Chapter 23

Insect Pest Management

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Summary

The success of regeneration programs at all stages of development, from seeds and cones to nurseries, plantations, and maturing forests, can often be limited by insects. Many of the problems are caused by native insects in their natural habitats; others arise because an artificial ecosystem has been created, providing an environment favourable to an insect or group of insects. In some cases, the problem is an introduced insect that gains a foothold in a new location in the absence of its native parasites and predators.

When insects attack seeds or cones, they either prevent them from forming or they eat them. Most of these insects are native to Ontario. The insects that affect nursery production are usually generalists. They often invade from surrounding habitats to take advantage of abundant host material and low populations of predators and parasites.

Plantations also create an artificial ecosystem of abundant host trees. The practice of regenerating to a preferred species often results in pockets of individual trees on poor microsites. This favours insects, which overcome the defences of stressed trees. The common pests of plantations include both native and introduced insects, such as defoliators and shoot feeders. Many of these problems become less intense once a stand reaches crown closure.

Both native and introduced pests attack maturing forests, sometimes affecting millions of hectares of forest.

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These insects, especially the defoliators, can significantly alter stand composition and rates of succession.

Many insect problems can be prevented through good forest management planning and suitable silvicultural practices. Nevertheless, insect problems will still occur. When they do, most can be managed through the judicious use of insecticides, or by cultural or mechanical methods. A management strategy for insects at all the stages of regeneration must do the following:

- incorporate insect management into other management programs and objectives
- anticipate and plan for their occurrence
- design silvicultural programs to reduce the impact of the pests
- conduct effective monitoring to detect, identify, quantify, and forecast pest problems
- take timely remedial action to reduce potential losses
- evaluate insect management strategies and adjust them accordingly

Insects will continue to affect the success of forest regeneration. Among the challenges for insect pest management will be the availability of effective, safe, socially acceptable insecticides; the reactions of insects to the effects of intensive silviculture on the forest; and introduced insects with potential to significantly affect native trees.

23.1 Introduction

Insects are a significant factor in the regeneration of Ontario's forested lands. As pests, they cause average annual losses of 11.4 million m^3 on over 40.3 million ha; this compares to annual harvest levels of approximately 24.6 million m^3 (Ont., MNR 1996; Can., Nat. Resour. 1997; Scarr et al. 1999). Insects make up the greatest portion of biological diversity in forest ecosystems, and they provide major links within community food webs, contributing extensively to carbon breakdown and nutrient recycling (Schowalter et al. 1997).

The recent emphasis on sustainable forest management has had a twofold effect on how insects are viewed in the forest. Their ecological function is now being examined more carefully. This includes both their response (at the level of individual ecology or overall biodiversity) to changes in forest structure after natural and human disturbances, and their ecological function as intermediaries between vegetation and larger groups of animals (small mammals, amphibians, and birds).

With the increased emphasis on addressing potential wood supply shortages given the constraints of sustainable forest management, "new" forest insect pests have appeared that require innovative approaches to pest management (Smith 1990). These new pests include species that have moved onto regeneration from agricultural crops or natural forests; established indigenous species whose effects are now more significant because of our increased need for fibre; species that take advantage of our changes to forest structure and composition; and introduced (i.e., exotic) species that have become established in the province.

A third way that insects in the forest are being viewed is in response to predictions about global warming, such as the question of what tree species will make up the forest of the future and which insects will be serious pests (Fleming and Volney 1995).

While the majority of insects encountered by a forest manager will be integral to the ecosystem, and thus beneficial or innocuous, several will be pests requiring intervention to reduce damage to the regenerating forests. This chapter contains information on important insects in the four stages of forest regeneration: seed and cone production, nursery production, young plantations, and naturally maturing forests.

23.2 Seed and Cone Production Areas

In Ontario, most seed orchards are just beginning, or will soon begin, to produce seeds (Chap. 8). Seed production can fail for four main reasons: pollination failure, resource deficiency, developmental failure, or predation (Fenner 1985; see also Chap. 13). Seed predators include insects, mites, mammals, and birds (Janzen 1971; Marquis et al. 1976; Hedlin et al. 1980; Rose and Lindquist 1982; Sallabanks and Courtney 1992). In Ontario, our knowledge of predators of conifer seed cones and hardwood seeds is limited to the pre-dispersal phase, when seeds are still on the parent tree. Historically, surveys have concentrated on seed cones of economically important Pinaceae such as fir, larch, spruce, and pines (Rose and Lindquist 1984; 1985; Hedlin et al. 1980; de Groot et al. 1994).

Insects affect seed production either directly by feeding on seeds or on seed structures (e.g., cones) at any stage of development, or indirectly by damaging twigs and branches that bear reproductive structures (Janzen 1971). Of those affecting seed production directly, only insects that actually feed on the plant (as opposed to the fungi associated with them) significantly reduce the quantity of seed. The following section provides an overview of the diversity of insects exploiting conifer and hardwood seeds in Ontario, their impact, a summary of methods available to predict populations, and options available for control.

23.2.1 Richness and Diversity of Insect Species

Approximately 50 species of insects attack conifer seed cones in Ontario (Table 23.1), and most of these require seeds to complete their development (Turgeon 1994). They belong to six orders: Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, and Lepidoptera, of which the Lepidoptera has the greatest number of important species and genera. Detailed information for most of these insects is available in Rose and Lindquist (1980; 1984; 1985), Ruth (1980), Hedlin et al. (1980), Churcher et al. (1985), Syme and Nystrom (1988), and Turgeon and de Groot (1992). Limited information is available on insects attacking seed cones of red spruce, pitch pine, eastern hemlock, eastern white cedar, eastern red cedar, and Canada yew.

