost 1986 |
| *Coleotechnites blastovora* | *Picea* | H | Cp | - | Prévost 1986 |
| *Coleotechnites laricis* | *Larix* | H | Cp | - | Amirault 1984; Prévost 1986 |
| *Coleotechnites piceaella* | *Picea* | H | Cp | - | Prévost 1986 |
| Geometridae | | | | | |
| *Eupithecia albicapitata* | *Picea* | C | Csp | Ex | Hedlin *et al.* 1980; Turgeon & de Groot 1992 |
| *Eupithecia columbrata* | *Picea* | C | Csp | Ex | Hedlin *et al.* 1980; Turgeon & de Groot 1992 |
| *Eupithecia mutata* | *Picea* | C | Csp | Ex | Hedlin *et al.* 1980 |
| *Eupithecia spermaphaga* | *Pinus* | C | Csp | Ex | Hedlin *et al.* 1980 |
| *Hypagyrtis piniata* | *Larix* | H | Cp | - | Amirault 1984 |
| Pyralidae | | | | | |
| *Dioryctria abietivorella* | *Larix, Picea, Pinus* | C | Cp | Ex | Hedlin *et al.* 1980; Turgeon & de Groot 1992; Sweeney (pers. comm.) |
| *Dioryctria auranticella* | *Pinus* | C | Cp | En | Hedlin *et al.* 1980 |
| *Dioryctria cambiicola* | *Pinus* | H | Cp | - | Lyons 1957a |
| *Dioryctria disclusa* | *Pinus* | C | Cp | En | Hedlin *et al.* 1980; Turgeon & de Groot 1992 |
| *Dioryctria pentictonella* | *Pinus* | H | Cp | - | Hedlin *et al.* 1980 |
| *Dioryctria reniculelloides* | *Larix, Picea, Pinus* | C | Cp | Ex | Hedlin *et al.* 1980 |
| *Dioryctria resinosella* | *Pinus* | ? | ? | ? | Mutuura 1982 |
| *Dioryctria rossi* | *Pinus* | C | Cp | En | Hedlin *et al.* 1980 |
| *Herculia thymetusalis* | *Picea* | H | Cp | - | Prévost 1986 |
| Tortricidae | | | | | |
| *Acleris variana* | *Picea* | H | Cp | - | Prévost 1986 |
| *Archips packardiana* | *Picea* | H | Cp | - | Prévost 1986 |
| *Archips alberta* | *Picea* | H | Cp | - | Prévost 1986 |
| *Barbara mappana* | *Picea* | C | Csp | En | Hedlin *et al.* 1980 |
| *Choristoneura fumiferana* | *Larix, Picea* | H | Cp | - | Hedlin *et al.* 1980; Amirault 1984 |
| *Choristoneura occidentalis* | *Larix, Picea* | H | Cp | - | Hedlin *et al.* 1980 |
| *Choristoneura pinus pinus* | *Pinus* | H | Cp | - | Hedlin *et al.* 1980 |
| *Choristoneura rosaceana* | *Larix, Picea* | H | Cp | - | Prévost 1986; Amirault 1984 |
| *Cydia piperana* | *Pinus* | C | Csp | En | Hedlin *et al.* 1980 |
| *Cydia strobilella* | *Picea* | C | Csp | En | Hedlin *et al.* 1980 |
| *Cydia toreuta* | *Pinus* | C | Csp | En | Hedlin *et al.* 1980 |
| *Eucosma monitorana* | *Pinus* | C | Csp | Ex | Hedlin *et al.* 1980 |
| *Eucosma ponderosa* | *Pinus* | C | Csp | Ex | Hedlin *et al.* 1980 |
| *Eucosma rescissoriana* | *Pinus* | C | Csp | Ex | Hedlin *et al.* 1980 |
| *Eucosma tocullionana* | *Pinus* | C | Csp | Ex | Hedlin *et al.* 1980 |
| *Spilonata lariciana* | *Larix* | H | Cp | - | Amirault 1984; Prévost 1994 |
| *Zeiraphera canadensis* | *Picea* | H | Cp | - | Pilon 1965; Schooley 1983 |
| *Zeiraphera improbana* | *Larix* | H | Cp | - | Prévost 1994 |
| *Zeiraphera unfortunana* | *Picea* | H | Cp | - | Turgeon (unpublished data) |

[a] C: Conophytes; H: Heteroconophytes
[b] Cp: Conophages; CSp: Conospermatophages; Sp: Spermatophages; P: Seed predator
[c] En: Endoconophytic; Ex: Exoconophytic

**spermatophages** (insects that develop entirely For within seeds) (Turgeon *et al.* 1994). Finally, the life cycles of conophytes can be categorized as either **endoconophytic** (insect that spends it's entire preimaginal development within the cone or seed) or **exoconophytic** (insect that exits the host as a mature larva) (Turgeon *et al.* 1994).

This list was used to compare the structure and the patterns of exploitations of the insect community of each host genera, and to examine for the first time the faunal uniqueness and similarities of these three host genera. This synthesis, although ecological in nature, should also assist those involved in the management of these pests by providing the necessary framework to sort biological information and knowledge in a manner that can be easily remembered. For example, all five species of cone maggots, *Strobilomyia* spp, notwithstanding the host attacked, are conophytes and conospermatophages. They all exit the cones before the seed cone is mature and pupate in the litter.

## STRUCTURE

### GENERAL PATTERNS

The structure of insect communities exploiting conifer seed cones of larch, spruce, and pine native to Canada can be described in a number of ways: the simplest are probably the number of coexisting species and the diversity of species within the seed cones. The species richness and diversity of this entomofauna are somewhat restricted. For example, the seed cones of larch are exploited by only 20 species of phytophagous insects, whereas those of spruce and pine are exploited by 35 and 29 species, respectively (Appendix 1, Fig. 1). Because several species (e.g., *Resseliella* spp., *Holcocerina immaculella*[1], *Dioryctria abietivorella* and *D. reniculelloides*) are polyphagous (i.e., exploit more than one tree genus), the total number of species known to exploit these 15 species of conifer is 71 (Table 1). There is no doubt that many more species remain undiscovered, as detailed studies like those conducted in Canada on *Larix laricina* (Du Roi) K. Koch (Amirault 1984; Prévost 1994), *P. mariana* (Mill.) B.S.P. (Prévost 1986), *P. glauca*

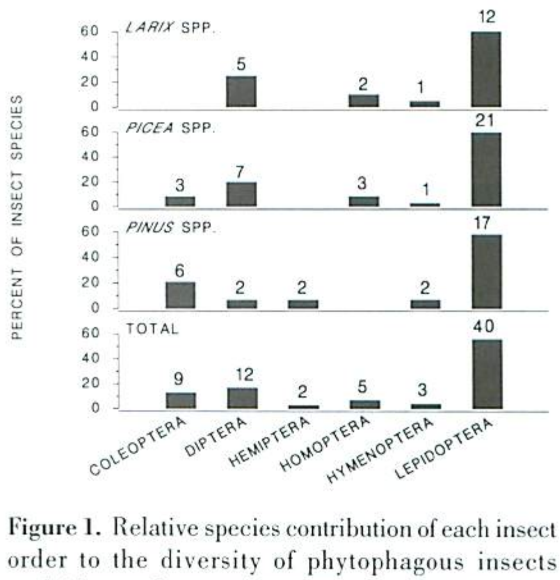


**Figure 1.** Relative species contribution of each insect order to the diversity of phytophagous insects exploiting seed cones of native species of *Larix, Picea* and *Pinus*. Note that hosts are not exploited by insects belonging to all orders.

[1] The authority of each insect species is given in Appendix 1

**Table 2. Diversity of the phytophagous insects exploiting seed-cones of *Larix* spp, *Picea* spp. and *Pinus* spp. native to Canada**

| ORDER | Number of families | Name of family | Number of genera | Number of species |
|---|---|---|---|---|
| COLEOPTERA | 3 | Anobiidae | 1 | 5 |
| | | Scolytidae | 1 | 3 |
| | | Trogositidae | 1 | 1 |
| DIPTERA | 3 | Anthomyiidae | 1 | 5 |
| | | Cecidomyiidae | 5 | 6 |
| | | Lonchaeidae | 1 | 1 |
| HEMIPTERA | 2 | Coreidae | 1 | 1 |
| | | Scutellaridae | 1 | 1 |
| | | | 1 | |
| HOMOPTERA | 2 | Aphididae | 1 | 2 |
| | | Phylloxeridae | 1 | 3 |
| HYMENOPTERA | 1 | Torymidae | 1 | 3 |
| LEPIDOPTERA | 7 | Blastobasidae | 1 | 1 |
| | | Cochylidae | 1 | 1 |
| | | Coleophoridae | 1 | 1 |
| | | Gelecheiidae | 1 | 4 |
| | | Geometridae | 2 | 5 |
| | | Pyralidae | 2 | 9 |
| | | Tortricidae | 8 | 19 |
| **TOTAL** | **18** | | **31** | **71** |

(Moench) Voss (Tripp and Hedlin 1956; Hedlin 1973), *Pinus banksiana* Lamb (de Groot and Fleming 1994) and *P. resinosa* Ait (Lyons 1956, 1957a, 1957b, 1957c), are lacking for several species such as *Larix occidentalis* Nutt. and *L. lyallii* Parl., *Picea engelmanii* Parry, *P. rubens* Sarg. and *P. sitchensis* (Bong.) Carr., and *Pinus rigida* Mill. and *P. strobus* L. Furthermore, there are no known records of insects exploiting native species such as *Pinus flexilis* James, and *P. albicaulis* Engelm.

Approximately 60% of the entomofauna are Lepidoptera, no matter which host they exploit (Fig. 1). The remainder belong to 5 orders: Coleoptera, Diptera, Hemiptera, Homoptera, and Hymenoptera (Table 1). There are no reports of any of the remaining orders of phytophagous insects (Collembola, Orthoptera, Phasmida, and Thysanoptera) exploiting seed cones of these conifer species in Canada, although some Thysanoptera have been reported on pines in other parts of the world (Hedlin *et al.* 1980; Turgeon *et al.*

**Table 3. Species richness for each genus of phytophagous insects exploiting seed-cones of *Larix* spp., *Picea* spp. and *Pinus* spp. native to Canada**

| No. of Species/genus | Genus (Order[a]) |
|---|---|
| 1 | *Tenebroides* (C), *Asynapta, Earomyia, Mayetiola, Plemeliella, Resseliella* (D), *Leptoglossus, Tetyra* (He), *Acleris, Barbara, Coleophora, Henricus, Herculia, Holcocerina, Hypagyrtis, Spilonata* (L) |
| 2 | *Kaltenbachiola* (D, *Mindarus* (Ho), *Archips* (L) |
| 3 | *Conophthorus* (C), *Adelges* (Ho), *Megastigmus* (Hy), *Cydia, Zeiraphera* (L) |
| 4 | *Choristoneura, Coleotechnites, Eucosma, Eupithecia* (L) |
| 5 | *Ernobius* (C), *Strobilomyia* (D) |
| 8 | *Dioryctria* (L) |

[a] C, Coleoptera; D, Diptera; He, Hemiptera; Ho, Homoptera; Hy, Hymenoptera; L, Lepidoptera

1994). The number of families, genera and species in each insect order is relatively low, except for Lepidoptera, which have the greatest richness at each level (Table 2). Typically, each of the 18 families of phytophagous insects is composed of one genus (Table 2). Notable exceptions are the Cecidomyiidae, which have five, and the Tortricidae, which have eight. Furthermore, more than 90% of the families have less than 10 species. Again the Tortricidae is the only exception with 19 known species. A total of 61% of the genera are represented by two species or less (Table 3): the exceptions are *Ernobius* and *Conophthorus* (Coleoptera), *Strobilomyia* (Diptera), *Megastigmus* (Hymenoptera), and, *Choristoneura*, *Cydia*, *Dioryctria*, *Eucosma* and *Eupithecia* (Lepidoptera). Interestingly, most of the genera with more than two species are characterized by species that can greatly affect seed production.

## CONOPHYTES

The diversity of conophytes is much more limited than that of the entire phytophagous fauna and is confined to four orders: Coleoptera, Diptera, Hymenoptera, and Lepidoptera (Fig. 2). Although the Lepidoptera and the Diptera are the most important overall, 45% and 30% respectively, differences exist between the 3 host genera (Fig. 2). For larches, the Diptera are the most abundant conophytes whereas for spruces, conophytes are almost equally divided between Diptera and Lepidoptera and for pines, more than 55% of the conophytes are Lepidoptera. Furthermore, some host genera have a less diversified entomofauna than others. For example, the pines and spruces are exploited by insects belonging to all four orders whereas larches are not: there are no known Coloeptera exploiting larch seed cones.

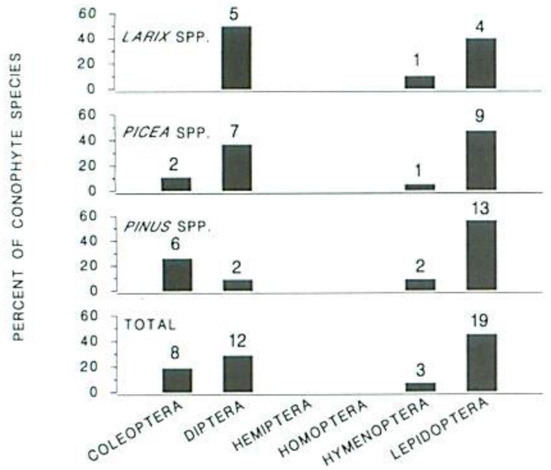


**Figure 2.** Relative species contribution of each insect order to the diversity of conophytes exploiting seed cones of native species of *Larix, Picea* and *Pinus*. Note that Hemiptera and Homoptera have no conophytes and that the relative contribution and importance of the Lepidoptera to this fauna is lower than that of the phytophagous fauna indicating that several Lepidoptera are heteroconophytes.

## HETEROCONOPHYTES

The diversity of heteroconophytes is limited almost exclusively to the Hemiptera, Homoptera and Lepidoptera (Table 1); there is only one species of Coleoptera. The majority of the heteroconophytes also belong to the Lepidoptera. Slightly more than half of the Lepidoptera exploiting seed cones of larch, spruce and pine are heteroconophytes. Conversely, all hemipteran and homopteran species are heteroconophytes.

## COMPARISON WITH STRUCTURE OF EUROPEAN FAUNA

The species richness of the phytophagous entomofauna of conifers native to Canada, although restricted to only three host genera, is similar to that obtained for conifers from western Europe by Roques (1991). According to Roques (1991), the limited species richness of phytophagous insects is an indication of a relatively stable seed cone-insect relationship, whereas the limited diversity suggest that the speciation process within seed cones has been limited to a few genera of insects. Interestingly, most of the genera exploiting the seed cones of larches, spruces, and pines in Canada (e.g., *Ernobius, Strobilomyia, Eucosma, Cydia, Dioryctria, Eupithecia*, etc.) are the same as those found in Europe. One exception is the lack of *Conophthorus* spp. on European pines.

# PATTERNS OF EXPLOITATION

## ASSOCIATIONS

Approximately 60% of the phytophagous insects of native larches, spruces and pines are specialists that feed and develop only in seed cones (Fig. 3). This proportion is slightly lower than the 71% of conophytes reported for the indigenous conifers of Western Europe (Roques 1991), but indicates nonetheless that the entomofauna of conifer seed cones is exploited predominantly by conophytes. The proportion of conophytes however, differs markedly among host genera (Fig. 3). For example, on larch and spruce, 50% and 56% of the insects are conophytes, respectively. On pine however, this proportion is higher than 80%.

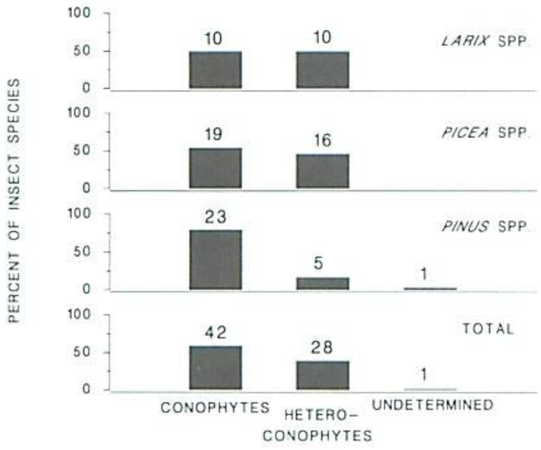


**Figure 3.** Relative importance of the cono- and hetero-conophyte fauna. The number of species is indicated on top of each bar.

Except for the *Dioryctria*, which has conophyte and heteroconophyte species, congeneric species share the same type of associations, even if they exploit different host genera (Table 1). Similar observations were reported for insects exploiting the conifers of western Europe (Roques 1991).

## FEEDING GUILDS

Conophytes and heteroconophytes exploit seed cones differently. All heteroconophytes are conophages (Table 1), except *Leptoglossus corculus* and *Tetyra bipunctata* (Hemiptera), which are considered seed predators, as both species feed upon the seed but do not develop in the cone (Hedlin *et al.* 1980). Conversely, all three feeding guilds (conophages, conospermatophages and spermatophages) are represented in the conophytes. Overall, slightly more than 10% of the conophyte fauna are spermatophages, whereas the proportion of conospermatophages and conophages is 45% and 43%, respectively. Deviations from this pattern exist between the three host genera; the proportion of conophages exploiting pines (61%) is twice that of the conospermatophages (30%) (Fig. 4). The presence of all three guilds on each host genera can be viewed as the result of an evolutionary process that led to the complete utilization of the seed cone as a unique habitat (Roques 1991).

The relative importance of the spermatophages (25%) exploiting the conifers of western Europe, though lower than the conospermatophages (40%) and conophages (32%) (Roques 1991), is almost twice that

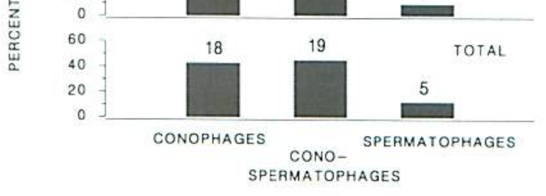


**Figure 4.** Relative importance of the number of conophytes belonging to each feeding guild.

observed in Canada. This disparity may be related to the number of native host genera studied, five for western Europe versus three for Canada, or to the host genera studied as differences in the relative importance of each guild exist between host genera.

Congeneric species of conophytes belong to the same guild irrespective of the host they exploit. For example, all *Conophthorus* spp. are conophages, all *Strobilomyia* spp, *Cydia* spp. and *Eucosma* spp. are conospermatophages, whereas all *Megastigmus* spp. are spermatophages. Because similar conclusions were reported by Roques (1991) in his study of conifers from western Europe, it is more than likely that this pattern applies to the entire community of world conifer seed cones.

## LIFE CYCLES

The proportion of species that exhibit exo- and endo-conophytic cycles varies substantially among the three feeding guilds (Fig. 5). All spermatophages (100%) and most conophages (68%) have an endoconophytic cycle, whereas the majority of conospermatophages (80%) have an exoconophytic cycle. Endoconophytic species overwinter as diapausing larvae or pupae within the brood cone or seed (de Groot *et al.* 1994; Roques 1983) still attached to the tree or on the ground, whereas exoconophytic species usually overwinter in the duff beneath the tree or on the tree, mostly as diapausing pupae (e.g., *Strobilomyia* spp.) or mature larvae (e.g., *Dioryctria* spp), and rarely as adults (e.g., *Conophthorus* spp.) (de Groot *et al.* 1994). Most exoconophytic species exit at the time of seed fall, except *Strobilomyia* spp., which leave half way through seed cone development (de Groot *et al.* 1994).

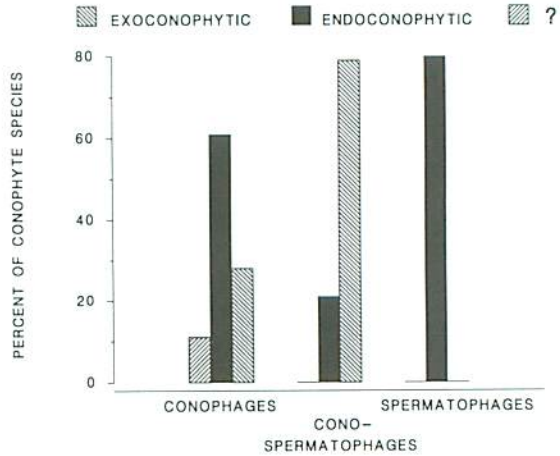


**Figure 5.** Relative importance of each type of life cycle (endo- and exo-conophytic) amoung each of the feeding guilds of conophytes.

The proportion of species with exo- and endo-conophytic cycles varies also between host genera (Table 4). Most insects exploiting larches (including polyphagous species) are exoconophytic, whereas the majority of those exploiting spruces and pines are endoconophytic. The smaller size and the faster decomposition rate of eastern larch cones, could possibly be responsible for this variation between hosts.

Conophytes belonging to the same genus usually have similar life cycles irrespective of the host it exploits. For example, all *Strobilomyia* spp., *Eucosma* spp, and

**Table 4. Number of conophytes exploiting seed cones of *Larix* spp., *Picea* spp., and *Pinus* spp. native to Canada that have endo- or exo-conophytic life cycles**

| Type of life cycle | HOST | | | | | |
|---|---|---|---|---|---|---|
| | *Larix* | *Picea* | *Pinus* | *Larix-Picea* | *Picea-Pinus* | *Larix-Picea-Pinus* |
| Exoconophytic | 4 | 5 | 7 | 1 | 0 | 3 |
| Endoconophytic | 1 | 8 | 9 | 0 | 1 | 1 |
| Undetermined | 0 | 0 | 2 | 0 | 0 | 0 |
| **TOTAL** | 5 | 13 | 18 | 1 | 1 | 4 |

*Eupithecia* are exoconophytic, whereas all the *Cydia* spp. and *Megastigmus* spp. are endoconophytic. The only notable exceptions are *Conophthorus resinosae*, which overwinters in shoots, whereas the other species of *Conophthorus* remain in the cones, and *Dioryctria* spp. which either remain in the cones or leave cones to pupate.

To date there are no recognizable patterns in the life cycles of heteroconophytes, even for species of the same family, other than they rarely complete larval development in the cone. When this occurs however, larvae exit the cone to pupate.

## FAUNAL UNIQUENESS AND SIMILARITIES

The next step was to examine the entire conophyte fauna reported thus far and to identify insect genera and species that appear typical of congeneric conifers (Table 5). For example, all species of larches were exploited by one to two species of *Strobilomyia*, and one to two species of *Dioryctria*. Based on other reports, (Roques 1991), it is likely that all species of larch native to Canada are also exploited by at least one species of *Megastigmus*. Spruces are exploited by one species of *Strobilomyia*, one to two species of *Kaltenbachiola* and other Cecidomyiidae, one species of *Megastigmus*, one species of *Cydia*, and one to two species of *Dioryctria* and *Eupithecia*, whereas pines are attacked by one species of *Conophthorus*, one species of *Cydia*, one to two species of *Dioryctria*, one species of *Eucosma*, and one species of *Holcocerina*.

This typical fauna is not definitive, as it is based only on the Canadian entomofauna. Nonetheless, it certainly provides a framework to predict the fauna of conifers that belong to these genera but that have not been studied yet. This approach also offers an opportunity to examine the uniqueness and similarities between the fauna of these conifers.

### UNIQUENESS

The conophyte fauna of each tree genus considered in this study has some degree of

**Table 5. Typical conophyte entomofauna of *Larix* spp., *Picea* spp. and *Pinus* spp. native to Canada**

| HOST | Family | Genus | Number of species | Feeding guild | Life cycle |
|---|---|---|---|---|---|
| ***LARIX*** | Diptera | *Strobilomyia* | 1-2 | Conospermatophage | Exoconophytic |
| | | Cecidomyiidae | 1 | Conophage | Endoconophytic |
| | Hymenoptera | *Megastigmus* | 1 | Spermatophage | Endoconophytic |
| | Lepidoptera | *Dioryctria* | 1-2 | Conophage | Exoconophytic |
| ***PICEA*** | Diptera | *Strobilomyia* | 1 | Conospermatphage | Exoconophytic |
| | | *Kaltenbachiola* | 1-2 | Conophage | Endoconophytic |
| | | Cecidomyiidae | 1-2 | Spermatophage | Endoconophytic |
| | Hymenoptera | *Megastigmus* | 1 | Spermatophage | Endoconophytic |
| | Lepidoptera | *Cydia* | 1 | Conospermatophage | Endoconophytic |
| | | *Dioryctria* | 1-2 | Conophage | Exoconophytic |
| | | *Eupithecia* | 1-2 | Conospermatophage | Exoconophytic |
| ***PINUS*** | Coleoptera | *Conophthorus* | 1 | Conophage | Exo- or Endoconophytic |
| | Lepidoptera | *Cydia* | 1 | Conospermatophage | Endoconophytic |
| | | *Dioryctria* | 1-2 | Conophage | Exo- or Endoconophytic |
| | | *Eucosma* | 1 | Conospermatophage | Exoconophytic |
| | | *Holcocerina* | 1 | Conophage | Endoconophytic |

uniqueness. For example, *Pinus* is the only genus exploited by *Conophthorus* and *Eucosma* spp., whereas *Picea* is the only one colonized by *Kaltenbachiola* and *Eupithecia* spp. (Table 5). There is a strong possibility however, that the degree of faunal uniqueness at the insect genus level, might be lower than is presently observed, especially if other conifer genera native to Canada were considered. The faunal uniqueness at the insect species level is much higher as most species limit their exploitation to a single host genus (Table 1).

Some level of uniqueness can be observed among the heteroconophyte fauna. For instance, only pine seed cones are attacked by Heteroptera whereas only those of spruces and larches are exploited by Homoptera.

### SIMILARITIES

Similarities between the conophyte fauna of these three conifer genera also exist. For example, all species of larch, spruce and pine were colonized by one to two species of *Dioryctria* (Table 5). Larch and spruce seed cones were both colonized by *Strobilomyia* and *Megastigmus* and one to two species of Cecidomyiidae, whereas those of pine and spruce were both colonized by only one, though different, species of *Cydia*.

## CONCLUSIONS

From this study it is clear that the species richness and diversity of the phytophagous fauna of larch, spruce and pine seed cones or seeds native to Canada is limited to a few insect genera and highly specific. Although species may differ between Canada and Eurasia, the genera exploiting seed cones however, remain the same.

The structure and the patterns of exploitation of this fauna are also similar to those previously reported for congeneric conifers (Stadnitsky 1971; Roques 1991). Indeed, most of the insect species exploiting seed cones of these conifers are specialists (i.e., must develop in seed cone to survive) as evidenced by the higher proportion of conophytes over heteroconophytes. Several species possess similar biological characteristics and share similar relationships with the seed cone. Usually, congeneric species of insects share the same type of association with the cone (e.g., cono- and hetero-conophyte) belong to the same feeding guild, have the same type of life cycle and use the same strategy (e.g., extended diapause or other) to compensate for the temporal fluctuations in cone abundance. This structure varies slightly among host genera.

For those involved in the management of insects damaging conifer seed cones, detailed information on pest identification, life cycles, and damage or impact can be difficult to remember, and sometimes confusing. This overview should make it easier to remember biological information on specific pests or group of pests.

## ACKNOWLEDGEMENTS

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**Appendix 1.** **Phytophagous insects exploiting seed-cones of *Larix* spp., *Picea* spp., and *Pinus* spp. native to Canada and their impact[a] on seed production[b]**

| Species[c] | Common name[d] | *Larix* *laricina* | *Larix* *lyallii* | *Larix* *occidentalis* | *Picea* *engelmannii* | *Picea* *glauca* | *Picea* *mariana* | *Picea* *rubens* | *Picea* *sitchensis* | *Pinus* *banksiana* | *Pinus* *contorta* | *Pinus* *monticola* | *Pinus* *ponderosa* | *Pinus* *resinosa* | *Pinus* *rigida* | *Pinus* *strobus* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Coleoptera** | | | | | | | | | | | | | | | | |
| *Conophthorus coniperda* (Schwarz) | White pine cone beetle | . | . | . | . | . | . | . | . | . | . | . | . | . | . | S |
| *Conophthorus ponderosae* Hopkins | Ponderosa pine cone beetle | . | . | . | . | . | . | . | . | . | L | L | S | . | . | . |
| *Conophthorus resinosae* Hopkins | Red pine cone beetle | . | . | . | . | . | . | . | . | S | . | . | . | S | . | . |
| *Ernobius bicolor* White | | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Ernobius nigrans* Fall | | . | . | . | . | . | . | . | . | . | L | . | . | . | . | . |
| *Ernobius pallitarsis* Fall | | . | . | . | . | . | . | . | . | . | . | . | L | . | . | . |
| *Ernobius punctulatus* (LeConte) | Douglas-fir cone beetle | . | . | . | . | . | . | . | . | . | . | . | L | . | . | . |
| *Ernobius schedli* Brown | | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Tenebroides* sp. | Cadelle | . | . | . | . | . | U | . | . | . | . | . | . | . | . | . |
| **Diptera** | | | | | | | | | | | | | | | | |
| *Asynapta hopkinsi* Felt | Cone resin midge | . | . | . | . | . | . | . | . | . | L | . | L | ? | . | . |
| *Earomyia aquilonia* McAlpine | | U | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Kaltenbachiola canadensis* (Felt) | Spruce cone gall midge | . | . | . | . | U | L | . | . | . | . | . | . | . | . | . |
| *Kaltenbachiola rachiphaga* (Tripp) | Spruce cone axis midge | . | . | . | L | L | L | L | . | . | . | . | . | . | . | . |
| *Mayetiola carpophaga* (Tripp) | Spruce seed midge | . | . | . | ? | O | L | . | ? | . | . | . | . | . | . | . |
| *Plemeliella* sp. | | . | . | . | . | . | U | . | . | . | . | . | . | . | . | . |
| *Resseliella* sp. | | L | . | . | . | . | L | . | . | L | . | . | L | . | . | . |
| *Strobilomyia appalachensis* Michelsen | Black spruce cone maggot | . | . | . | . | . | S | U | . | . | . | . | . | . | . | . |
| *Strobilomyia laricis* Michelsen | Larch cone maggot | S | . | O | . | . | . | . | . | . | . | . | . | . | . | . |
| *Strobilomyia macalpinei* Michelsen | Alpine larch cone maggot | U | U | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Strobilomyia neanthracina* Michelsen | White spruce cone maggot | . | . | . | S | S | . | . | S | . | . | . | . | . | . | . |
| *Strobilomyia viaria* (Huckett) | Tamarack cone maggot | S | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Hemiptera** | | | | | | | | | | | | | | | | |
| *Leptoglossus occidentalis* Heidemann | Western conifer seed bug | . | . | . | . | . | . | . | . | . | U | U | U | . | . | . |
| *Tetyra bipunctata* (Herrich-Schäffer) | Shield-backed pine seed bug | . | . | . | . | . | . | . | . | L | . | . | . | U | U | U |
| **Homoptera** | | | | | | | | | | | | | | | | |
| *Adelges cooleyi* (Gilette) | Cooley spruce gall adelgid | . | . | . | . | L | . | . | . | . | . | . | . | . | . | . |
| *Adelges lariciatus* (Patch) | Spruce gall adelgid | U | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Adelges laricis* Vallot | Pale spruce gall adelgid | U | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Mindarus abietinus* Koch | Balsam twig aphid | . | . | . | . | . | U | . | . | . | . | . | . | . | . | . |
| *Mindarus* sp. | Spruce twig aphid | . | . | . | . | U | U | . | . | . | . | . | . | . | . | . |
| **Hymenoptera** | | | | | | | | | | | | | | | | |
| *Megastigmus albifrons* Walker | A ponderosa pine seed chalcid | . | . | . | . | . | . | . | . | . | . | . | U | . | . | . |
| *Megastigmus atedius* Walker | Spruce seed chalcid | . | . | . | U | U | U | O | . | . | . | . | . | . | . | U |
| *Megastigmus laricis* Marcovitch | Larch seed chalcid | U | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Lepidoptera** | | | | | | | | | | | | | | | | |
| *Acleris variana* (Fernald) | Eastern blackheaded budworm | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Archips packardiana* (Fernald) | Spring spruce needle moth | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Archips alberta* (McDonnough) | | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Barbara mappana* Freeman | | . | . | . | . | L | . | . | . | . | . | . | . | . | . | . |

**Appendix 1. Cont'd**

| Species[c] | Common name[d] | *Larix* laricina | *Larix* lyallii | *Larix* occidentalis | *Picea* engelmannii | *Picea* glauca | *Picea* mariana | *Picea* rubens | *Picea* sitchensis | *Pinus* banksiana | *Pinus* contorta | *Pinus* monticola | *Pinus* ponderosa | *Pinus* resinosa | *Pinus* rigida | *Pinus* strobus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lepidoptera cont'd** | | | | | | | | | | | | | | | | |
| *Choristoneura fumiferana* (Clemens) | Spruce budworm | O | . | . | . | O | O | O | . | . | . | . | . | . | . | . |
| *Choristoneura occidentalis* Freeman | Western spruce budworm | . | . | O | O | O | . | . | . | . | . | . | . | . | . | . |
| *Choristoneura pinus pinus* Freeman | Jack pine budworm | . | . | . | . | . | . | . | . | O | L | . | . | L | . | . |
| *Choristoneura rosaceana* (Harris) | Obliquebanded leaf roller | U | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Coleotechnites atrupictela* (Dietz) | | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Coleotechnites blastovora* (McLeod) | | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Coleotechnites laricis* (Freeman) | Orange larch tube maker | L | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Coleotechnites piceaella* (Kearfott) | Orange spruce needle miner | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Coleophora laricella* (Hubner) | Larch case bearer | U | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Cydia piperana* Kearfott | Ponderosa pine seed worm | . | . | . | . | . | . | . | . | . | . | . | S | . | . | . |
| *Cydia strobilella* (L.) | Spruce seed moth | . | . | . | S | S | O | L | O | . | . | . | . | . | . | . |
| *Cydia toreuta* (Groté) | Eastern pine seed worm | . | . | . | . | . | . | . | . | L | L | . | . | L | . | . |
| *Dioryctria abietivorella* (Groté) | Fir cone worm | L | . | ? | . | L | O | ? | . | L | L | O | L | L | . | L |
| *Dioryctria auranticella* (Groté) | Ponderosa pine coneworm | . | . | . | . | . | . | . | . | . | . | . | O | . | . | . |
| *Dioryctria cambiicola* (Dyar) | Western pine moth | . | . | . | . | . | . | . | . | . | U | . | . | . | . | . |
| *Dioryctria disclusa* (Heinrich) | Webbing coneworm | . | . | . | . | . | . | . | . | O | . | . | . | O | O | . |
| *Dioryctria pentictonella* Mutuura, Munroe and Ross | | . | . | . | . | . | . | . | . | . | . | . | U | . | . | . |
| *Dioryctria reniculelloides* Mut. & Mun. | Spruce coneworm | U | . | . | L | O | O | L | L | ? | L | . | . | . | . | . |
| *Dioryctria resinosella* Mutuura | | . | . | . | . | . | . | . | . | . | . | . | . | U | . | . |
| *Dioryctria rossi* Munroe | | . | . | . | . | . | . | . | . | . | . | . | U | . | . | . |
| *Eucosma monitorana* Heinrich | Red pine cone borer | . | . | . | . | . | . | . | . | U | . | . | . | O | . | . |
| *Eucosma ponderosa* Powell | A ponderosa pine cone borer | . | . | . | . | . | . | . | . | . | . | . | L | . | . | . |
| *Eucosma rescissoriana* Heinrich | Lodgepole pine cone borer | . | . | . | . | . | . | . | . | . | L | L | . | . | . | . |
| *Eucosma tocullionana* Heinrich | White pine cone borer | . | . | . | . | . | . | . | . | . | . | . | . | . | . | L |
| *Eupithecia albicapitata* Packard | | . | . | . | U | U | U | . | . | . | . | . | . | . | . | . |
| *Eupithecia columbrata* McDunnough | | . | . | . | . | U | . | . | U | . | . | . | . | . | . | . |
| *Eupithecia mutata* Pearsall | Spruce cone looper | . | . | . | . | U | . | . | . | . | . | . | . | . | . | . |
| *Eupithecia spermaphaga* (Dyar) | Fir cone looper | . | . | . | . | . | . | . | . | . | . | L | L | . | . | . |
| *Henricus fuscodorsanus* (Kearfott) | Cone cochylid | . | . | L | . | L | . | . | L | . | . | . | . | . | . | . |
| *Herculia thymetusalis* (Walker) | | . | . | . | . | . | L | . | . | . | . | . | . | . | . | . |
| *Holcocerina immaculella* (McDonnough) | | U | . | . | . | . | L | . | . | L | L | . | . | L | . | . |
| *Hypagyrtis piniata* (Packard) | Pine looper | U | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Spilonata lariciana* Heinrich | Brown larch tube maker | L | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Zeiraphera canadensis* Mut. and Free. | Spruce bud moth | . | . | . | . | L | . | . | . | . | . | . | . | . | . | . |
| *Zeiraphera improbana* (Walker) | Larch bud moth | U | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Zeiraphera unfortunana* Powell | | . | . | . | . | L | . | . | . | . | . | . | . | . | . | . |

[a] The impact is either of low (L), significant (S), occasionally significant (otherwise low) (O), or unknown or undetermined (U) importance. "?" indicates a possible host.
[b] Modified and updated from de Groot *et al.* 1994.
[c] As given by Yates (1986).
[d] As given by Benoit (1985) or in other published material.

# PEST DAMAGE TO SEED ORCHARD TREES

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## ABSTRACT

Pest surveys of Ontario seed orchards were conducted between 1990 and 1992. Black spruce, white spruce and jack pine were assessed twice annually for pest incidence and damage to foliage and woody tissue. Armillaria root rot was considered the most damaging disease in both black and white spruce orchards, causing up to 6% annual mortality. The eastern spruce budworm was the most common insect in spruce seed orchards affecting up to 100% of the trees in some orchards but causing generally low levels of defoliation during the study period. White pine weevil occurred in 65% of black spruce orchards causing leader damage on up to 20% of the trees. Weevil and the eastern pine shoot borer were also observed in all jack pine orchards surveyed. Weevil affected up to 10% of the trees while the shoot borer damaged terminals and lateral branches on up to 35 % of the trees. Diseases were not found at damaging levels on jack pine. The occurrence of other pests and the value of pest surveys in Ontario seed orchards are also discussed.

## RÉSUMÉ

De 1990 à 1992, on a recensé les ravageurs dans des vergers à graines. Ainsi, deux fois par année, on a évalué l'incidence des ravageurs et les dégâts causés au feuillage et au tissu ligneux chez l'épinette noire, l'épinette blanche et le pin gris. Les observations ont révélé que, dans les vergers d'épinettes noires et blanches, le pourridié-agaric, qui peut causer jusqu'à 6% de la mortalité annuelle, est la maladie la plus dommageable. La tordeuse des bourgeons de l'épinette est l'insecte le plus commun dans les vergers à graines d'épinettes : dans certains vergers, jusqu'à 100% des arbres étaient touchés, mais la tordeuse n'a en général causé qu'une faible défoliation durant la période d'étude. On a trouvé le charançon du pin blanc dans 65% des vergers d'épinettes noires; cet insecte, qui endommage la pousse apicale, a attaqué jusqu'à 20% des arbres. On a également observé le charançon et le perce-pousse du pin dans tous les vergers de pins gris. Jusqu'à 10% des arbres étaient touchés par le charançon; quant au perce-pousse, qui endommage les branches terminales et latérales, il a attaqué jusqu'à 35% des arbres dans certains vergers. Chez le pin gris, aucune maladie n'a atteint un stade assez avancé pour causer des dégâts. Il est également question des autres ravageurs observés et de l'intérêt des recensements dans les vergers à graines de l'Ontario.

## INTRODUCTION

Seed orchards have become an important management tool for tree improvement. Because of the initial investment and intensive management required, seed orchards are arguably the most expensive tree plantations in Canadian forestry. After orchard establishment, pests can have an impact on the health and survival of trees. To date, most effort has concentrated on cone and seed pests because of their obvious impact on seed production. Excellent summaries of these pests have been produced (e.g., Churcher *et al.* 1985; Hedlin *et al.* 1980; Sutherland *et al.* 1987; Turgeon and de Groot 1992). On the other hand, the impact of insects and diseases affecting foliage and woody tissue in orchards have received less attention. Insects and diseases can kill trees or can affect cone and seed production by decreasing tree vigour, destroying vegetative and reproductive buds, and causing branch mortality.

In Ontario, seed orchard establishment on a large scale is a recent phenomenon, with most orchards being established in the 1980s. Presently, there are a total of 68 seed orchards in the province representing approximately 600 ha of managed plantations (Nitschke and Wanner 1994). The issue of the general effect of pests on seed orchard trees in Ontario has not been previously investigated. To address this shortage of information, the Forest Insect and Disease Survey (FIDS) undertook a three-year survey of Ontario seed orchards to develop an inventory of pest problems on trees and determine their relative abundance and ability to cause damage in seed orchards. The survey reported here is unique in its scope and distribution and could serve as a model for further pest surveys in seed orchards. Other formats for extensive and intensive surveys however, might be equally or more applicable to pest problems in orchards. These options and their potential for monitoring pest activity in seed orchards are discussed.

## METHODS

Twenty eight orchards comprised of 16 black spruce, eight white spruce, and four jack pine, were randomly selected for evaluation in 1990 (Fig. 1). Orchards were distributed across northern Ontario from North Bay to the Manitoba border. The survey was conducted over three field seasons, 1990 to 1992, and consisted of two evaluations each year. The first visit occurred in mid-June followed by a second visit in late July or early August. In each orchard 150 trees (10 transects of 15 trees each) were evaluated. The majority (22) of seed orchards evaluated were established between 1982 and 1986. However, several older orchards established in 1959 (2) and from 1970-1975 (4) were also included. Each sample tree was assessed for the incidence of insects and diseases and for levels of defoliation or woody tissue damage caused by the pest. For non-foliar pests such as armillaria root rot, *Armillaria* spp.,

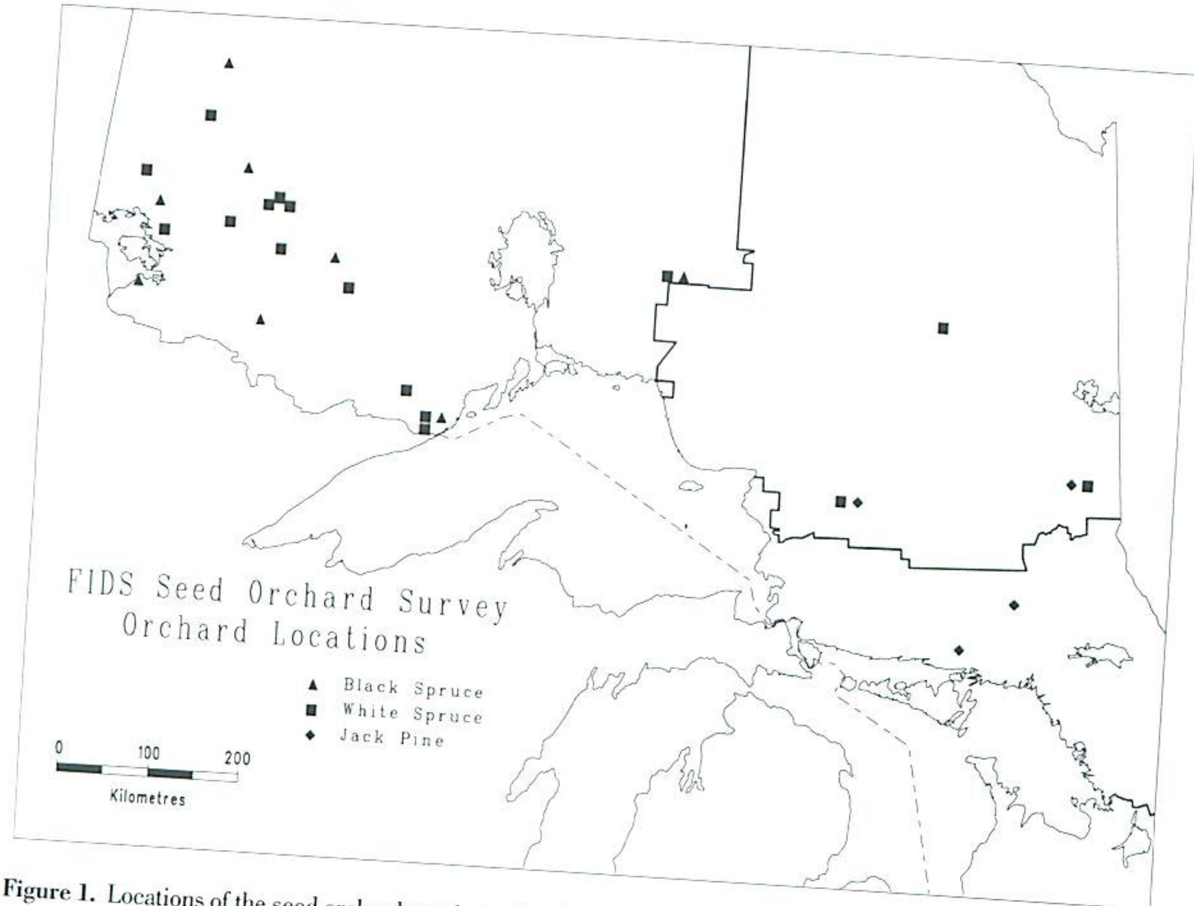


**Figure 1.** Locations of the seed orchards evaluated by the Forest Insect and Disease Survey- Ontario, 1990-1992.

diplodia tip blight, *Sphaeropsis sapinea* (Fr) Dyko and B. Sutton, the white pine weevil, *Pissodes strobi* Peck, eastern pine shoot borer, *Eucosma gloriola* Heinrich, red pine cone beetle, *Conophthorus resinosae* Hopkins, spruce cone rust, *Chrysomyxa pirolata* Wint., or western gall rust, *Endocronartium harknessii* (J.P. Moore) Y. Hirat., damage levels (Figs. 2, 4, 6) were assessed on the basis of incidence (trace-light damage = 1-5% trees affected, moderate-severe damage = >5% trees affected). For defoliating pests such as the eastern spruce budworm, *Choristoneura fumiferana* (Clemens), jack pine budworm, *Choristoneura pinus pinus* Freeman, spruce bud moth, *Zeiraphera canadensis* Mutuura and Freeman, spruce coneworm, *Dioryctria reniculelloides* Mutuura and Munroe, yellow-headed spruce sawfly, *Pikonema alaskensis* Rohwer, spruce needle rusts, *Chrysomyxa ledicola* Lagh., and *C. ledi* By., pine needle rust, *Coleosporium asterum* (Diet.) Syd., needle casts, *Davisomycella* sp. and *Lophodermium* sp., and frost, damage was based on average defoliation levels (trace-light damage = 1-25%, moderate-severe damage = > 25%).

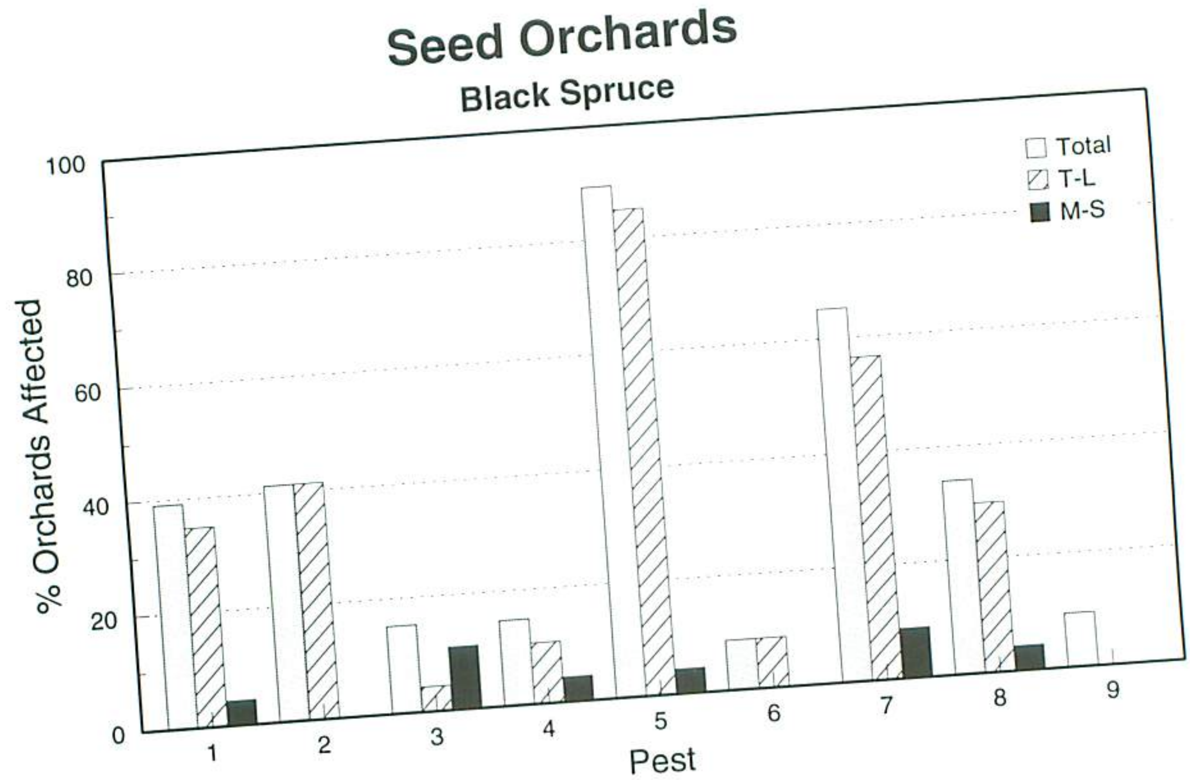


**Figure 2.** Frequency of pest occurrence and damage levels in black spruce seed orchards (1990-1992). Pests: 1, *Armillaria*; 2, spruce needle rust; 3, diplodia; 4, frost; 5, spruce budworm; 6, spruce coneworm; 7, white pine weevil; 8, yellow-headed spruce sawfly; 9, spruce bud moth.

## RESULTS OF SURVEYS

### BLACK SPRUCE SEED ORCHARDS

ARMILLARIA ROOT ROT Tree mortality caused by *Armillaria* was evident in 39% of the orchards (Fig. 2). Generally, less than 1% of the trees in these orchards were affected annually by *Armillaria*, although annual mortality reached 6% in some orchards in 1990 and 1992 (Fig. 3). Whitney (1988) found an average rate of *Armillaria*-induced mortality of 2% in young black spruce plantations. In his plantations the maximum annual mortality rate was 5%, similar to that found in the seed orchards covered by this survey.

Stress is considered an important factor in predisposing trees to *Armillaria* (e.g., Wargo and Harrington 1991), although some species are considered able to attack healthy trees. This disease usually causes tree mortality when orchard trees suffer prolonged period of stress. *Armillaria* can rapidly spread throughout sections of the orchard because of the proximity of trees and frequent root grafting. The disease generally spreads from its initial location, usually previously infected stumps, through root contact or by rhizomorph production (Redfern and Filip 1991). *A. ostoyae* [Romagn.] Herink, the most common species in northern Ontario (Dumas 1988), is a highly pathogenic species that shows more limited rhizomorph production. This species likely spreads predominantly through root contact. It is seldom widespread in a stand and is usually evident by pockets of tree mortality. The best method to control this disease is to establish orchards on previously untreed sites such as agricultural fields, which seldom contain significant amounts of inoculum (Sutherland 1991). If site selection is limited, inoculum reduction or disease control is possible through stump removal and site preparation (Morrison 1981), in addition to other silvicultural and non-silvicultural procedures (Hagle and Shaw 1991). Once the disease is established in an orchard some workers (e.g., Sutherland 1991) recommend the complete removal of the diseased tree and the associated root system. A pest specialist should be contacted to evaluate the situation prior to commencing control measures.

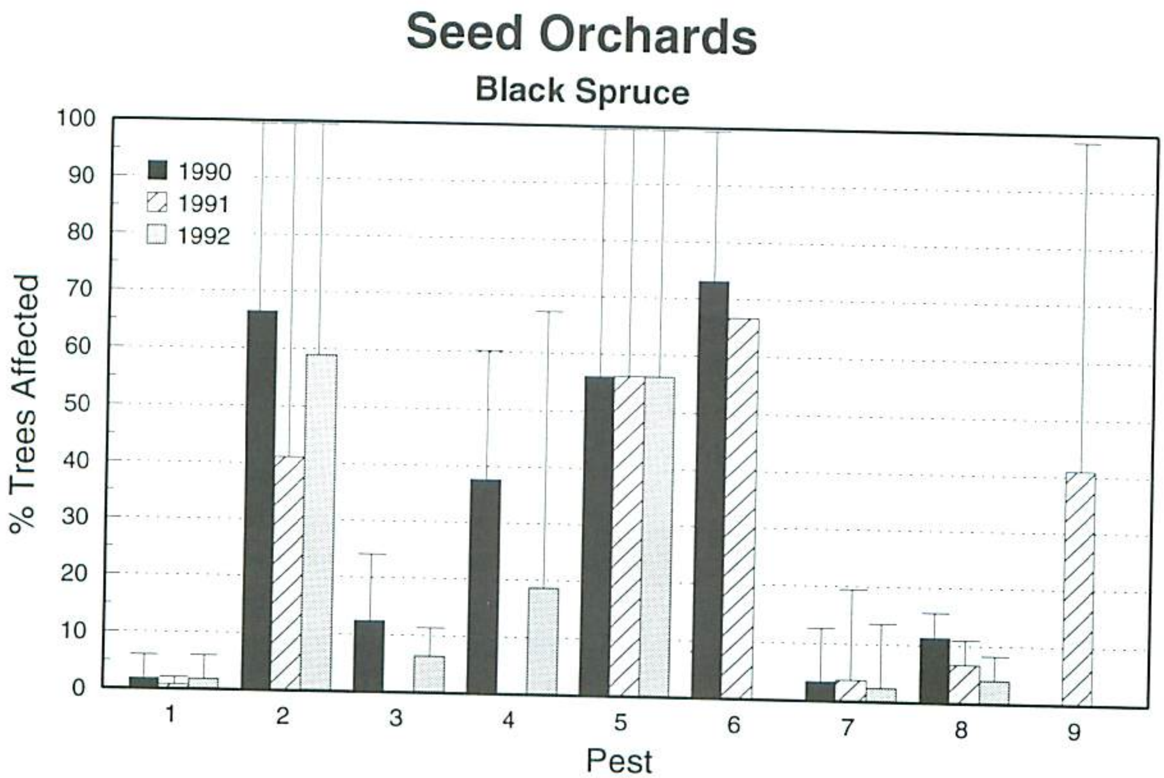


**Figure 3.** Average annual incidence of pests in affected black spruce seed orchards. Note: Bars mark the maximum pest incidence. Pests: 1, *Armillaria*; 2, spruce needle rust; 3, diplodia; 4, frost; 5, spruce budworm; 6, spruce coneworm; 7, white pine weevil; 8, yellow-headed spruce sawfly; 9, spruce bud moth.

SPRUCE NEEDLE RUST This disease was observed in 41% of the evaluations (Fig. 2). In affected orchards incidence of needle rust was high in all years with up to 100% of trees being affected (Fig. 3). Defoliation however, was rated at only trace to light levels (Fig. 2). This rust has been previously documented as causing severe defoliation during moist years (e.g., Ingram *et al.* 1991), but impact is generally considered minimal and control is only justified under epidemic situations (Ziller 1974). Infection can be prevented by establishment of orchards away from swampy areas where the alternate host *Ledum* sp. occurs. While it is not necessary for *Ledum* sp. to exist within the orchard, it is generally accepted that it must exist in sufficient quantity within 1 km of the stand.

DIPLODIA TIP BLIGHT This disease was recently reported for the first time on black spruce in Ontario (Myren 1991). Diplodia was evident in 15% of the orchards. Damage was assessed at moderate to severe levels in 11% of the orchards (Fig 2.). In affected orchards, diplodia infected an average of 12% and 7% of the trees in 1990 and 1992, respectively, with infection levels as high as 24% (Fig. 3). The disease, which typically causes a tip blight, can kill significant portions of the upper stem of the tree. The disease can be particularly damaging to trees exposed to stress such as wounding, drought or poor site conditions (Nicholls and Ostry 1990). Sanitation involving the removal of diseased branches and severely affected trees apparently controlled the disease as it was not detected in previously affected orchards in 1991. However, the disease reappeared in three additional orchards in 1992. In pines, seed cones can serve as an important source of inoculum (Palmer *et al.* 1988), but *S. sapinea* has to date not been found associated with black spruce cones, thus making their removal in orchards affected by this disease unnecessary.

FROST Frost damage to new foliage was evident in 15% of the orchards (Fig 2). Damage was assessed at trace to light levels in 11% of the evaluations, having little effect on the tree. Its impact on cone production was not evaluated. Moderate to severe damage was evident in 4% of the evaluations (Fig.2). In one orchard, frost damaged as many as 60-67% of the trees in 1991 (Fig 3).

Frost damage generally occurs on new foliage, although direct damage to black spruce cones has been reported (West 1986). The occurrence of frost and the extent of damage are often related to exposure and topography. Site selection and the avoidance of depressions and north facing slopes and flat plateaus, where reduced air flow is more likely, are simple control measures (Stathers 1989). In addition, site preparation techniques that increase air movement on the site, and ploughing of the soil to incorporate the organic horizon and increase soil heat storage (e.g., Bjor and Sandvik 1984) have been found to be effective.

EASTERN SPRUCE BUDWORM This budworm was the most common pest in black spruce orchards. It was found in 89% of the evaluations (Fig. 2) and the average incidence of the pest in affected orchards was consistently between 50% and 60% over the three-year survey, with up to 100% of the trees in a given orchard infested (Fig. 3). Although damage to orchard trees is potentially high when the insect is at epidemic levels, only 4% of the orchards received moderate to severe levels of defoliation during the study (Fig. 2).

Low levels of defoliation, while not affecting tree vigor, can reduce future cone crops (Schooley 1980). In addition, heavy defoliation is known to inhibit cone production for up to several years (Powell 1973). The spruce budworm can also be a serious pest of cone crops on spruce. Previous studies conducted on black spruce in Ontario (Prévost *et al.* 1988; Syme 1981) revealed that the spruce budworm was the most damaging insect of pollen- and seed-cones. This defoliator feeds initially on closed buds and pollen cones when available, then on the expanding structures as the season progresses (Rose and Linquist 1977). The impact of spruce budworm on black spruce survival and vigour is uncertain at this time. In forest situations, pure stands of black spruce (lowland or plantation) generally survive budworm outbreaks as compared to mixed-wood stands (Howse 1981). Control measures should be considered either when heavy defoliation or loss of reproductive structures is observed, or when a severe outbreak is observed in the surrounding area.

SPRUCE CONEWORM This insect was found in 9% of orchards (Fig. 2). The incidence of infection was considered high in 1990 and 1991 (Fig. 3). Up to 100% of the trees in affected orchards were infested with spruce coneworm (Fig. 3) in 1990 although defoliation was rated at trace to light levels (Fig. 2). In 1992, spruce coneworm was not detected; earlier work has suggested that populations are related to the availability of cones (McLeod and Daviault 1963). Most orchards surveyed were not yet producing cones or only had light cone crops. This likely accounts for the low populations in most orchards. In each orchard, the pest was found in association with spruce budworm, making it difficult to determine its impact on the host tree. However, unlike spruce budworm, this coneworm is not considered a serious defoliator, although it has been found to cause significant damage to cone crops (e.g., Prévost *et al.* 1988; Syme 1981).

WHITE PINE WEEVIL This pest was evident in 65% of the evaluations. Its incidence in affected orchards, and damage levels, were generally low (Figs. 2, 3), although moderate to severe damage was evident in 9% of the evaluations (Fig. 2). Within affected orchards, an average of 3% of the trees were affected each year, although up to 20% of the trees were found to be affected in one orchard

(Fig. 3). This insect can reduce cone crops on young trees (2-3 m) when the leader is attacked. Damaged terminals can also allow fungal pathogens to enter the tree causing further damage (Martineau 1984). The impact of this weevil on black spruce, particularly in orchards, is unclear, although cones near the leader were frequently destroyed because of the weevil. Most published accounts of this insect concern its association with white pine, on which it is considered to be the major insect problem (e.g., Lavallée 1992a). FIDS surveys in plantations suggest that weevil on black spruce is less prevalent on trees over 6 m in height, which is consistent with observations on white pine. Conversely, this reinforces the general belief that smaller open grown trees such as those in seed orchards are at greater risk. Control of weevil through mechanical or chemical means should be considered in young black spruce orchards.

YELLOW-HEADED SPRUCE SAWFLY This sawfly was detected every year and in 34% of the evaluations (Fig. 2), although the incidence in affected orchards never exceeded 15% (Fig. 3). Damage was generally at the trace to light levels, although moderate to severe defoliation was evident in 4% of the evaluations (Fig. 2). Severe and repeated defoliation can result in loss of tree vigor and mortality. Yellow-headed spruce sawflies feed first on current year needles and then on previous years foliage and can defoliate trees completely. Total defoliation is common on young spruce (0.5-2.0 m) in Ontario (e.g., Evans *et al.* 1992). Generally though, infestations are short in duration and are confined to small areas (Martineau 1984). The insect prefers open-grown trees and concentrates its attack on previously defoliated trees (Ives and Wong 1988), increasing the likelihood of damage to orchard trees.

SPRUCE BUD MOTH This tortricid was detected in 9% of the evaluations (Fig. 2), but in 1991 affected up to 99% of the trees in affected orchards (Fig. 3). The damage caused by this pest was not determined. Typically, larvae of the spruce bud moth feed on young needles under the budcap and also on the cortical tissue of shoots. This latter activity results in a weakening, bending and sometimes breakage of the shoot.

Feeding activity is concentrated in the upper crown and on the leader (Turgeon 1992). This insect also feeds on pollen- and seed-cones of black spruce (Schooley 1983). The economic impact of this insect in black spruce orchards is uncertain but possibly minimal as the insect is most often associated with white spruce and only occasionally with other conifers (Rose and Linquist 1977; Carrow 1985).

## WHITE SPRUCE SEED ORCHARDS

ARMILLARIA ROOT ROT This disease was detected in 17% of the evaluations (Fig. 4) over the three-year period. On average, 1-3% of the trees were killed by *Armillaria* annually

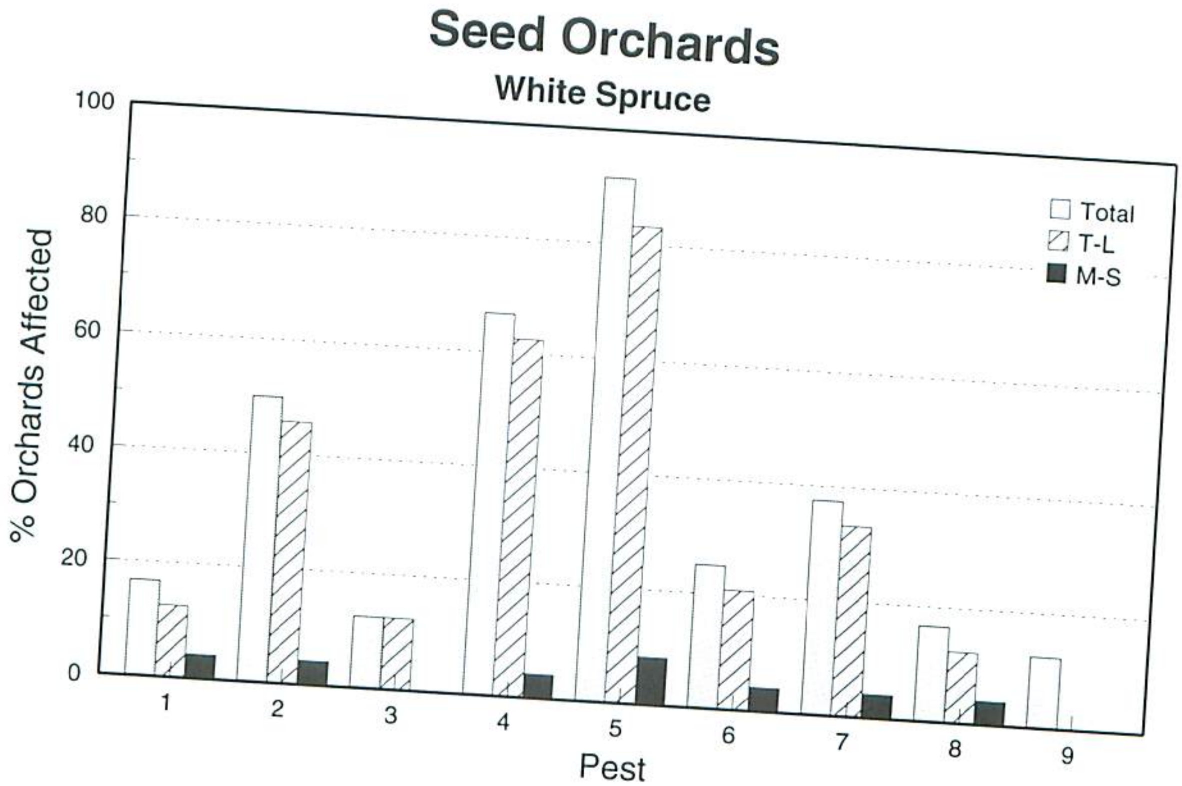


**Figure 4.** Frequency of pest occurrence and damage levels in white spruce seed orchards (1990-1992). Pests: 1, *Armillaria*; 2, spruce needle rust; 3, spruce cone rust; 4, frost; 5, spruce budworm; 6, spruce coneworm; 7, white pine weevil; 8, yellow-headed spruce sawfly; 9, spruce bud moth.

in affected orchards (Fig. 5), with up to 5.0% mortality in one orchard. Whitney (1988) noted an annual average mortality of 1% in young white spruce plantations affected by this rot. He also noted that black and white spruce were more susceptible than jack pine. In our survey of spruce and pine, the highest damage levels also occurred in spruce orchards. As in black spruce, the disease is one of the main causes of mortality in white spruce orchards and has good potential for spread after it is established.

SPRUCE NEEDLE RUST This organism was observed in 50% of the orchards (Fig. 4). Up to 100% of the trees were infected, although average values were between 21-40% in affected orchards (Fig. 5). The defoliation caused by the disease was generally rated at trace to light levels (Fig. 4). Its impact is usually not significant but epidemic levels should be controlled. While epidemics are not common, they have been reported over large areas where high populations of *Ledum* exist (e.g., McBeath 1986).

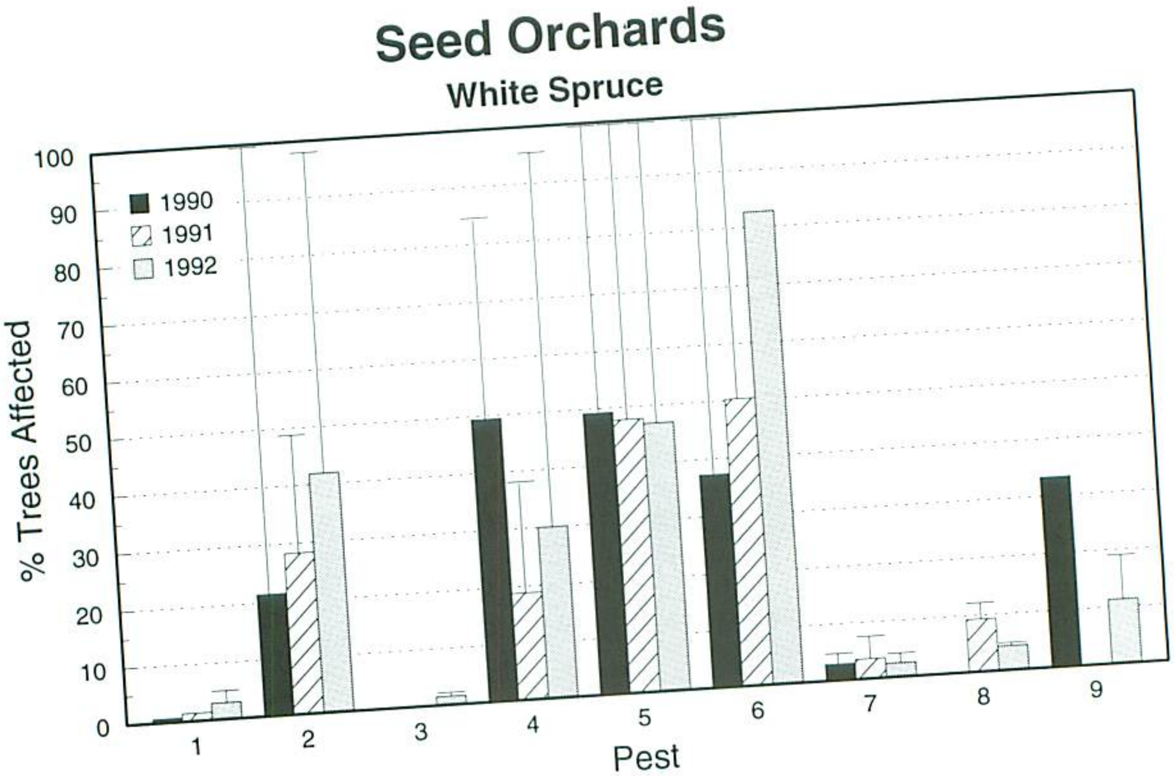


**Figure 5.** Average annual incidence of pests in affected white spruce seed orchards. Note: Bars mark the maximum pest incidence. Pests: 1, *Armillaria*; 2, spruce needle rust; 3, spruce cone rust; 4, frost; 5, spruce budworm; 6, spruce coneworm; 7, white pine weevil; 8, yellow-headed spruce sawfly; 9, spruce bud moth.

SPRUCE CONE RUST This rust was found in 13% of the evaluations at trace to light levels (Fig. 4). It was recorded only in 1992 and was found to infect a maximum of 2% of the trees (Fig. 5). This disease is considered as one of the major cone diseases by many pathologists and can significantly reduce cone crops (Sutherland *et al.* 1987). Singh and Carew (1990) observed sporadic and localized epidemics of cone rust on black and white spruce in Newfoundland. These infections resulted in a reduction of available seed from these areas. Although the spruce cone rust can infect both white and black spruce, it was not observed on the latter during this survey. The disease has been reported throughout much of northern Ontario, particularly in the Great Lakes region during annual FIDS surveys. Although high levels of infection have not been commonly recorded in this province, they do occur sporadically (McPherson *et al.* 1982). Routine monitoring of cone crops, in areas where the disease is present, is recommended. Like the spruce needle rust, the cone rust alternates between an alternate host (*Pyrola* spp.) and the spruce, and can disperse over several kilometers. Avoidance of areas containing the alternate host is the best control measure against this pest. Other methods of control exist (Sutherland 1991), but are usually impractical. A pest specialist should be consulted to discuss control options in spruce orchards where the disease is evident or in high risk areas, near the Great Lakes.

FROST Frost damage to new foliage was observed in 67% of the orchards evaluated, although damage was generally rated at trace to light levels (Fig. 4). Within affected orchards, 19-49% of the trees were damaged between 1990 and 1992, although up to 95% could be affected (Fig. 5). The incidence of frost damage was greater than in black spruce, but damage levels did not differ greatly. Generally, white spruce is considered to be more susceptible to frost damage than either black spruce or jack pine (e.g., Lavallée 1992b), and greater care should be given to reducing frost incidence.

EASTERN SPRUCE BUDWORM This insect was the most common pest found in white spruce orchards, infesting 92% of the sites (Fig. 4). The incidence of budworm was high every year, with up to 100% of the trees infested (Fig. 5). As in black spruce orchards, only a minority of the orchards (8.3%) showed moderate to severe levels of defoliation (Fig. 4), although the potential for significant damage exists.

SPRUCE CONEWORM This coneworm was observed in 25% of the evaluations and was associated with moderate to severe defoliation in 4% of the surveys (Fig. 4). Within affected orchards the incidence of coneworm damage was high every year, reaching 100% in some orchards (Fig. 5). Although damage was associated with moderate to severe defoliation in some orchards, spruce budworm was likely responsible for most of this damage as it cannot be distinguished from that caused by coneworms. Generally, coneworm larvae consume less foliage and have less effect on host vigor than spruce budworm (Ives and Wong 1988), and reportedly favour cones as a food source (Hedlin *et al.* 1980).

WHITE PINE WEEVIL Damage by this weevil was observed in 38% of the orchards (Fig. 4). Pest incidence in affected orchards was about 3%, although levels as high as 7% were found in some orchards (Fig. 5). Over the three-year survey, the weevil was found less frequently in white spruce orchards than in black.

YELLOW-HEADED SPRUCE SAWFLY This sawfly was found in less than 17% of the orchards with 4% of these sustaining moderate to severe defoliation (Fig. 4). This pest was recorded only in 1991 and 1992, affecting on average 9% and 4% of the trees, respectively (Fig. 5). The highest proportion of trees damaged was 12%. This pest affected fewer white spruce orchards than black, although damage levels in affected orchards appeared similar for both species.

SPRUCE BUD MOTH The spruce bud moth was found in 13% of the orchards (Fig. 4). This pest was observed in white spruce orchards only in 1990 and 1992. A total of 33% of the trees of one orchard were attacked in 1990, whereas in 1992 the maximum was 19% (Fig. 5). The impact of this pest is as yet uncertain in orchard and plantation situations, but pure stands of white spruce are reportedly most susceptible to vegetative feeding (Carrow 1985). The insect has also been reported to feed on white spruce pollen- and seed-cones (Pilon 1965). Carroll *et al.* (1993) determined that in white spruce, radial growth was affected only after several years of severe damage, but that crown architecture was also affected by chronic herbivory resulting in shrub-like growth. Altered crown architecture might affect cone production. Changes in crown architecture resulting from feeding by *Dioryctria albovitella* Hulst on pinyon pine reportedly caused the loss of seed cones (Whitman and Mopper 1985). Spruce bud moth populations are highest in plantations under 3 m in height and typically decline with increased tree height and crown closure (Turgeon 1992). This would suggest that white spruce orchards, which are typically open grown, would be at greater risk than those in plantations, which would normally undergo crown closure.

## JACK PINE SEED ORCHARDS

ARMILLARIA ROOT ROT *Armillaria* was observed in 42% of the orchards. Damage was always at trace to light levels (Fig. 6), as, typically, less than 1% of the trees were affected (Fig. 7). The disease killed less pines than spruces over the survey period. Whitney (1988) noted that jack pine was more resistant to root rot than either white or black spruce. He also observed that *Armillaria* caused an annual average mortality of <1% in young jack pine plantations.

PINE NEEDLE RUST This needle rust was common, occurring in 67% of the evaluations, but defoliation was at trace to light levels (Fig. 6). Pest incidence varied over the three-year survey. Abundance was highest in 1991 and 1992, when on average, more than 40% of the trees were affected (Fig. 7).

The rust is common in Ontario, but is not considered a major problem, as only heavily infected or old diseased needles are prematurely cast. Nevertheless, moderate to severe levels of infection have been periodically recorded in Ontario (e.g. MacLeod *et al.* 1989). Control of the disease should only be considered under epidemic situations. As with most rust fungi, pine needle rust requires alternation between *Aster* spp and pine (Ziller 1974). Infection of pines occurs in the late summer-early fall but is not apparent until the following spring.

WESTERN GALL RUST This disease, which can be a major problem of hard pines, affected 33% of the orchards, although only at trace to light levels (Fig. 6). Infection (branch and stem) levels were below 6% (Fig. 7).

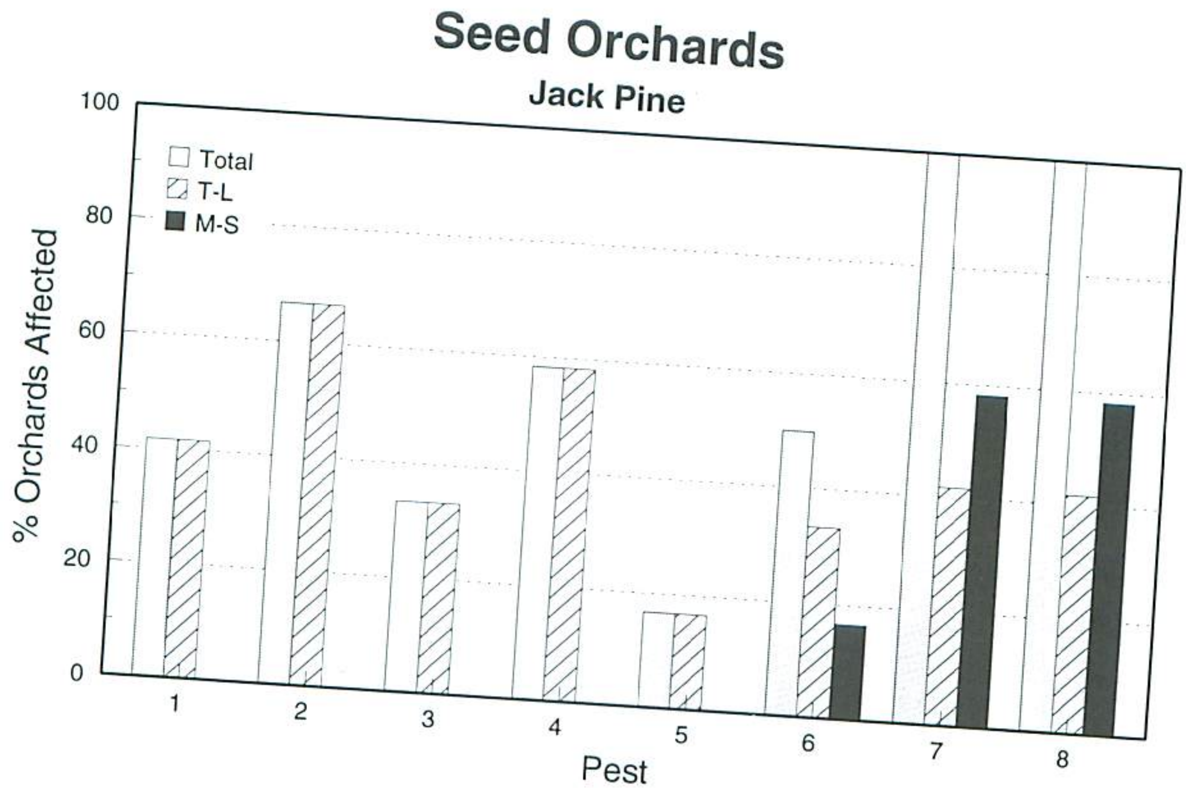


**Figure 6.** Frequency of pest occurrence and damage levels in jack pine seed orchard evaluations (1990-1992). Pests: 1, *Armillaria*; 2, pine needle rust; 3, western gall rust; 4, pine needle cast; 5, jack pine budworm; 6, red pine cone beetle; 7, white pine weevil; 8, eastern pine shoot borer.

This disease is harmful to trees only when stem infections or numerous branch infections occur. Mortality is common on young jack pine affected by stem galls (Gross 1983). Juzwik and Chong (1990) found average cumulative mortality in jack pine plantations to be 3% with the level of infection increasing up to age 10. The effect of branch galls on tree survival is more questionable. This rust does not require an alternate host (Ziller 1974). Infection occurs through young shoots resulting in galls on branches, or the main stem if the leader is infected. Galls produced by this disease are perennial and produce spores annually. This combination can result in effective spread within a stand when conditions for infection are suitable. The best control method is to avoid establishing orchards in areas where gall rust is common. Pruning of infected branches also provides an efficient control as long as the site is not surrounded by high populations of the pathogen.

PINE NEEDLE CASTS Needle casts were observed in 58% of the evaluations, but

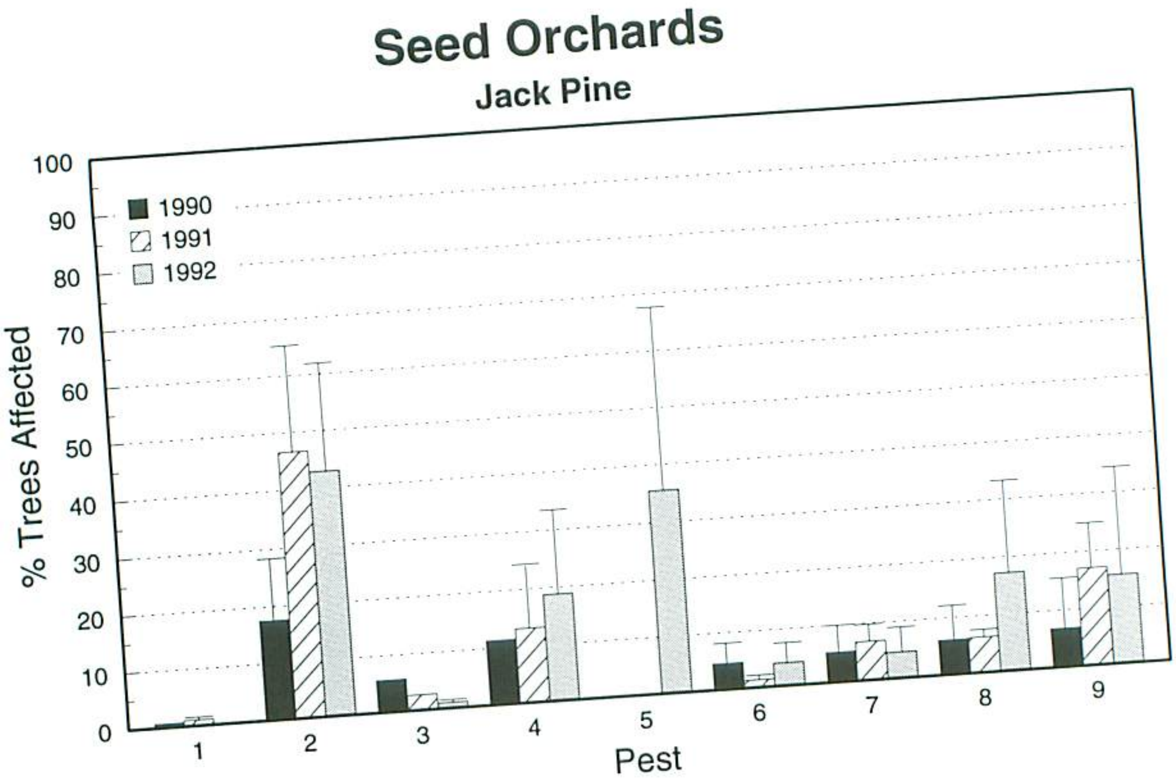


**Figure 7.** Average annual incidence of pests in affected jack pine seed orchards. Pests: 1, *Armillaria*; 2, pine needle rust; 3, western gall rust; 4, pine needle cast; 5, jack pine budworm; 6, red pine cone beetle; 7, white pine weevil; 8, eastern pine shoot borer.

caused only trace to light levels of defoliation (Fig. 6). In affected orchards, an average of 11-19% of the trees were infected; the maximum was 33% (Fig. 7). This disease, while common on jack pine, only impacts on tree health after repeated severe defoliation; control is only warranted under extreme conditions.

JACK PINE BUDWORM This insect was observed in 17% of the evaluations, but defoliation was at trace to light levels (Fig. 6). The jack pine budworm was observed only in 1992, defoliating on average 36% of the trees in infested orchards. In one orchard, 67% of the trees were affected (Fig. 7). Although outbreaks are generally short lived, the pest can cause tree mortality or loss of vigor. The survey failed to detect any significant defoliation, although the insect is known to destroy young pollen- and seed-cones. There is evidence suggesting that populations of this pest might be related to the availability of jack pine reproductive structures (Mattson *et* *al.* 1991). Routine surveillance of population levels of this insect in orchards is recommended when outbreaks are anticipated.

RED PINE CONE BEETLE This beetle was found in 50% of the orchard evaluations (Fig. 6). Damage caused to leaders was rated at moderate to severe levels in 17% of the visits (Fig. 6). The mean proportion of trees that were attacked in affected orchards varied between 1-5% (Fig. 7). This cone beetle does not kill trees and generally, does not cause significant loss of vigour. Its impact on the leader was measured, but not on the loss of cones that could result from damage to lateral and terminal branches. The insect does not usually feed on jack pine seed cone but can indirectly cause cone loss by killing twigs. Control of the organism is not required as this pest seldom causes significant damage (de Groot 1990).

WHITE PINE WEEVIL Weevil damage was recorded in all evaluations (Fig. 6). In almost 60% of these, damage was moderate to severe. The mean annual incidence in affected orchards varied between 5-7%, with the highest incidence at 10% (Fig. 7). The weevil typically affects tree form. Such damage can affect the outcome of progeny trials, but in orchards it can affect cone production.

EASTERN PINE SHOOT BORER Damage by this pest was observed at each visit (Fig. 6). Within affected orchards, between 6-17% of the trees were damaged annually. One orchard sustained damage to the lateral branches of 34% of the trees (Fig. 7). The percentage of trees sustaining leader injury was used to establish damage levels for this pest. Moderate to severe levels were recorded in 58% of the evaluations (Fig. 6). This shoot borer is most common on open grown trees (Rose and Linquist 1977) and prefers jack pine of an intermediate height class (Wong *et al.* 1966). Normally, the insect causes the greatest damage to leaders and lateral branches in the upper crown. Repeated feeding causes stunted and deformed growth (DeBoo *et al.* 1971). In our survey, the incidence of damage to laterals was equal or greater than damage to leaders each year (Fig. 7).This lateral damage might indirectly affect cone crops by causing shoot damage and mortality in addition to leader damage. Other surveys (e.g., McKeague and Simmons 1978) have found this pest at high levels and recommended pruning as a standard control measure.

## PEST SURVEYS AS APPLIED TO SEED ORCHARDS, VALUE AND LIMITATIONS

Pest surveys are an important part of seed orchard management because damage caused by insects and diseases can result in a loss of seed cones or of trees. Surveys provide information on pest populations, which is fundamental to the development of control strategies, if so required.

In Ontario, the host population in a seed orchard usually includes thousands of trees over an area of up to 10 ha. The goal of a pest survey is to estimate the size of its population and to assess its relative impact based on a relatively small number of trees. These surveys can be extensive such as the one reported here involving a number of pests and locations, or intensive, involving as little as one orchard or one pest. Extensive surveys covering large areas are not usual in seed orchards to date. However, similar surveys have been undertaken in conifer plantations by regional FIDS units (Amirault and Pope 1989; Humphreys and Van Sickle 1992). Both of these surveys used similar methodology to that employed in our work to assess the occurrence of pests and their relative damage.

Extensive surveys have limitations. For example, the methods used for the detection of insects and foliar diseases distribution and damage usually differ from those used to detect pests that cause localized infection such as root rots. Methods to quantify levels of root rot damage have been developed (e.g., Bloomberg *et al.* 1980), but should be supplementary to survey techniques used for foliar pests. Extensive surveys, such as those carried out by FIDS, also require a dedicated and significant resource in both personnel and operating budgets. These surveys do however provide overviews of pest problems and provide consistency in data collection over time.

Intensive surveys can provide detailed information on a pest or group of pests, as the methods can be tailored to suit the problem. This can involve the use of special survey techniques as for root rots, cone and seed insects (Dombrosky and Schowalter 1988) or the use of pheromones in conjunction with ground surveys for insects (e.g., Shea *et al.* 1986). Intensive surveys, local in nature, can also be carried out by local seed orchard staff, provided they have suitable training and access to a diagnostics facility. Such efforts can provide seed orchard managers with sufficient information on pest type and damage to enable them to consider the necessity of control. To be cost and biologically effective, control options should only be considered with full knowledge of the pests involved and their impact on the resource.

## SUMMARY

Seed orchard trees are often under stress, which in turn can predispose them to damage by already known pests or by agents that were never considered as pests before. Because of the value of orchards and individual orchard trees, acceptable damage levels by insects or diseases will be based on the goal set for each orchard. Churcher *et al.* (1985) suggested four basic recommendations for control of cone and seed insects that are applicable to all pests of seed orchards: i) determine what pests are involved; ii) determine the importance of the pests; iii) conduct biological studies on damaging pests where information is lacking; and iv) on the basis of the pests impact and available biological information, decide on the need for preventative or control measures.

The first step in controlling pests in seed orchards or elsewhere is to determine the pests involved at a local or regional level and the levels of damage associated with each. This survey revealed that the majority of the trees in these young seed orchards sustained only trace to light levels of damage over the three-year survey. However, some pests were found to cause significant damage in individual orchards and/or were found at high levels indicating the potential for damage to seed trees and future cone crops. Perhaps the most critical information required before control actions are contemplated is the impact of the damage to the tree on seed production. The actual impact of pests on seed orchard trees was not addressed by this survey. Pest induced mortality is an obvious impact and easy to quantify. However, the indirect impact pests have on potential cone crop is beyond the scope of this study and should be the focus of future work.

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# MONITORING CONE CROPS IN JACK PINE SEED ORCHARDS: WHY BOTHER?

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## ABSTRACT

Monitoring jack pine cone and seed crops in seed orchards is essential to accurately assess the impact of various mortality factors. Although jack pine does not suffer typical catastrophic losses from insects as do other species of pines, there are circumstances in which insects and predators such as the red squirrel can cause severe losses. Seed losses can easily be overlooked, but significant losses can occur from seed bugs and seedworms, which leave little or no external evidence of damage. An appreciation of the biological capacity of the orchard to produce seeds is an essential prerequisite to pest management.

## RÉSUMÉ

La surveillance des récoltes de cônes et de graines de pin gris dans les vergers à graines est essentielle pour l'évaluation exacte de l'impact des divers facteurs de mortalité en jeu. En effet, même si les insectes ne causent généralement pas de pertes catastrophiques chez le pin gris comme chez d'autres espèces de pins, il y a des circonstances où leurs attaques et celles de prédateurs comme l'écureuil roux peuvent entraîner des dégâts considérables. Les pertes de graines peuvent facilement passer inaperçues, mais des pertes considérables peuvent résulter des dégâts à peine visibles, sinon inexistants, causés par la tétyre biponctuée et les tordeuses séminivores des pins. Il est donc essentiel de connaître la capacité biologique à produire d'un verger à graines pour lutter contre les ravageurs susceptibles de s'y attaquer.

## INTRODUCTION

Although jack pine, *Pinus banksiana* Lamb., contributes significantly to the economy, is widely planted and artificially seeded, and is one the most important seed orchard species in Canada, the problems of cone and seed production have paradoxically received limited attention. In pine orchards, insects cause the most serious economic loss (DeBarr 1990). However, an examination of the literature on insects and diseases of jack pine cones and seeds (Hedlin *et al.* 1980; Sutherland *et al.* 1987) can lead to the notion that, in general, insect and disease problems will be infrequent. While it is comforting to note from a pest management perspective that extensive damage by the major pests belonging to the genera *Conophthorus* (cone beetles), *Dioryctria* (coneworms), *Eucosma* (cone borers) *Strobilomyia* (cone maggots), and *Cronartium* (cone rusts), have been rare or absent, this comfort should not lead to a complacence about the management of jack pine cone crops.

The purpose of this paper is to demonstrate that jack pine cone and seed losses can be severe under certain circumstances, and to discuss the importance of cone crop monitoring as a part of a crop and pest management program. Data on the known levels of damage caused by the various mortality factors is presented, followed by conjecture on their potential impact. Information about cone losses has been gathered primarily from the only cone life table studies of jack pine cones (Rauf *et al.* 1985; de Groot and Fleming 1994), references cited therein, and from references cited in Turgeon and de Groot (1992). Seed loss information has been obtained from the literature and ongoing work by the author.

To facilitate this presentation, the mortality factors are discussed relative to the development of jack pine seed cones, i.e., stage 1: pollination and early development (0–16 weeks); stage 2: seed cone dormancy (16–52 weeks), and stage 3: rapid growth and maturation of cones and seeds (52–68 weeks). The mortality factors of jack pine seeds, while occurring throughout the development of the cone, are discussed at the end of stage 3.

## CONE LOSSES

### STAGE 1

Seed cone abortion is common and is usually the most dominant mortality factor. Abortion rates of jack pine conelets have ranged from about 5 to 25%. Typically, pine abortion occurs during the first month and can be caused by inadequate pollination (Sarvas 1962), low temperatures (Hard 1963; Hutchinson and Bramlett 1964), drought stress (Rehfeldt *et al.* 1971), and insects (DeBarr and Ebel 1974; Rauf *et al.* 1984, 1985). Rauf *et al.* (1984) reported that *Platylygus luridus* (Reuter) caused up to 75% jack pine conelet abortion in a Wisconsin seed orchard. This insect has not been found in jack pine seed orchards in Canada, although it is known to occur (de Groot 1986). Seed bugs (Hemiptera) have been a major cause of conelet abortion in other pines (DeBarr and Ebel 1974; Rauf *et al.* 1984).

The jack pine budworm, *Choristoneura pinus pinus* Freeman, has caused up to 11% cone losses in jack pine seed orchards (Rauf *et al.* 1985). The damage caused to date by this insect in seed orchards is likely underrated, as it is known to cause severe damage (>80%) damage to flowers and conelets under outbreak conditions (Graham 1935). The eastern pine shoot borer, *Eucosma gloriola* Heinrich, and the red pine cone beetle, *Conophthorus resinosae* Hopkins, destroy young conelets by boring into the cone's stem. Neither has been a serious problem thus far, and are unlikely to be.

STAGE 2

This stage is a period of dormancy for cones, but serious losses can occur. To date, the experience in seed orchards indicates about 10-20% mortality during this interval. The primary causes of death are abortion and shoot-clipping by the red squirrel, *Tamiasciurus hudsonicus* (Erxleben). Shoots damaged by bark beetles in the genus *Pityophthorus* Eichhoff can also cause conelet losses [8% loss recorded by Rauf *et al.* (1985)], particularly when shoots have been damaged by squirrels or other insects. Insects that feed directly on seed cones do not contribute to losses during this stage.

STAGE 3

The red squirrel is usually the main cause of cone mortality. Red squirrels usually begin heavy feeding on jack pine cones in early September. If cones are not harvested until mid- or late-October, losses of 30% or more (of the total cone crop) are not uncommon (Rauf *et al.* 1985; de Groot and Fleming 1994). Cone predation by the red squirrel will vary from site to site and year to year, depending on the availability of other local foods (Kemp and Keith 1970). Much of the damage by the squirrel could be avoided if cones were harvested in late August or early September, before squirrels begin intensive predation, although there will be some loss in the number of viable seeds (Cecich and Rudolf 1982; West and de Groot 1990). It appears almost certain that management of red squirrel populations will be necessary in seed orchards.

Cone life table studies conducted in central Ontario, found that 3% of the cones were destroyed by the cone resin midge, *Asynapta hopkinsi* (Felt), the jack pine budworm, the red pine cone beetle, the webbing coneworm, *Dioryctria disclusa* Heinrich, the red pine cone borer, *Eucosma monitorana* Heinrich, and unknown Lepidoptera (de Groot and Fleming 1994). Rauf *et al.* (1985) found that about 13% of the cones were destroyed by these insects, the most significant of which was the red pine cone borer, which caused about 7–10% cone loss. Two other moths, the spruce coneworm, *Dioryctria reniculelloides* Mutuura and Monroe, and the fir coneworm, *D. abietivorella* (Groté), are known to feed on jack pine cones, but their primary hosts are spruce and fir (Hedlin *et al.* 1980). The diplodia tip blight, *Sphaeropsis sapinea* (Fr) (Dyko and B. Sutton) has been recorded on jack pine cones in Ontario, where the incidence of damage has been as high as 8% (Constable and Jansons 1986). Of this group of pests, the need to manage the red pine cone borer, where jack pine seed orchards are near red pine stands, and the fir coneworm appears most likely.

## SEED LOSSES

There are several ways seed is 'lost' to production. Seed loss is often assessed by quantifying the reproductive capacity of the cone (seed potential), then carefully determining what caused losses, and calculating the proportion of seeds that survived (Bramlett *et al.* 1978). Seed potential is simply twice the number of fertile scales (Lyons 1956). Seed efficiency is the number of sound (filled) seed divided by the seed potential and expressed as a percent (Bramlett and Godbee 1982). Cone analysis (*sensu* Bramlett *et al.* 1978) was conducted in Ontario on cones from three natural stands

**Table 1. Summary statistics of seed potential per cone, number of filled seed per cone, and seed efficiency for natural stands (1985-87) and seed orchards (1992) in Ontario**

| Year | Site | Seed Potential (No.) | Filled Seed (No.) | Seed Efficiency (%) |
|---|---|---|---|---|
| 1985 | Thessalon | 46 | 17 | 37 |
| 1986 | Thessalon | 56 | 25 | 45 |
| | Thessalon | 64 | 23 | 36 |
| | Espanola | 62 | 37 | 60 |
| 1987 | Thessalon | 52 | 29 | 56 |
| | Thessalon | 50 | 22 | 44 |
| | Espanola | 54 | 35 | 65 |
| 1992 | Kirkland Lake | 48 | 42 | 72 |
| | Wawa | 52 | 25 | 48 |
| | Temagami | 52 | 32 | 62 |
| | Espanola | 48 | 34 | 71 |
| | Espanola | 40 | 22 | 55 |
| | Chapleau | 50 | 27 | 54 |
| | Thunder Bay | 52 | 33 | 64 |
| | **Average** | 52 | 29 | 55 |

from 1985-87, and from 7 seed orchards in 1992 (Table 1). The seed potential of these cones ranged from 40 to 64 seeds, with an average of 52 seeds. The average yield of filled seeds per cone was 29 seeds (range 17 to 37), agrees well with the 27 filled seed per cone found by Rauf *et al.* (1985). Seed efficiency values ranged from 37 to 72% with an average of 55%.

The data from the natural stands revealed that during the first year, about 18% of the ovules failed to develop. The causes are unknown but could include pollination failure, seed bug damage, or abortion. In the second year, another 5% aborted. An average of 17% of the seed from all sites in 1985-87 and 1992 was empty. Again the exact causes remain unknown, but probably include the lethal effects of homozygous recessive genes. Seed losses by the eastern pine seed worm, *Cydia toreuta* (Groté), were low in Ontario: only about 1% of the seed was destroyed. Rauf *et al.* (1985) noted that about 6% of the seeds were destroyed by this insect in Wisconsin. Kraft (1968) found infestation rates in natural stands varied from 10 to 78% depending on the size of the cone crop. It is likely that the impact from this insect could be considerably higher in seed orchards and that this insect will be a major seed consumer in certain years, as noted recently in red pine orchards (Katovich and Kulman 1991). The western conifer seed bug, *Leptoglossus occidentalis* Heidemann, and the shield-backed pine seed bug, *Tetyra bipunctata* (Herrich-Schäffer), are known to occur in the Great Lakes region (Hedlin *et al.* 1980; McPherson *et al.* 1990; Katovich and Kulman 1987), but have not yet caused serious problems in jack pine seed orchards. It is likely that the impact of these insects will also become greater as seed orchards mature.

## DISCUSSION

The survival of jack pine cones from the time of pollination to the time of cone harvest will vary among years and sites. The data from life tables indicates that survival may be as high as 75% (de Groot and Fleming 1994) to as low as 14% (Rauf *et al.* 1985). While life table data are useful in identifying the mortality factors and their potential impact, the data can only serve as a guide to what might happen in a particular seed orchard. Monitoring systems such as the Inventory Monitoring System (Bramlett and Godbee 1982) or the Cone Crop Monitoring System (de Groot and Turgeon 1992) are based on life table methods and are of great benefit to the seed orchard manager in assessing the cone crop. Monitoring systems identify the type and time of losses for an orchard, and thus can act as an early warning system of a potential buildup of pest populations. They can also be used to help make decisions about the need for control, and can help develop more cost-effective pest management programs. An excellent account of their value, from a seed orchard managers point of view, can be found in Huffman (1988).

The data from life tables can be used to set "bench marks" or realistic levels of expectation from seed orchards: these are discussed thoroughly by Bramlett (1987). For jack pine, it is probably unrealistic to expect cone survival levels higher than 75% and seed efficiency levels higher than 75%, which means that production from the orchard achieves about 55% of its potential. This compares well with the 60% efficiency expected from a southern pine seed orchard that receives maximum protection (Bramlett 1987). Cone-to-seed orchard efficiency values below 55% indicate that improvements may be possible.

One method to make improvements is to increase flower production while holding the cone survival and seed efficiency values constant, or reduce the losses of one or more mortality factors. Another is to use the monitoring information about cone crop size to manage large crops very well, and small crops less well. Careful attention to the health and size of the cone crop by seed orchard managers will undoubtedly provide many benefits to ensure that seed production levels are set realistically and are met.

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# SAMPLING INSECTS AND PREDICTING IMPACT IN SEED ORCHARDS

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**ABSTRACT**

Methods of sampling insect pests and predicting their damage are necessary components of an integrated pest management strategy in seed orchards. This paper briefly discusses the information required to design and develop a method of predicting pest damage, and some common sources of errors in prediction. Some pest sampling methods currently used, or in development for use, in seed orchards are presented. Finally, ways that sampling methods can be made more accessible and useful to seed orchard personnel are proposed.

**RÉSUMÉ**

Dans toute bonne stratégie de lutte intégrée mise en œuvre contre les ravageurs des vergers à graines, il faut des méthodes pour échantillonner les insectes nuisibles et prévoir les dégâts. Dans cet article, on explique brièvement ce qu'il faut savoir pour concevoir et mettre au point une méthode de prévision des dégâts attribuables aux ravageurs et l'on décrit certaines des sources d'erreur courantes en prévision. On présente aussi certaines des méthodes d'échantillonnage actuellement utilisées ou en voie de développement pour les vergers à graines, et on explique enfin comment rendre les méthodes d'échantillonnage plus accessibles et utiles pour les exploitants de vergers à graines.

## INTRODUCTION

Every seed orchard manager should have a crystal ball that he or she could use to predict pest impacts, the weather, and the results of NHL playoff games. The ability to accurately forecast the potential reduction in seed yield due to an insect pest would greatly assist managers in making decisions regarding the need for pesticide applications or other pest controls. Although they are not crystal balls, sampling methods can provide managers with reasonably accurate forecasts of the amount of seed loss to expect in a given year and ensure that pest controls are applied only when necessary. Sampling can also be used to improve the timing and efficacy of control operations and to determine the efficacy of controls after they have been applied. Methods of pest sampling and damage prediction are basic components of any pest management strategy. Their primary role is to assist resource managers in decision making.

If they have so much to offer, why have pest sampling methods not been used more widely in seed orchard management to date? What can be done to make them more accessible and useful to seed orchard personnel? These questions are addressed in this paper, which is intended to provide orchard managers with an overview of sampling and damage prediction and their role in integrated pest management in seed orchards[1]. It has three objectives: i) to briefly discuss the sort of information required to design and develop a method of predicting pest damage; ii) to describe some pest sampling methods currently used in seed orchards or in development; and iii) to discuss ways that sampling methods can be made more accessible and useful to seed orchard personnel.

## DESIGNING A SAMPLING METHOD

Sampling methods must be practical if they are ever to be used operationally in seed orchard management. In other words, they must be simple, cheap, and reliable; a successful compromise of cost *versus* accuracy and consistency. They must also provide enough lead time for decisions and control actions, and should be easily integrated (or at least not conflict greatly) with other seed orchard routines. Most importantly, objectives must be clearly established through consultation with seed orchard managers before designing a sampling method. For example, orchard managers may want to know, with adequate confidence, whether or not the seed loss to insect "x" will exceed a threshold of 10 or 30%; they are probably not concerned with precise estimates of pest density.

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[1] Pheromone traps can be useful tools for sampling pests and predicting impact but they have been discussed by Grant (1994). Similarly, cone crop monitoring, has been addressed by de Groot (1994).

Development of a sampling method requires some basic knowledge of biology and ecology of the pest and the host (seeds, cones, trees) combined with practical considerations (e.g., costs of sampling *versus* value of seed), and may be broken down into four steps.

## SELECT A SUITABLE SAMPLING UNIT AND WINDOW

For seed orchard insect pests, the most appropriate sampling unit is often a cone but it could be a reproductive bud, vegetative bud, branch tip, graft union, or even a coloured sticky trap, depending on the species and life stage being sampled. Sampling should be done at the stage of insect (and host) development that provides a reliable estimate of pest density and potential seed loss, as well as providing sufficient time to take appropriate control actions to reduce seed losses. The sampling window can be specified by a range of accumulated heat units or by the developmental stage of the host (e.g., conelets 1/2 to fully pendant) if these have been determined for the insect. The chances for error are greater for sampling methods that require the collection of samples within a very short period of time, i.e., a narrow window, than for methods with a broad window. Also, a broad sampling window will result in fewer scheduling conflicts between pest sampling and other orchard management activities. For example, overwintering second-instar larvae of the spruce budworm, *Choristoneura fumiferana* (Clemens), can be sampled almost anytime in the fall or winter. On the other hand, a sampling method that required precise timing during the period when conelets were receptive would stand a slim chance of being adopted by seed orchard personnel, already busy with controlled pollination.

Obviously, the most appropriate sampling unit and window depends on the pest insect and its life cycle. For example, 3/4- to fully-pendant conelets are suitable sampling units for the spruce seed moth, *Cydia strobilella* (L.), and the spruce cone maggots, *Strobilomyia appalachensis* Michelsen and *S. neanthracina* Michelsen, which lay their eggs directly in spruce cones. However, cones are not suitable for sampling seed chalcids, *Megastigmus* spp., because their eggs are tiny and laid directly into seeds; seed dissections would be difficult and too laborious. Seed wasps, and perhaps cone maggots as well, might be sampled more easily in the adult stage using colored sticky traps, so long as the relationship between trap catch and seed loss was quantified.

## DETERMINE THE PEST'S DISTRIBUTION

The spatial and frequency distribution of the pest largely determines where and how many samples must be collected to provide relatively unbiased estimates of pest density with known precision and confidence. Pest densities are compared among aspects and crown levels within trees and among trees within sites to determine where to collect samples that are truly representative of the population.For example, there was no consistent trend in average egg density associated with aspect or crown level for the Douglas-fir cone moth, *Barbara colfaxiana* (Kearfott), so it was concluded that conelets could be collected randomly from the crown (Sweeney and Miller 1989).

The optimum number of sampling units to collect per tree can be determined by a simple formula that takes into consideration the proportion of total variation in pest density within *versus* among trees, and the costs (usually in units of time) of selecting and moving to a tree *versus* collecting a sampling unit from the tree and processing it (Southwood 1966). The minimum number of sampling units (e.g., cones) required to estimate pest density with known precision and confidence depends on the relationship between the mean and variance over a range of pest densities. Generally, as the level of infestation increases, fewer samples are required to reliably estimate the pest density. This information can be derived from the frequency distribution of the pest, i.e., whether it is aggregated, random, uniform, or binomial (i.e., there, not there).

### DETERMINE THE RELATIONSHIP BETWEEN PEST DENSITY AND DAMAGE

It is critical that estimates of pest density be translated into estimates of damage that are relevant to seed orchard managers, e.g., cone losses, percent loss of filled seed, or tree mortality. For example, the percentage of conelets infested with cone maggot eggs can be used to predict the percent loss of filled seed in a spruce seed orchard by: i) converting the estimate of percent conelets infested to a percentage of mature cones with maggot damage, using a regression developed from data collected in several sites and years; and ii) multiplying the percentage of mature cones infested by the mean percent loss of extractable filled seed per damaged cone, e.g., in white spruce, 69% fewer filled seeds are extracted from maggot-damaged cones than from healthy cones (unpublished data), so 10% loss of filled seed will result from 14-15% damaged cones (14.5 x .69).

### ESTABLISHMENT OF TREATMENT THRESHOLDS

The threshold density at which pest damage exceeds a tolerable level is calculated from the relationship between pest density and damage but should also include the efficacy of control methods, when these are known. For example, Miller (1986a), chose a critical value of 2.6 egg-infested scales to represent a 10% loss of seed due to the Douglas-fir cone gall midge, *Contarinia oregonensis* Foote, based on: i) a regression between egg-infested scales per conelet and galled seeds per cone; ii) a regression between the increase in filled seeds per cone and the reduction in galled seeds per cone due to insecticide applications; and iii) an average control efficacy of 85%.

The amount of seed loss that managers are willing to tolerate will vary depending on the demand for seed, the costs of control, the size of the cone crop, and projected seed yield. Even 5% seed loss may be considered too much when the demand for seed is high; conversely, with a 10-year supply of seed in storage, complete destruction of the cone crop might be acceptable. Managers may also tolerate a high percent seed loss in years of heavy cone crops if the expected seed yield, after pest losses, still fulfils seed requirements. Therefore, it is a good idea to design a flexible sampling method with several threshold densities corresponding to different levels of seed loss. Problems associated with setting economic damage thresholds in seed orchards have also been discussed by Boulet (1992).

## SOME SOURCES OF ERROR

No sampling method is without a certain amount of error but, if properly designed and used according to plan, the chances of making an error are at least quantified. For example, sequential sampling plans (discussed in more detail later) are often designed to classify pest density, or resulting damage, as either low (e.g., <10%), medium, or high, with 90% confidence. A 90% confidence level means that there is a 10% chance of making an error in classification, e.g., calling a medium infestation light; the correct decision will be made about nine times out of ten (Waters 1955). Choosing a greater confidence level, say 95%, will reduce the error to one in twenty but will also require more sampling and time.

Errors in sampling and prediction may be higher than those stated for a sampling method when: **i) the timing of sample collection is poor,** e.g., collecting black spruce conelets before they are 3/4 to fully pendant (and egg lay is 75-100% complete) will underestimate the egg density of the cone maggot, *S. appalachensis*, and the predicted percent seed loss; **ii) cones or trees are selected with bias,** e.g., egg densities of the Douglas-fir cone gall midge are generally higher in the upper crown than in the lower crown (Miller 1986b), so samples collected mainly from the lower crown or upper crown will under- or over-estimate egg densities, respectively; **iii) the pest's survival between the stage sampled and the completion of damage is unusually high or low,** i.e., survival strays well outside the average relationship upon which the sampling plan is based; and **iv) pest densities are near a critical threshold.** Nyrop and Simmons (1984) showed that, for some sequential sampling plans (Iwao 1975), the chances of making a wrong decision were much higher than the nominal level (e.g., 10%) when densities were near the critical threshold. Fortunately, sequential sampling methods usually perform well (<5-10% error) when true densities are not within about 20% of the critical threshold (Turgeon and Régnière 1987; Sweeney and Miller 1989).

## SOME SAMPLING METHODS IN USE IN SEED ORCHARDS OR IN DEVELOPMENT

One of the reasons why pest sampling and damage prediction methods have not been used more widely in seed orchards is because very few quantitative methods have been developed, tested and documented. Orchard pest surveys are conducted by the Canadian Forest Service, Forest Insect and Disease Survey personnel in some provinces (e.g., Ontario) and by provincial pest management extension personnel in others (e.g., Nova Scotia, New Brunswick, British Columbia (BC), Québec), but with few exceptions, these surveys provide estimates of pest infestation levels or damage that has already occurred. Most of these surveys do not provide predictions of damage so that action may be taken to prevent it. However, seed orchards in BC are regularly sampled for the Douglas-fir cone gall midge, spruce cone maggots, western red cedar cone midge, *Mayetiola thujae* (Hedlin), western spruce budworm, *Choristoneura occidentalis* Freeman, green spruce aphid, *Elatobium abietinum* (Walker), and gall *adelgids*, Adelges spp., and managers are informed of infestation levels before significant damage occurs (Robb Bennett, pers. comm.). Except for the Douglas-fir cone gall midge, however, these samples do not provide quantitative estimates of seed loss.

The cone crop monitoring programs underway in Ontario and starting up in Quebec provide quantitative estimates of expected seed yield (and cumulative pest-caused losses) at various times during the season, but do not detect the presence of certain pests, such as the spruce cone maggots, until seed damage has already occurred. Seed orchard staff in Québec conduct two pest surveys, one during the last week of June and the other during the last 2 weeks of August. A number of trees are selected from a number of orchard rows and on each tree the total number of healthy and damaged cones are counted. Samples of damaged cones are sent to the "Service de la protection contre les insectes et les maladies" of the "ministère des Ressources Naturelles du Québec", and if damage is considered significant, a forest protection technician in the region conducts a follow-up survey (Bruno Boulet, pers. comm.).

Some quantitative methods of damage prediction in use in seed orchards or in development include sequential sampling plans for the Douglas-fir cone gall midge, the spruce cone maggots, and aphids and mites in tamarack. These are discussed briefly.

### SEQUENTIAL SAMPLING TO PREDICT SEED LOSS CAUSED BY THE DOUGLAS-FIR CONE GALL MIDGE

One of the few sequential sampling methods used operationally in seed orchards is that developed by Miller (1986a) for the Douglas-fir cone gall midge, a serious pest of Douglas-fir seed orchards in BC. Orchard staff collects 100-150 cones (one per tree) when scales have closed and cones are becoming pendant.

This sample is sent to the seed pest management group of the Silviculture Branch, BC Ministry of Forests, who process it within an average of 7-8 h (Miller 1986a) and, as a policy, inform seed orchard managers of the predicted seed loss within 24 h (Robb Bennett, pers. comm). Managers can then decide whether or not they will apply an insecticide to control the gall midge.

The sample is usually processed by one or two people with experience in dissecting conelets and recognizing the gall midge eggs. Cones are dissected scale-by-scale and the egg-infested scales are counted. Cones are dissected until the cumulative number of egg-infested scales is above or below the threshold number (associated with 10% seed loss) for the number of cones dissected thus far. For example, if fewer than 60 infested scales are found in a total of 40 cones, one can predict (with 90% confidence and 10% sampling error) that gall midge infestation will result in less than 10% seed loss. If more than 140 infested scales are found in 40 cones the method predicts greater than 10% seed loss. If the number of infested scales per number of cones dissected does not fall above or below a decision line then cone dissection continues.

This sampling plan has been used operationally in BC since 1981 and, as of 1985, was correct 31/31 times (Miller 1986a).

### SEQUENTIAL SAMPLING TO PREDICT SEED LOSSES CAUSED BY THE SPRUCE SEED MOTH AND SPRUCE CONE MAGGOTS

Ruth *et al.* (1982) suggested sampling ten conelets per tree from 5-10% of the cone-bearing trees in an orchard; if a mean of two conelets per tree contained eggs of either the seed moth or the cone maggot, seed losses of 10-20% could be expected. This method would be useful but its errors are unknown and the number of cones requiring dissection (e.g., 250 to 500 cones from an orchard with 500 cone-bearing trees) may be impractical. Methods similar to that developed to sample the cone gall midge, have been developed for predicting the category of percent seed loss to the white spruce cone maggot, *S. neanthracina*, and the seed moth, based on the cumulative numbers of eggs or infested conelets per number of cones dissected (Sweeney *et al.* 1990; JDS unpublished data)[2]. For example, for the cone maggot, orchard staff collect two cones from each of 50 trees when scales have closed and cones are 3/4 pendant to fully pendant. A minimum of 20 cones are dissected, scale-by-scale, and the number of cones with eggs or larvae are recorded. Then, the cumulative number of infested cones per total cones dissected is compared with a range of values

[2] Details of the sequential sampling plans for the cone maggot and seed moth are in manuscripts that will be submitted to scientific journals and are not presented here. However, seed orchard managers interested in testing the methods may contact me directly.

in a table to see whether the predicted level of seed loss falls into a category of <8%, >12%, or >40%. As in the gall midge sampling method, if the number of infested cones per total cones dissected does not fall within a specified range of values, cone dissection continues until a maximum of 100 cones are dissected.

With the cooperation and assistance of seed orchard staff, the sequential sampling plan for cone maggot has been tested in a number of white spruce seed orchards since 1990 and has correctly predicted the category of seed loss 9/11 times. It was necessary to dissect an average of 45 cones before damage could be predicted. It takes between 2-5 min to dissect a cone, depending on experience, so the average sample can be processed in 2-4 h. Although the method is based on the spatial and frequency distribution of *S. neanthracina* in white spruce and Engelmann spruce, *Picea engelmannii* Parry, it has been adapted (by adjusting the percent loss of filled seed per infested cone) and tested for prediction of *S. appalachensis* damage in black spruce orchards. The method predicted correctly only 13/17 times (76%) in black spruce and must be further refined by incorporating data on the spatial and frequency distribution of *S. appalachensis* in black spruce and additional data on impact (JDS unpublished data).

## SEQUENTIAL SAMPLING PLAN FOR MITES AND APHIDS ON TAMARACK

Aphids and mites can occur in high populations in seed orchards and cause yellowing of the foliage. They cause enough concern among some orchard managers that insecticides are often applied several times per season. Whether insecticide applications have been necessary in all cases is unknown because means of estimating the density of a particular species of aphid or mite in seed orchards, and its impact on seed yield or tree health, did not exist. However, Webster (1993) has developed a method of collecting black larch aphids, *Cinara laricifex* (Fitch), and spruce spider mites, *Oligonychus ununguis* (Jac.) and sequential sampling plans for estimating their densities with known precision (% error). One branch on each of 25 randomly selected trees is beat ten times with a padded stick; and dislodged insects are caught in a container held under the branch (this procedure works best with two people). The mites and aphids are then rinsed from the collection container into a vial and taken back to the lab. It takes 10-15 min to process each sample, but not all samples require processing. Processing stops when the cumulative number of mites (or aphids) per number of trees sampled (samples processed) exceeds a threshold value associated with a given level of precision. The greater the level of precision desired, the greater the number of samples that require processing. Before this method is adopted and used by seed orchard staff, further research is necessary to determine the impact associated with different mite and aphid densities, and critical threshold densities.

## WHY ARE SAMPLING METHODS NOT USED MORE WIDELY?

One of the main reasons why sampling methods have not been used more widely is simply because there are not many available. We still **lack the basic knowledge** of life cycle, phenology, and impact necessary to develop sampling methods for some significant seed orchard insect pests, e.g., the fir coneworm, *Dioryctria abietivorella* (Groté). In cases where a practical sampling method exists and is well documented, it may not be used because **human resources are limited and spread too thin.** Some seed orchards, especially those attached to or near nursery facilities, may have a resident manager and staff who handle all sorts of management practices. Other orchards might be off in the woods, several hours away from a manager who has several responsibilities in addition to the management of that particular orchard; in these situations they are doing well if they manage to harvest the cones. **Seed orchard staff may also lack the necessary equipment or expertise** required to properly handle the samples. For example, the sequential sampling plan for predicting seed loss to the Douglas-fir cone gall midge requires that the number of egg-infested scales be counted under a stereoscopic microscope (Miller 1986a); it takes some training and experience to recognize the small gall midge eggs and not every orchard has access to a stereo microscope. Finally, **the tolerance level for pests varies among managers and orchards.** Sampling for a pest may seem like a waste of time to managers who have already decided whether they are going to control it, based on other considerations. In some cases this makes perfect sense. If managers have a 10-year supply of seed, or orchard terrain that is too rough to allow for practical control operations, controls may not be warranted or feasible regardless of the level of damage predicted by sampling. What is more difficult to justify is the decision to use insecticides without assessing the need to do so with some sampling, e.g., "cone maggot damage was bad last year so we're spraying for them this year, no matter what." The level of infestation in the previous year is not necessarily a good indicator of infestation in the current year because the size of the cone crop fluctuates from year to year, and seed and cone insect pests are capable of remaining dormant for more than one winter. If controls are being considered and a practical method of damage prediction is available, then sampling should be done.

## HOW CAN WE MAKE SAMPLING METHODS MORE ACCESSIBLE AND USABLE?

Firstly, as stated earlier, **sampling methods should be designed to be practical,** i.e., cheap, simple and effective. Otherwise, they will likely not be used operationally. To help ensure that they remain practical, **development and testing of sampling methods should directly involve the participation of seed orchard personnel, whenever possible.** This helps to ensure development of a practical sampling method and allows seed orchard personnel to become familiar with sampling procedures as they are developed, i.e., both research and tech transfer benefit. A lack of necessary expertise may be overcome by **providing training in workshops.** For some methods it may be more practical to **provide a central sample processing service,** e.g., the processing of Douglas-fir cone gall midge samples collected by staff in provincial and industry seed orchards in BC is handled by seed orchard pest management staff of the BC Ministry of Forests. Where provincial extension services are unavailable or otherwise tied up, it may be possible for orchard managers to contract services with a private company or individual. Fruit growers in BC's Okanagan valley often hire the services of small pest management companies to sample for red mites, codling moth, etc., and to provide advice regarding the need for pest control. As stated earlier, **sampling plans should be made more flexible.** Depending on the demand for seed, managers may be willing to absorb 40% seed loss one year, but less than 10% seed loss in another. Sequential sampling plans should, therefore, be designed or modified to include more than one damage threshold. Finally, **we should not wait until a sampling plan is perfect before trying it out.** A rough prediction of damage, so long as its precision (or lack of) is somewhat defined, is better than no prediction when considering the need for pest controls. Preliminary sampling plans may still provide useful information and should be tested with the assistance of orchard staff and refined when necessary.

## FUTURE CONSIDERATIONS

Sampling methods in seed orchards could be improved by better defining the impact of a pest in terms of its effect on seed quality as well as quantity, i.e., the reduction in yield of seedlings, not seeds. Simply estimating the percent loss of filled seed due to a given pest may underestimate its true impact if the seeds from infested cones also have reduced germination capacity, as found for black spruce cones infested with cone maggot (Prévost *et al.* 1988).

A basic drawback to many sampling methods is that they are pest specific, i.e., each predicts the seed loss due to one pest only. This could lead to situations in which the combined seed loss caused by, for example, three insect pests exceeds acceptable levels (e.g., 20%) but no control actions are taken because each of three independent sampling methods predicts acceptable levels of damage (e.g., <10% seed loss). To avoid this situation, efforts should be made to **integrate sampling methods for more than one pest.** This may be fairly simple for pests such as the spruce cone maggot and the spruce seed moth, both of which may be sampled for by collection and dissection of conelets in spring. It may be possible to devise a method that uses one sample to predict the combined seed loss to both pests.

Cone crop monitoring is an excellent way of integrating seed losses inflicted by a complex of pest species into an estimate of cumulative seed loss incurred at different stages of cone development (de Groot and Turgeon 1992; Bramlett and Godbee 1982). Predictions of seed loss from other sampling methods, e.g., a sample of conelets dissected to determine percent infested with maggot eggs, could be incorporated into the cone crop monitoring system to adjust the overall estimates of seed efficiency, germination efficiency, etc., before damage occurred. Decisions regarding the need for control actions would therefore be based on overall estimates of seed yield, as affected by a number of factors, and not just losses due to a single pest species.

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# PRACTICAL CONSIDERATIONS IN THE USE OF PHEROMONES AND SEMIOCHEMICALS FOR MANAGEMENT OF INSECT PESTS IN SEED ORCHARDS

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## ABSTRACT

Although identified pheromones are available for most of the important lepidopteran and coleopteran pests of coniferous seed orchards in Ontario, their use in pheromone-based trapping systems to detect, monitor, or forecast pest populations is still largely experimental. Thus, the key elements for developing a standardized pheromone-based trapping system, including trap design, lure formulation, trap placement, and trapping objectives are discussed. Potential difficulties, such as the occurrence of insect diapause and capture of non-target insects, are also considered. Information on commercial sources of traps and related supplies and conditions for optimum trapping of selected orchard pests is summarized in tables.

## RÉSUMÉ

Bien que l'on connaisse les phéromones de la plupart des lépidoptères et des coléoptères considérés comme de grands ravageurs dans les vergers à graines de conifères de l'Ontario, l'utilisation de ces substances pour le piégeage, à des fins de détection, de surveillance et de prévision, reste largement expérimentale. Cet article traite des principaux aspects à considérer dans la mise au point d'un système normalisé de piégeage à base de phéromone; il est notamment question de divers modèles de pièges, de la composition des appâts, de l'emplacement des pièges et des objectifs du piégeage. On parle aussi des problèmes pouvant se présenter, par exemple l'entrée en diapause de l'insecte étudié ou encore la capture d'espèces non visées. On présente également des tableaux contenant divers renseignements sur les fournisseurs commerciaux de pièges et de fournitures et sur les conditions optimales pour le piégeage de certains ravageurs des vergers.

## INTRODUCTION

Considerable effort has gone into establishing coniferous seed orchards for the production of genetically improved stock in Ontario. To protect orchards crops and trees from losses caused by insects, orchard managers need convenient methods for detecting specific pests, estimating their population levels and forecasting potential damage. Ideally, the methods should be inexpensive, easy to use, and reliable. Pheromone-baited traps provide a practical solution to some of these needs. They are widely used in Canadian forestry for insect surveys and monitoring (Grant 1990), but their operational use in seed orchards is largely experimental (Grant 1991). The intent of this paper, therefore, is to provide basic information about pheromones, traps and their practical applications for seed orchard managers and their insect problems. Effective pheromones are available for many of the insect species of importance in Ontario orchards (Tables 1 and 2) .

Trapping insects with pheromone-baited traps is not quite as easy as it first appears. There are pitfalls and some care and attention are always needed. Moreover, the exercise of deploying traps, which provides a sense of taking action, and the discovery of insects in those traps, which provides a sense of success, are deceptive accomplishments. In

**Table 1. Insect pests with known sex or aggregation pheromones attacking cones and seeds in coniferous cones and seeds in Ontario orchards**

| Family<br>Insect | Major Hosts[a] | Lure Availability | Reference |
|---|---|---|---|
| Coleoptera | | | |
| *Conophthorus coniperda* | wP | Contact P. de Groot | de Groot *et al.* (in prep.) |
| *C. resinosae* | rP, jP | Contact P. de Groot | |
| Lepidoptera | | | |
| *Cydia strobilella* | wS,bS | Contact G. Grant | Grant *et al.* 1989 |
| *C. toreuta* | rP, jP | Not available | Katovich *et al.* 1989 |
| *Dioryctria abietivorella* | wP,bS | Still experimental | Grant 1990 |
| *D. disclusa* | rP, jP, sP | Commercially avail. | Meyer *et al.* 1982 |
| *D. reniculelloides* | wS, bS, rS | Contact G. Grant | Grant *et al.* 1987 |
| *D. resinosella* | rP | Contact G. Grant | Grant *et al.* 1993 |
| *Eucosma monitorana* | rP | Contact G. Grant | Grant *et al.* (in prep.) |
| E. *tocullionana* | wP | Contact G. Grant | Grant *et al.* (in prep.) |

[a] jP, jack pine; rP, red pine; sP, scotch pine; wP, white pine; bS, black spruce; rS, red spruce; wS, white spruce.

**Table 2. Insect pests with known sex or aggregation pheromones attacking coniferous trees in Ontario seed orchards**

| Family<br>Insect | Major<br>Hosts[a] | Lure<br>Availability | Reference |
|---|---|---|---|
| Coleoptera | | | |
| *Pissodes strobi* | wS, bS, jP, sP | Needs further research | Booth *et al.* 1983 |
| Hymenoptera | | | |
| *Pikonema alaskensis* | wS, bS | Unknown | Bartelt and Jones 1983<br>Bartelt *et al.* 1983 |
| Lepidoptera | | | |
| *Choristoneura fumiferana* | wS, bS | Great Lakes IPM [c] | Silk *et al.* 1980 |
| *C. pinus pinus* | jP | P. Silk[d] | Silk *et al.* 1985 |
| *Eucosma gloriola* | jP, wP | Contact G. Grant | Grant *et al.* 1985 |
| *Rhyacionia* spp.[b] | jP, rP | Contact G. Grant | Grant *et al.* 1985 |
| *Zeiraphera canadensis* | wS, bS | Contact G. Grant | Turgeon and Grant 1988<br>Silk *et al.* 1989 |

[a] Abbreviations as in Table 1.
[b] Several species observed on pines in Orono seed orchard.
[c] Address given in Table 4
[d] RPC, 921 College Rd., Fredericton, N.B.

reality, trap catches provide little useful information unless the objectives of the trapping program are clearly defined. These objectives influence decisions about the key elements of a pheromone trapping system (trap design, lure formulation and trap placement), and determine the course of action that will result from the trapping data.

## TRAPPING OBJECTIVES

### DETECTION SURVEYS

Insects are extremely sensitive to sex pheromones and aggregation pheromones, and are readily attracted by them. Therefore these compounds are useful as lures in traps for detecting insect pests, particularly when their populations are at low levels. Detection traps are especially useful for surveys of cone and seed pests because the cryptic feeding habits of their larvae make them difficult to detect and identify except by destructive sampling of cones. Currently, detection trapping in Ontario is done on an experimental basis, mainly for the insects listed in Table 1, but annual surveys are conducted for the spruce seed moth, *Cydia strobilella* (L.)(= *C. youngana*) and the spruce coneworm, *Dioryctria reniculelloides* Mutuura and Munroe, in the Maritimes.

## MONITORING AND FORECASTING

Advance warning of insect outbreaks is necessary for early intervention to prevent damage. By monitoring insect populations annually with pheromone-baited traps at the same location from year to year, population levels can be tracked and rising or falling trends determined. However, interpretation of population trends may not be straight forward for cone and seed pests because some species go unpredictably into diapause. Thus numbers can fluctuate because of diapause rather than actual changes in population levels.

Determining when trap catches signal a possible outbreak requires the establishment of a quantitative relationship between catch and damage. Often correlations are established between trap catches and other measures of insect abundance such as eggs or larvae, which are traditionally used to forecast insect outbreaks. Because these insect life stages are more difficult and time consuming to sample, trap catches provide a more convenient sampling method once reliable correlations are established. However, trap catches may not be as reliable as other sampling methods, particularly for forecasting damage. In this case, trap catch thresholds can be established which, when reached, trigger population sampling by other more accurate methods to confirm the preliminary forecast based on the trap catches (Shepherd *et al.* 1985). Catch thresholds are used in a more direct fashion to provide a hazard rating for pine seed orchards across the southern U.S.A. attacked by several *Dioryctria* coneworm species (DeBarr *et al.* 1982; Weatherby *et al.* 1985). When trap catches are less than 10 moths per trap, the probability of damage is deemed low, but when catch exceeds 50 moths per trap there is a high risk of damage and control action is probably warranted. These thresholds are based on observations and experience, and are somewhat arbitrary; therefore, control decisions also take into account population trends as indicated by trap catch. No pheromone-based monitoring system is currently operational in Canadian seed orchards. Several systems are in place for forest defoliators (Grant 1991).

## TIMING CONTROL TREATMENTS

There are two important questions when considering the application of control agents. First, is there a need to initiate control action and second, precisely when should the control agent be applied. The ability to accurately forecast insect outbreaks with pheromone traps would allow for a reliable "treat only when necessary" policy and alleviate the need for prophylactic treatments. When treatment is necessary, it is important to time the application to coincide with the vulnerable life stage, usually newly hatched larvae, of the target insect. This is more important for contact than systemic materials because of the narrow window of time when the vulnerable stage of most cone pests are exposed (Summers and Miller 1986). The application can be timed by using the date of the first capture of insects in a pheromone trap to indicate the start of the insect's flight period. Information is also needed about the amount of time from the start of flight to egg hatch to know precisely when to spray. Timing can be refined by incorporating a degree-day model which uses the date of the first trap catch to initiate the model (Gargiullo *et al.* 1983).

## TRAP DESIGN

There are numerous commercially available trap designs but basically they fall into two general categories: sticky traps, which have a limited trapping surface for retaining insects, and reservoir type traps (such as the Multi-Pher® and milk carton traps), which are often referred to as high-capacity or "nonsaturating" traps. The latter usually incorporate a Vapona® insecticide strip in the reservoir for retaining and killing insects, but soapy water may also be used. Sticky traps have a capacity of about 30-100 moths, depending on the size of the insects, environmental conditions (especially dust, debris and rain), and the area of the sticky surfaces. Thus sticky traps are easily saturated with insects and once saturated they no longer provide useful information about population levels or trends. Some trap designs have replaceable sticky surfaces but changing these requires frequent servicing of the traps to prevent saturation. Thus sticky traps are best suited for general detection surveys.

Removing insects, particularly moths, from sticky traps to identify them or produce voucher specimens for future reference can be a problem. A procedure for removing insects from sticky trap material and saving them for later identification has been described (Murphy 1985).

Commercially available reservoir traps can accommodate 1000 or more insects, considerably reducing the likelihood of saturation. Thus they are frequently used in monitoring programs where a wide range of insect populations must be accommodated. Occasionally, high catches in these traps can be a problem because as they fill they become less efficient either because the captured insects decompose and become repellant or because moths entering a half-full trap can escape more easily (Sanders 1986; Elkington 1987). Some large capacity traps, such as the milk-carton trap are disposable whereas others, such as the plastic Multi-pher trap and Unitrap, are meant to be reused. These reusable traps are more complex in design (they have an internal funnel and other features to aid capture and retention of moths) and they are more costly initially but this is mitigated with repeated use. A further problem is the danger of cross contamination of these traps with different pheromones if more than one lure formulation is used in them. Pheromones from different lures may be absorbed by the trap and then re-released. Traps contaminated in this way can cause confusion by attracting non-target insect

Table 3. **Effective lure dosages and trap designs for some lepidopteran pests of coniferous seed orchards in Ontario, and some species for which traps in upper canopy or tree tops are more effective**

| Species | Main Pheromone Component[a] | Optimum Dosage (μg) | Effective Trap Designs | Trap Height Effect Shown | Reference |
|---|---|---|---|---|---|
| *Choristoneura fumiferana* | Z11-14:Ald | wide range | Pherocon 1C, 1CP<br>Multi-pher | yes | Sanders 1986<br>Sanders 1992 |
| *Conophthorus coniperda* | not publ. | - | Japanese beetle<br>trap top | yes | de Groot *et al.* 1991<br>de Groot *et al.* (in prep.) |
| *C. resinosae* | not publ. | - | Same as *C. coniperda* | yes | de Groot *et al.* 1991<br>de Groot *et al.* (in prep.) |
| *Cydia strobilella* | Z8-12:Ac | 0.3 - 3 | Pherocon 1C or 1CP<br>Zoecon II | yes | Grant *et al.* 1989 |
| *Dioryctria disclusa* | Z9-14:Ac | 30 - 300 | Pherocon 1C | yes | Meyer *et al.* 1982 |
| *D. reniculelloides* | Z9-14:Ac | 3 | Pherocon 1C & 1CP | yes | Grant *et al.* 1987 |
| *D. resinosella* | Z9-14:Ac | 30 - 100 | Pherocon 1C | yes | Grant *et al.* 1993 |
| *Eucosma monitorana* | Z9-12:Ac | 100 | Pherocon 1C & 1CP<br>Zoecon II | ? | Grant *et al.* (in prep.) |
| *E. tocullionana* | Z9-12:Ac | 3 - 10 | Same as *E. monitorana* | ? | Grant *et al.* (in prep) |

[a] Abbreviations follow the models: Z11-14:Ald = (Z)-11-tetradecenal; Z8-12:Ac = (Z)-8-dodecenyl acetate.

species, which also increase the effort to sort, identify and count the catch. Thus reusable traps should be employed for only one target species and with only one lure formulation.

An important consideration in choosing a trap design is whether it is suitable for the target species. *Dioryctria* coneworm species, for example, are readily caught in Pherocon® 1C or 1CP sticky traps, but not with other sticky trap designs or with reservoir traps (Hanula *et al.* 1984; Grant, unpubl. data). Table 3 lists suitable trap designs for some coniferous cone pests.

## LURES

The number of moths caught in a trap and its specificity for the target species is also controlled by the lure formulation in it, that is, by the blend of pheromone components, their dosage (which influences pheromone release rate), and the substrate (e.g., rubber septa) carrying the pheromone. Generally, these factors are fixed if commercial lures are used, although few lures are commercially available for seed orchard pests (Tables 1 and 2). Because lures are potentially an important source of variation in trap catches from year to year, users should know what lure formulation (dosage, composition and substrate) they are using and its source, and, if satisfied with its performance, should stick to the same lure source, commercial or otherwise, to reduce variation in trap performance. Currently, Canadian Forest Service personnel are coordinating their pheromone use by publishing an annual report that includes specific information about lures, their sources and composition (West 1993).

Lure dosage is often a critical factor in lure performance of cone and seed lepidopteran pests. A surprising number of them respond to low potency lures (Table 3) and their response declines dramatically as the dosage increases (Grant *et al.* 1989). Similarly, for insects that respond to high dosage lures, catch will decrease as the lure potency decreases. Knowledge of dosage relationships are useful because occasionally pairs of similar insects, such as the white pine coneborer, *Eucosma tocullionana* Heinrich, and the eastern white pine shoot borer, *E. gloriola* Heinrich, or the spruce seed moth, *Cydia strobilella*, and *C. rana* Forbes, share similar pheromone components but differ considerably in their response to pheromone dosage (Grant *et al.*, in prep). Selecting an appropriate lure dosage ensures optimum trap specificity.

Where a range of dosages are available, and detection is not the objective of the trapping program, lower dosages in the acceptable range are generally preferred because fewer moths will be caught, which reduces the chance of trap saturation and simplifies counting. Large catches can be estimated accurately by weighing the insects or measuring their volume and using regression analysis to convert weight or volume to numbers of insects (Allen *et al.* 1986).

### TRAP POSITION AND DENSITY

Generally for seed orchard pests, traps at the tree tops or in the upper canopy perform better (i.e., catch more insects) than those at the bottom of the tree (Table 3). Therefore, they may provide a more reliable indication of population levels than traps in the lower levels (Hanula *et al.* 1984; Grant *et al.* 1993), although this hypothesis has not been validated.

Location of traps within a plantation can also influence trap captures. Traps at the periphery of a stand often capture more insects than those located within the stand. It is likely that the pheromone plume from traps at the edge are less affected by interference from foliage and so have a greater range. This edge effect is a significant source of variation in catches among traps and should be avoided.

The optimum density of traps per unit area of seed orchards is a largely unexplored question. However, it is likely to be dependent on the target insect, size of the orchard, density of trees and foliage, and the trapping objectives. Hanula *et al.* (1984) examined the effects of trap densities on catch of *D. merkeli* Mutuura and Munroe in a South Carolina seed orchard. With densities of 1, 2, 4 and 8 Pherocon 1C traps per 0.1 ha, they found that catch per trap declined only at the highest density, indicating that interference or competition between traps was occurring. However, because there was no difference in catch among the other densities, it is clear in this case that traps at the lowest density were sufficient and no additional information was gained by deploying more traps. The formal trapping system developed for surveying some 63 pine seed orchards in the southern U.S.A. uses 10 traps per orchard (size not specified) laid out on a grid so that traps are at least 27 m (90 ft) apart (Weatherby *et al.* 1985).

### CAPTURE OF NON-TARGET INSECTS

It should not be assumed that all insects caught in pheromone-baited traps are the target species. As mentioned, insects often share one or more pheromone components so that more than one species may be captured with the same lure despite efforts to make them as target specific as possible. This is a serious problem if the attracted species are morphologically similar. For example, in Ontario and New Brunswick, traps baited with lures (3 µg (Z)-8-dodecenyl acetate in rubber septa) for the spruce seed moth, *C. strobilella*, also attract some *C. rana*, a slightly larger but morphologically similar species, which is not a seed orchard pest but occurs on similar hosts and has a flight period that overlaps that of the spruce seed moth (Grant *et al.*, in prep.). Similarly, the white pine coneborer, *E. tocullionana*, and the red pine coneborer, *E. monitorana* Heinrich, which are morphologically very similar, and a third more easily recognized species, *E. gloriola*, may be attracted to the same lures, even within plantations of non-host trees (Grant *et al.*, unpubl. data). Finally, many species of *Dioryctria*, which are difficult to identify, share pheromone components and may be attracted to the same traps (Grant *et al.* 1993).

The accidental capture of non-target insects, which blunder into traps, occurs frequently with sticky traps. This problem can be alleviated by reducing the size of the trap opening. For this reason, Pherocon 1CP traps with their smaller trap opening are sometimes preferred over Pherocon 1C traps. Generally, accidental catch of extraneous insects is not a problem with reservoir traps such as the milk carton and Multi-pher traps. However, the tops of Unitraps are yellow, as are the tops of Japanese beetle traps, which are used for *Conophthorus* cone beetles (de Groot *et al.* 1991). Yellow tends to attract various types of bees, flies and other insects. For this reason, unbaited, yellow sticky-board traps used for *Strobilomyia* cone flies capture other fly species. Distinguishing between target and non-target flies may require examination of their genitalia, a tedious and time consuming process (Sweeney *et al.* 1990).

## COMMERCIAL SOURCES OF TRAPS AND LURES

Table 4 provides a limited list of commercial sources of traps, lures and related materials. Catalogues and pest brochures from these and other companies are valuable sources of practical information. Commercially available lures for seed orchard pests are limited (Table 1 and 2) because there is currently little demand for these products. If pheromone trapping is to become a component of seed orchard management in the future, this lack of commercial lure availability will have to be addressed and some coordination of user interests will be required. Commercialization is probably the best solution to the source question because quality control is likely to be high. Contracting out for lure production may be a suitable alternative. Regardless of the approach taken, a clear understanding of the lure requirements is necessary to ensure the optimum product. If a lure does not work effectively, several field seasons may go by before the problem is recognized.

## STANDARDIZATION OF TRAPPING PROTOCOL

Once the various questions concerning selection of trap design, lure formulation, lure source, and trap location are resolved then these factors should not be changed without good reason. Otherwise, it may not be possible to compare results from year to year. Thus detailed records of the above

**Table 4. Some commercial sources of pheromone traps, lures, semio-chemical baits and IPM supplies and equipment**

| Company | Address | Phone / Fax | Comments |
|---|---|---|---|
| Cooper Mill, Ltd. | RR 3<br>Madoc, Ont.<br>K0K 2K0 | Tel (613) 473-4847<br>Fax (613) 473-5080 | Various traps & lures |
| Le Groupe Bio-Contrôle | 2600 Dalton<br>Ste-Foy, Québec<br>G1P 3S4 | Tel (418) 653-3101<br>Fax (418) 653-3096 | Source for Multi-pher traps and Vapona strips |
| Phero Tech Inc. | 7572 Progress Way<br>Delta, B.C.<br>V4G 1E9 | Tel (604) 940-9944<br>Fax (604) 940-9433 | Various traps & lures<br>Beetle traps<br>Wide range of other products |
| Plant Products, Ltd. | 314 Orenda Rd.<br>Bramalea, Ont.<br>L6T 1G1 | Tel (416) 793-7000<br>Fax (416) 793-9157 | Various traps & lures |
| Great Lakes IPM | 10220 Church Rd. NE<br>Vestaburg, Michigan<br>U.S.A. 48891 | Tel (517) 268-5693<br>Fax (517) 268-5311 | Various traps & lures<br>Wide range of other products |

parameters should be kept. Sanders (1992) provides a useful account of the development of the trapping protocol for the spruce budworm in forests and addresses some of the problems encountered.

### OTHER SEMIOCHEMICALS

Sex pheromones attract only one sex, usually males in the case of Lepidoptera. This is a disadvantage because male catches provide an indirect index of the female population and no direct information on female oviposition, which determines where larvae will do their damage. Moreover, mated females of some species, such as the spruce budworm and possibly some *Dioryctria* species, migrate and may appear suddenly in orchards and create unexpected outbreaks. Because surveillance of females would clearly be advantageous, current semiochemical research involving cone and seed insects is focusing on attractants for mated females.

Recently, tree volatiles emanating from cones, rust galls and stem oleoresin have been shown to stimulate ovipositing females of *Dioryctria* coneworms. Typically, the compounds involved are monoterpenes and a number of them have been shown in laboratory bioassays to induce oviposition at the odor source (Fatzinger and Merkel 1985; Hanula *et al.* 1985). Host terpenes that attract mated female fir coneworm, *D. abietivorella* (Groté), and stimulate oviposition have also been identified (Shu, Langevin and Grant, unpublished data). However, this work is still at the experimental stage and requires evaluation under field conditions.

### CONTROL BY MATING DISRUPTION WITH PHEROMONES

Pheromones and other semiochemicals offer a potential alternative to insecticides or biologicals for direct control of seed orchard pests by mating disruption. When high levels of pheromone are dispersed into the atmosphere, sexual communication between the sexes can be disrupted and mating prevented. Although there are no published reports of successful control by mating disruption in a seed orchard, successful control of two insect pests of pine plantations, *Eucosma sonomana* Kearfott (Daterman *et al.* 1982) and *Rhyacionia zozana* (Kearfott) (Niwa *et al.* 1988) have been achieved by this method. Plantations are reasonable surrogates for seed orchards, which suggests that this control tactic should work with appropriate target insects. Seed orchards, by virtue of their limited size, well-spaced trees, easy access, and high value crops, offer ideal conditions for treatment by the disruption technique. Treatments can even be hand applied.

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# STATUS AND FUTURE OF INSECT PEST MANAGEMENT IN SEED ORCHARDS[1]

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## ABSTRACT

Critical to the success of applied tree improvement programs, already existing or currently underway, is the production of genetically improved seed from orchards. However, an array of insect pests seriously limits seed production for each tree species. With few exceptions, current pest management activities rely on chemical insecticides for insect control. Pest management issues facing forest entomologists and seed orchard managers include how to: i) ensure that insecticides remain available for use in seed orchards, ii) reduce insecticide loads in orchards, iii) improve efficiency of control tactics, iv) address changing orchard management goals, v) select orchard sites with lower pest hazards, vi) gain new knowledge of pest biology, and vii) develop an array of potentially useful non-insecticidal tactics and strategies. The status of pest management in orchards and prospects for the future are discussed.

## RÉSUMÉ

Le succès des programmes pratiques d'amélioration des arbres qui ont déjà été mis en oeuvre ou qui ont été entrepris récemment, repose en grande partie sur la production en verger de graines génétiquement améliorées. Or, divers insectes ravageurs limitent dans une mesure appréciable la productivité de ces essences. Actuellement, à quelques exceptions près, les mesures de lutte font appel aux insecticides chimiques. Pour les entomologistes et les exploitants de vergers à graines, la lutte contre les ravageurs forestiers signifie notamment : 1) veiller à ce qu'il soit toujours possible d'employer des insecticides pour le traitement des vergers à graines, 2) réduire la quantité d'insecticide appliquée dans les vergers à graines, 3) améliorer l'efficacité des tactiques de lutte, 4) prendre en considération les nouveaux objectifs de la gestion des vergers, 5) choisir des terrains où les risques d'infestation par des ravageurs sont moindres pour l'établissement de nouveaux vergers, 6) acquérir de nouvelles connaissances sur la biologie des ravageurs et 7) mettre au point un ensemble de tactiques et de stratégies ne faisant pas appel aux insecticides pour lutter contre les insectes ravageurs des cônes et des graines. En outre, on fait le point sur la lutte contre les ravageurs dans les vergers et l'on se penche sur les nouvelles approches et sur les possibilités pour l'avenir.

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[1] **Adapted from a paper presented at the 22nd Southern Forest Tree Improvement Conference, Atlanta, GA. June 17, 1993.**

## INTRODUCTION

Seed orchards are an important part of applied tree improvement programs in North America (Zobel and Talbert 1984) and are key elements for the success of these programs. Whereas less than 8,000 ha of orchards exist in North America, these areas represent a major forestry investment. Individual orchards are small, ranging in size from 2 to 200 ha. Management is for the single purpose of supplying the tons of genetically improved seeds needed to grow seedlings for the reforestation of millions of hectares of commercial forest lands. An array of insect pests threatens seed crops (Ebel *et al.* 1976; Hedlin *et al.* 1980; Turgeon and de Groot 1992). Each tree species has its own unique complex of cone and seed insect pests.

As first-generation seed orchards came into production during the 1970s, the demands for genetically improved seed were high. Once the impact of cone and seed insect pests was clearly recognized, entomologists developed insect control methods and orchard managers quickly put them into practice (DeBarr 1990). These methods were highly effective and yields exceeded expectations of tree improvement specialists and geneticists. Wakeley (1954) noted that in harvests from natural stands of southern pines, "each species averages about 1 lb. per bushel of cones in good years, about 0.5 lb. per bushel in years of moderate crops and 0.2 lb. per bushel or less in very poor crop years". Twenty years later, a loblolly pine seed orchard in the North Carolina State University-Industry Cooperative yielded 2.36 lb. of seed per bushel (Anon. 1985) (1 lb per bushel = 1.29 kg per hL). The report stated that "effective orchard management practices have allowed cooperative members to reach production efficiencies once thought impossible".

In the 1990s forest entomologists and seed orchard managers will face a series of new issues related to seed orchard pest management. I discuss some of these issues and ways to meet these challenges in this paper.

## ENSURE INSECTICIDE AVAILABILITY FOR SEED ORCHARDS

Insecticides are the most widely used method for controlling cone and seed insects in forest tree seed orchards (DeBarr 1993; de Groot *et al.* 1994). They will continue to be important for seed orchard pest management, as long as they remain available to us. Insecticides most effective for cone and seed insect control have long residual or systemic activity. They are readily available, easy to use, cost-effective and provide broad-spectrum control of many different cone and seed insect pests. Both managers and the general public are also aware of their potential disadvantages. To ensure that insecticides are available for use, tree improvement specialists and forest entomologists must work together to keep current registrations, and register any new insecticides that are potentially useful for controlling orchard pests.

## RETAIN CURRENT REGISTRATIONS

Few insecticides are registered for seed orchard use in the United States (Table 1) and Canada (Table 2). Most of the registrations in the United States are at least 10 years old (van Buijtenen 1981). The Environmental Protection Agency (EPA) granted the last Federal registration in 1987 and canceled the use of Furadan® in seed orchards in October 1992. Other registrations are being reviewed by the EPA and some of these insecticides may not be re-registered by the chemical companies. Recently, the Southern Forest Tree Improvement Conference organized a subcommittee called the Seed Orchard Pest Management Committee (SOPMC) to address this problem. Working together, this group of tree improvement specialists and forest entomologists accomplished several important tasks. One was the reclassification by EPA of seed orchards from forestry sites to non-food crop, terrestrial sites. This action should make it somewhat easier to keep insecticides available for use in seed orchards.

**Table 1. Federal registrations of insecticides for cone and seed insect control in conifer seed orchards in the United States**

| Trade name | Common name | Class[a] | Year registered |
|---|---|---|---|
| Cygon® | dimethoate | OP | 1962 |
| Guthion® | azinphosmethyl | OP | 1974 |
| Furadane®[b] | carbofuran | CB | 1976 |
| Ambush® | permethrin | PY | 1980 |
| Pounce® | permethrin | PY | 1980 |
| Pydrin® | fenvalerate | PY | 1980 |
| ASANA®[c] | esfenvalerate | PY | 1987 |
| Foray® | Bt | MC | 1991 |
| Capture® | bifenthrin | PY | 199? |

[a] OP, organophosphate; CB, carbamate; PY, pyrethroid; MC, microbial insecticide.
[b] Canceled by EPA Oct., 1992
[c] Isomer of Pydrin.

**Table 2. Insecticides registered for cone and seed insect control in conifer seed orchards in Canada[a]**

| Trade name | Common name | Class[b] |
|---|---|---|
| Acecap 97® | orthene | OP |
| Ambush® | permethrin | PY |
| Cygon® | dimethoate | OP |
| Guthion® | azinphosmethyl | OP |
| Meta Systox®R | demetonmethyl | OP |

[a] Lanteigne and Burns (1993)
[b] OP, organophosphate; PY, pyrethroid

## REGISTER NEW INSECTICIDES

In the United States only a few new insecticides have become available in recent years. Furthermore, chemical companies no longer eagerly pursue registrations for forestry uses. These markets are small and there is increasing public concern with the use of insecticides on forest lands. Efficacy data for early registrations of insecticides for cone and seed insect control in seed orchards were based upon field tests using individual trees. However, the current method of choice for applying insecticides in Southern pine seed orchards is with aircraft. Region-wide efficacy tests of aerial applications of new insecticides are costly and difficult to carry out. Recently, the SOPMC committee conducted a Southwide efficacy test of the pyrethroid insecticide, Capture®. Two problems encountered were the uncertainty as to which formulation the manufacturer wanted to test and register for seed orchard use and limited replication due to the small number of orchards suitable for the test. In addition, all the time and resources for planning and conducting the test had to be contributed by members of the SOPMC and the participating orchard managers. Finally, standardized procedures had to be developed and orchard personnel from each site had to be trained to ensure consistency in the applications. Because of the efforts by the SOPMC, it is now permissible to use Capture® in seed orchards, under State 24-C registrations, in most of the southern states (Lowe *et al.* 1994). If registered by the Federal EPA, Capture® will be the first new registration of an insecticide for seed orchard use in the United States in almost a decade.

## MINIMIZE INSECTICIDE LOADS IN SEED ORCHARDS

Continuing to reduce the amount of insecticide applied in seed orchards will help to keep insecticides available for our use. Additional benefits include lower costs, increased worker safety, reduced environmental risks and delayed development of pest resistance. Two ways to reduce insecticide loads in seed orchards are to use less per application and make fewer applications.

### REDUCE INSECTICIDE RATES PER UNIT AREA

Using less insecticide per acre or hectare of orchard diminishes both costs and potential environmental problems. The rates used today in the Southern United States are much lower than those once applied for control in seed orchards (Table 3). This is the result of two important changes in pest management that occurred in the early 1980s.

**Table 3. Insecticide amounts per unit area for single applications with several control methods**

| Insecticide | Control method | Amount of active ingredient[a, b] |
|---|---|---|
| Furadan® | Soil systemic | 12[c] |
| Guthion® | Hydraulic sprayer | 8 |
| Guthion® | Mistblower | 5 |
| Guthion® | Aircraft | 3 |
| Ambush®/Pounce® | Aircraft | 0.75 |
| ASANA® | Aircraft | 0.19 |
| Capture® | Aircraft | 0.1 |

[a] Values in lb/acre (1lb/acre = 1.1 kg/ha).
[b] Assuming the maximum registered rate.
[c] Assuming 48 trees 10" dbh/acre (119 trees of 25 cm dbh/ha).

First, the pyrethroid insecticides, Ambush®, ASANA®, Capture®, Pounce®, and Pydrin®, were registered for seed orchards. These insecticides have higher relative toxicities to cone and seed insects (DeBarr and Nord 1978; DeBarr and Fedde 1980), and are more effective, on an active ingredient per unit area basis, than the older organophosphate insecticide, Guthion®, or the carbamate insecticide, Furadan®. ASANA® is a refined isomer of Pydrin®. Capture® is a second-generation pyrethroid, which is effective at even lower rates than Ambush®, Pounce® and ASANA®. We must continue to test for new insecticides with the potential to provide efficacy at even lower rates.

Second, the use of aircraft has made it possible to get the insecticide to cones in the tops of the trees more efficiently than with ground sprayers (Barry *et al.* 1984). Using aircraft often attracts more public attention and concern, but aerial applications are much more efficient than ground applications. Besides lower rates per unit area and better spray coverage, other advantages include reduced worker exposure, better timed applications and lower costs because of improved efficacy. It is particularly important that we retain the option of using aircraft to apply chemical and microbial insecticides in seed orchards. In the future, aircraft may also be needed to apply chemicals that modify insect behavior.

### REDUCE APPLICATION FREQUENCY

Fewer applications per year means less pesticide load in seed orchards. In the past it was not uncommon to spray orchards in the Southern United States as often as 6 times each year, when genetically improved seed was scarce. Since the importance of each pest often varies with the orchard site, orchard managers have learned how frequently they must spray to protect seed crops from pests that occur in their particular orchard. With cone crop monitoring (Bramlett and Godbee 1982), surveys using pheromone traps (DeBarr *et al.* 1982) and their own individual experience, the number of applications per year is now more likely to be 2 to 4.

## DEVELOP STRATEGIES FOR CHANGING ORCHARD MANAGEMENT GOALS

### LOW INTENSITY MANAGEMENT IN OLDER ORCHARDS

As new generation orchards become productive, pest management activities are often stopped in older orchards. However, some managers continue to harvest seed from the best clones in their old orchards. Without insect control yields will be poor. Spraying the entire orchard is not a cost-effective alternative. In this situation, individual tree protection appears to offer some advantages. The idea of controlling insects on individual trees in orchards is an old one (DeBarr 1971), but it never gained acceptance in the Southern United States because entire orchards were sprayed to meet the high demands for seed. Any of the insecticides currently registered for use in mistblowers or hydraulic sprayers can be used to protect individual trees. Systemic insecticides implanted into the trunks of pines are also an effective way to control cone and seed insects on individual trees (Merkel and DeBarr 1971). Numerous studies that have been published show the efficacy of systemic implants for spruces, firs and Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, in the Western United States and Canada. Recent examples include the work by Stein *et al.* (1993) on Douglas-fir and the work by West and Sundaram (1992) on black spruce, *Picea mariana* (Mill.) B.S.P. However, there are currently no systemic insecticides registered for use as implants in southern pine seed orchard trees.

### HIGH INTENSITY MANAGEMENT IN NEW GENERATION ORCHARDS

Seed yields from new generation orchards are always scarce, but insect control in these orchards is essential because managers are unwilling to tolerate losses. Because yields from protected first generation orchards in the Southern United States exceeded expectations, geneticists are establishing smaller orchards for the new generation. If high yields and sufficent supplies of genetically improved seed are to be maintained, the intensity of pest management in these new orchards will have to be equally or more intensive than for first-generation orchards.

## ORCHARD SITE AND INSECT PEST MANAGEMENT

Geneticists consider many factors in selecting a site for a new seed orchard. Unfortunately, the effect of location on future insect pest management is often ignored. Selecting the wrong site can result in chronic problems with cone and seed insect pests, and can severely limit the options for pest management. Guidelines for evaluating a prospective orchard site for potential pest management problems would be a valuable aid.

### MINIMIZE POTENTIAL FOR ORCHARD INFESTATION AND REINFESTATION

The new generation orchards established next to older ones that now have large cone-bearing trees, will likely be infested rapidly by cone and seed insects. They are also highly susceptible to reinfestation. For example, once harvesting has stopped in older orchards, insect control operations are seldom performed. Thus, abundant cones in these sanctuaries allow insect numbers to increase, the older orchards serving as a reservoir for pest populations. Managers should destroy these orchards if they cannot afford to control the pests. Invasion of a new orchard can also occur when cone-bearing trees are present in adjacent natural stands, plantations, abandoned fields, fence rows or parks and residential areas. Orchards should not be located near these types of sites. If more than one tree species is planted at the same orchard site, problems are created if the same insect pests infect both species. For example, in the Southern United States, when a loblolly pine orchard is next to a slash pine orchard, seed bugs may concentrate on the loblolly pines, after the slash pine cones are harvested.

### AVOID ENVIRONMENTALLY SENSITIVE SITES

Problems associated with pest management practices, especially the use of insecticides, are often not considered when choosing an orchard site. Health, safety and environmental problems due to insecticide drift or runoff, whether real or perceived, can rule out the use of insecticides. There have been many cases where insecticides could not be used or had to be used with extreme caution because orchards were located too close to springs, wells, streams, rivers, lakes, homes, farms, or urban areas.

## IMPROVE PEST MANAGEMENT TACTICS

With few exceptions, orchard managers apply insecticides on a preventive basis to control cone and seed insect pests. Two ways to make insect pest management more efficient are to develop methods for predicting the need for control and to time controls.

### DEVELOP TECHNIQUES TO PREDICT THE NEED FOR CONTROL

It is very difficult to predict losses caused by insects. Relatively few successful examples exist for agriculture, fewer still for forestry, and practically none for cone and seed insects in seed orchards. Sweeney (1994) discusses some of the difficulties involved in developing sample techniques for cone and seed insects. One exception is the egg sampling technique for the Douglas-fir cone gall midge, *Contarinia oregonesis* Foote (Miller 1986). Insect populations are affected by many biological and environmental factors and their interactions. Practical techniques for predicting losses must be reliable, inexpensive and easy to use. Cone and seed insects are particularly difficult to sample because low numbers cause substantial damage and they spend long periods of the time in life stages that are small and well hidden. These low numbers have a highly variable distribution within the orchard and the large spatial area of the tree crowns. To be most useful, prediction methods should be available for all the key pests for each host species. Otherwise, orchard managers will most likely opt for preventive sprays.

### DEVELOP TECHNIQUES FOR TIMING CONTROLS

There are a number of ways to time controls to coincide with periods of maximum vulnerability in the life cycle of an insect pest, if such periods are known. A readily identifiable event in the phenological development of the host can be used. An example for an important *Dioryctria* species on loblolly pine is described below.

Degree-day models are based on the fact that insect growth is largely controlled by temperature. Temperature development relationships have been determined for the southern coneworm, *Dioryctria amatella* (Hulst) (Hanula *et al.* 1987). Studies on the relationship between temperature and development of the leaffooted pine seed bug, *Leptoglossus corculus* (Say) and the shieldbacked pine seed bug, *Tetyra bipunctata* (Herrich-Schäffer) are currently underway in my laboratory. The challenge is to develop and demonstrate the reliability of degree-day models that are easy to use.

## INCREASE KNOWLEDGE OF SEED ORCHARD ECOLOGY

Research on cone and seed insects has focused on the general biologies and impacts of the major cone and seed insect pests. However, we know relatively little about interactions among these insects and other arthropod species found in seed orchards, the role of natural enemies in regulating these pests, or potential for problems with secondary insect pests. Understanding these biological details is essential to the development of new control strategies. Such knowledge can be the key to successful insect control and can prevent unforeseen problems. Two examples illustrate these points.

Observations of the webbing coneworm, *Dioryctria disclusa* Heinrich, led to the discovery that young larvae feed in the catkins of loblolly pines before attacking second-year cones. We discovered that these larvae were highly vulnerable to sprays applied within 7 days after peak pollen flight, just before they attack cones. Using this "7-day window of opportunity" to control the webbing coneworm is very reliable.

Outbreaks of secondary insect pests occurred when pyrethoid insecticides were first introduced for cone and seed insect control in southern pine seed orchards in the early 1980s. Pydrin® caused the most severe problems. These outbreaks occur because Pydrin® residues stay on pine foliage longer than those of other insecticides (Nord and DeBarr 1992). This residual activity provides excellent control of cone and seed insects; it also kills natural enemies of scale insects (Clarke *et al.* 1988), but not the scale insects. In contrast, Capture® was almost as toxic to the scale insects, as Guthion® (Clarke *et al.* 1992).

## DEVELOP NEW CONTROL STRATEGIES AND TACTICS

Seed orchards offer one of the most ideal situations in forestry to implement new approaches to insect pest management. Crop values are high and orchard sizes provide clearly defined areas for treatment. Skilled managers and rapid communication through the tree improvement cooperatives, make technology transfer easy. Some new approaches that are potentially useful for cone and seed insect control include cultural control, pathogenic microbials, behavioral chemicals and biocontrol. As the following examples show, each approach has its strong and weak points.

Cold water sprayed on Douglas-fir orchards prevents cone gall midge attacks by delaying female strobili development (Miller 1983). Limitations include the high costs for irrigation equipment and lack of control during years with cool temperatures. However, if the use of dimethoate, the insecticide commonly used to control the midge is banned, this tactic might be more acceptable. Prescribed fire kills overwintering cone beetles, *Conophthorus coniperda* (Schwarz), in eastern white pine seed orchards. Since EPA rescinded the registration of Furadan® in 1992, fire is the only alternative available for cone beetle control in the Southern United States and it has been used in several seed orchards. Major limitations are adequate fuel, relatively few days with optimum condition for burning and concern over the effects of repeated fires on tree health.

The microbial insecticide, *Bacillus thuringiensis* Berliner (Bt), will control some coneworm species. However, Bt only affects certain insect groups and will not kill seed bugs. There are many species of parasites and predators of cone and seed insect pests (Yates 1989), but we know little about their contribution to natural control in seed orchards. It seems likely that natural enemy populations are severely affected by the routine use of insecticides in seed orchards. Augmentation of natural enemies through rearing and release seems impractical in most cases, but less frequent use of more selective insecticides will conserve these potentially useful insects in seed orchards. The use of synthetic pheromones, attractants and inhibitors to modify insect behavior through such techniques as trap-out or male confusion offers promise, but much additional basic and applied research will be necessary to develop techniques that provide reliable cone and seed insect control. These chemicals are also subject to many of the same constraints and complexities of registration, production and marketing, as are traditional chemical insecticides.

Unfortunately, methods such as these are likely to be less reliable and more expensive than chemical insecticides. Therefore, even if these approaches prove to be effective, they may not be widely used, as long as chemical insecticides are available. To compete with insecticides, new tactics and strategies must be cheaper, more effective, offer environmental advantages or be easier or safer to use than the currently registered insecticides.

## CONCLUSIONS

Our knowledge of cone and seed insects and insect pest management in forest tree seed orchards has greatly increased during the past 25 years. The formidable challenges we face today are even more complex than those that we have confronted in the past. Research will lead to the discovery of new and better ways for dealing with cone and seed insect pests. However, there is a wide gap between the promise of research and practical pest management techniques. Continued cooperation by tree improvement specialists and forest entomologists is necessary to bridge this gap and ensure that managers have the tools they need to produce the large quantities of genetically improved seed essential for the success of applied tree improvement efforts in the United States and Canada.

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# ONTARIO'S SEED ORCHARD PROGRAM: AN UPDATE

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## ABSTRACT

The seed orchard program in Ontario is coordinated by the Ontario Tree Improvement Board. Members of this organization currently manage over 60 conifer seed orchards located across the province. Pest priorities range from mortality factors in orchards still being established to factors causing cone and seed loss in producing orchards. The implementation of control measures is complicated by limited staff, the distance between sites, and variation in the extent of site preparation.

## RÉSUMÉ

En Ontario, le programme de gestion des vergers à graines est dirigé par le Conseil pour l'amélioration des arbres de l'Ontario. Actuellement, les membres de cet organisme s'occupent de plus de 60 vergers de conifères, répartis dans l'ensemble de la province. En matière de lutte contre les ravageurs, divers points sont considérés en priorité, depuis les facteurs de mortalité dans les vergers en voie d'établissement, jusqu'aux facteurs causant les pertes de cônes et de graines dans les vergers en production. La mise en œuvre des mesures de lutte est difficile, car le personnel est peu nombreux, les vergers sont éloignés les uns des autres et le terrain n'a pas été préparé partout au même degré.

## BACKGROUND

In 1992, the Canadian Council of Forest Ministers produced a document describing a framework for the implementation of sustainable forestry practices (CCFM 1992). This report outlines a series of strategic directions for forest management in Canada. One of the concepts embraced within this document is a commitment to conserve the natural diversity of our forests while maintaining or enhancing their productive capacity and providing for their renewal. It is within this context that the delivery of the tree improvement program has been restructured under the Ontario Tree Improvement Board (OTIB).

The OTIB was legally incorporated as a not-for-profit company in April, 1993. In addition to coordinating intensive tree improvement programs across the province, its goals include gene conservation and the management of seed source to ensure that planting stock is adapted to the sites on which it is deployed. The organization provides a single entity that is committed to implementing a broad spectrum of programs within the spirit of the Canadian Council of Forest Ministers' strategic directions. This summary focuses on the intensive tree improvement program of OTIB and, in particular, seed orchards.

Under the OTIB umbrella, the province has been divided into 6 administrative zones, each of which receives the support of a specialist in tree improvement. Each of these zones is an autonomous cooperative involving the Ministry of Natural Resources, forest products companies, and other interested organizations. Local program priorities are set by Steering Committees made up of senior management representatives from each member of the cooperative, and program implementation is coordinated by local Operations Committees. The roles and responsibilities of the members are outlined in Memoranda of Understanding.

The organization is driven by local priorities and needs. At the provincial level, each organization actively participating in a zonal cooperative program has representation among the members of the corporation. Technical issues are addressed through the activities of a Technical Committee, and the Ministry of Natural Resources has committed to provide analytical and scientific advice to the program. As a part of this commitment, a tree improvement pest management specialist provides technical support to the operational programs.

## PROGRAM SIZE

Ontario has been active in tree improvement since the late 1950s, when clonal orchards were established for black, *Picea mariana* (Mill.) B.S.P., and white spruce, *P. glauca* (Moench) Voss, near Longlac. Since then, the program has grown in size and complexity. There are over 60 active breeding populations (conceptually, a seed orchard and its associated genetic tests) in the province. The largest effort is being directed at managing black spruce and jack pine seed orchards, since these species make up most of the stock used in reforestation efforts. A total of 21 black spruce and 27 jack pine seed orchards are being actively managed. Orchards of these species are planted using open-pollinated seedlings. In addition, there are 12 white spruce and 8 white pine grafted seed orchards located across the province. In all, over 500 hectares of seed orchards are being managed.

## PROBLEMS AND PRIORITIES

Because the program is so large, various parts of it are at different levels of maturity. Some seed orchards are entering the fully producing stage, while others are still being established. For this reason, pest priorities differ dramatically across the province. For younger seed orchards still in the establishment phase, factors that influence early survival and growth are most important. As orchards mature, emphasis shifts towards agents that damage cones and seed and reduce seed yields.

Across the province, seed orchards have been established in a wide variety of site conditions. The extent of land preparation varies widely, from intensively prepared agricultural-type sites, through to full-tree logged cutovers. The less intensively prepared sites have created obvious limitations in site accessibility, and maintenance standards tend to be lower. This creates problems that carry through the entire productive life of the orchard. Competition from other vegetation tends to be more severe, implementing pest management measures is limited by equipment accessibility, and there is a greater risk of alternate hosts for diseases such as cone rusts being present. These factors all contribute to generally slower tree growth, delayed cone production, and reduced seed yields.

Seed orchards on more intensively prepared sites suffer from different problems. Maintenance standards are generally higher -nutrient availability and competing vegetation are more closely monitored. Accessibility is less of a constraint, which offers greater flexibility in implementing pest management programs. Many of these sites suffer from very low organic matter in the soils because of the severity of the land clearing operation. This, coupled with the selection of extremely sandy soils, has severely stressed the black spruce orchards established on these sites. Excessive frost heaving and *Armillaria* root rot have caused high losses, and the droughty, nutrient-poor soils have slowed growth, despite efforts to irrigate and fertilize such sites.

Effective pest management solutions for Ontario can only be implemented within the context of the limitations faced by the staff managing these sites. Financial and staff resources are presently severely restrained, and this situation is not likely to change. For many seed orchard managers, their orchard management responsibilities are a minor part of their overall duties. They are also involved in other forest management activities which might range from fisheries and wildlife work to silviculture, and may be unavailable during critical times. In addition, one person often manages several widely separated seed orchards. The logistics of travel between sites that are several hours apart make time-sensitive activities difficult to accomplish.

## PESTS

Pests that cause tree mortality or severe growth reduction not only increase orchard establishment costs but also reduce the choice for selection when seed orchards are rogued, resulting in lower genetic gains. When entire families are lost, the genetic balance of a seed orchard can be disrupted.

Across Ontario, the root disease, *Armillaria ostoyae* (Romagn.) Herink, eastern spruce budworm, *Choristoneura fumiferana* (Clemens), and white pine weevil, *Pissodes strobi* Peck, are the most common pests causing severe growth loss or tree mortality. A recent Forest Insect and Disease Survey of Ontario seed orchards detected *A. ostoyae* in 39% of black spruce and 42% of jack pine evaluations, *C. fumiferana* in 89% of black spruce evaluations and *P. strobi* in 65% of black spruce and 100% of jack pine evaluations (Hopkin 1994). Mortality can result when young establishing seed orchard trees are attacked or defoliated over consecutive years by the white pine weevil or the eastern spruce budworm. When seed orchard trees are older, white pine weevil damage promotes tree bushiness. Establishment on sandy sites, resulting in drought stress, coupled with residual inoculum in stumps and roots from the previous stand, may account for the high incidence of *Armillaria* root disease observed in many black spruce orchards.

Any pest that causes mortality or terminal shoot damage reduces the quality of information that can be attained from genetic progeny tests by increasing the environmental variation in growth traits. This reduces heritability and results in lower genetic gains. The foremost damaging agent in this category is the white pine weevil. The pine shoot borer, *Eucosma gloriola* Heinrich, also causes significant leader damage in jack pine progeny tests.

Many seed orchards in Ontario are on the verge of cone production. One of the major factors causing cone and seed loss in black spruce seed orchards will likely be grazing damage by lepidopteran larvae. In Newfoundland, 94% of the cones from 40-45 year old black spruce trees were grazed by eastern spruce budworm larvae, resulting in 24% average mortality of female reproductive structures (Schooley 1980). In a 30-35 year old stand of black spruce near Sault Ste. Marie, Ontario, 61.8% and 44.4% of the cones were grazed by lepidopteran larvae in two consecutive years (Prévost *et al.* 1988). A complex of 12 lepidopteran species, including *C. fumiferana*, was responsible for the cone grazing damage (Prévost *et al.* 1988).

Significant eastern spruce budworm grazing damage to black spruce cones in the absence of significant defoliation has been observed (Schooley 1980). A Forest Insect and Disease Survey detected *C. fumiferana* in 89% of black spruce seed orchard evaluations, and average incidence within orchards was 50-60% (Hopkin 1994). However, defoliation was classified as light (1-25%) in almost all of the evaluations. The impact of eastern spruce budworm on cone crops has not been evaluated in Ontario's black spruce seed orchards.

The spruce cone maggot, *Strobilomyia neanthracina* Michelsen, will likely be the insect causing the most damage to black spruce cones next to lepidopteran grazers (Turgeon and de Groot 1992). *S. neanthracina* at three sites in Newfoundland damaged 22.9%, 30.1% and 41.3% of black spruce cones (West 1986).

Jack pine appears to be less susceptible to cone and seed damage by insects than is black spruce. Insect damage resulted in an average 1% conelet loss and 4.9% cone loss at three plantations in North Central Ontario (de Groot 1986).

Significant cone loss in Ontario seed orchards will result from cone harvesting by squirrels. The red squirrel, *Tamiasciarus hudsonicus* Erxleben, harvested 18.8% of black spruce cones (Prévost *et al.* 1988) and 31% of jack pine cones (de Groot 1986) at sites in Ontario.

## SUMMARY

Because seed is our product and orchards are now coming into production, cone and seed pests are currently a major concern to Ontario's seed orchard program. Questions about management of these pests will become more common over the next five years as more orchards enter the production phase of their life cycle. While issues of mortality and growth will always be present, these can be better addressed through proper site selection, preparation, and management to create environments that promote tree health.

Pest management solutions must recognize the limitations faced by the field staff who implement them. However, they cannot be designed to the lowest common denominator. A range of options must be presented which could be applied under both extensive and intensive management regimes and under a wide variety of site conditions. A major challenge will be to document the effectiveness of more intensive management practices.

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FRONT COVER PICTURE:
Norway spruce, *Picea abies* (L.) Karst, seed cone (taken by BF Zylstra)

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PHOTO DE LA COUVERTURE:
Cône d'épinette de Norvège, *Picea abies* (L.) Karst, (BF Zylstra)