Only 18 species of insects are known to attack hardwood seeds (Table 23.2), but our information is most certainly incomplete. These insects belong to the same orders as those that attack conifers except that there is no record of Homoptera attacking hardwood seeds. Again, the Lepidoptera is the most diverse group of hardwood seed predators. Supplementary information is available on the biology of these insects in Rose and Lindquist (1982) and on their impact in Syme and Nystrom (1988.

Table 23.1 Insects attacking conifer seed cones in Ontario

Species	Common name[a]	Host(s) genus	Impact[b]	References
Coleoptera				
Anobiidae				
Ernobius schedli Brown		*Picea*	L	Sweeney et al. 1993
Scolytidae				
Conophthorus coniperdo (Schwarz)	White pine cone beetle	*Pinus*	S	Turgeon and de Groot 1992
Conophthorus resinosae Hopkins	Red pine cone beetle	*Pinus*	S	Turgeon and de Groot 1992
Trogositidae				
Tenebroides spp.	Cadelle	*Picea*	L	Prévost et al. 1988
Diptera				
Anthomyiidae				
Strobilomyia abietis (Huckett)				
Strobilomyia appalachensis Michekseb	Black spruce cone maggot	*Picea*	S	Michelsen 1988, Turgeon and Sweeney 1993
Strobilomyia carbonaria (Ringdahl)		*Abies*	U	Turgeon (unpublished data)
Strobilomyia laricis Michelsen	Larch cone maggot	*Larix*	S	Michelsen 1988, Turgeon and de Groot 1992
Strobilomyia neanthracina Michelsen	White spruce cone maggot	*Picea*	S	Michelsen 1988, Turgeon and Sweeney 1993
Strobilomyia viaria (Huckett)	Tamarack cone maggot	*Larix*	L	Michelsen 1988, Turgeon and de Groot 1992
Cecidomyiidae				
Asynapta hopkinsi (Felt)	Cone resin midge	*Pinus*	L	Gagné 1989, Turgeon and de Groot 1992
Dasineura spp.		*Abies*	U	de Groot et al. 1994
Kaltenbachiola canadensis (Felt)	Spruce cone gall midge	*Picea*	L	Gagné 1989, Turgeon and de Groot 1992
Kaltenbachiola rachiphaga (Tripp)	Spruce cone axis midge	*Picea*	L	Prévost et al. 1988, Gagné 1989, Turgeon and de Groot 1992
Mayetiola carpophaga (Tripp)	Spruce seed midge	*Picea*	L	Gagné 1989, Turgeon and de Groot 1992
Plemeliella spp.		*Picea*	L	Gagné 1989, de Groot et al. 1994
Resseliella spp.		*Larix, Picea, Pinus*	L	Gagné 1989, de Groot et al. 1994
Lonchaeidae				
Earomyia spp.		*Larix, Abies*	L	Rose and Lindquist 1985, Turgeon and de Groot 1992
Hemiptera				
Scutellaridae				
Tetyra bipunctata (Herrich-Schäffer)	Shield backed pine seed bug	*Pinus*	U	Turgeon and de Groot 1992
Homoptera				
Aphididae				
Mindarus spp.		*Picea*	U	Prévost et al. 1988
Hymenoptera				
Torymidae				
Megastigmus atedius Walker	Spruce seed chalcid	*Picea, Pinus*	L	Turgeon and de Groot 1992
Megastigmus laricis Marcovitch	Larch seed chalcid	*Larix*	L	Turgeon and de Groot 1992
Megastigmus specularis Walley	Balsam fir seed chalcid	*Abies*	U	Rose and Lindquist 1985

Table 23.1 *continued*

Species	Common name[a]	Host(s) genus	Impact[b]	References
Lepidoptera				
Blastobasidae				
Holcocerina immaculella (McDonnough)		*Larix, Picea, Pinus*	L	Prévost et al. 1988, de Groot et al. 1994
Coleophoridae				
Coleophora laricella (Hubner)	Larch case bearer	*Larix*	U	Prévost 1995
Gelechiidae				
Coleotechnites atrupictela (Dietz)		*Picea*	L	Prévost et al. 1988
Coleotechnites blastovora (McLeod		*Picea*	L	Prévost et al. 1988
Coleotechnites laricis (Reeman)	Orange larch tube maker	*Larix*	L	Prévost et al. 1988
Coleotechnites piceaella (Kearfott)	Orange spruce needle miner	*Picea*	L	Prévost et al. 1988
Geometridae				
Eupithecia albicapitato Packard		*Picea*	L	Churcher et al. 1985, Turgeon and de Groot 1992
Eupithecia mutata Pearsall	Spruce cone looper	*Picea*	L	Churcher et al. 1985, Turgeon and de Groot 1992
Pyralidae				
Dioryctria abietivorella (Grote)	Fir cone worm *Pinus*	*Larix, Picea,*	O	Turgeon and de Groot 1992
Dioryctria disclusa (Heinrich)	Webbing cone worm	*Pinus*	O	Turgeon and de Groot 1992
Dioryctria reniculelloides Mut. & Mun.	Spruce cone worm	*Larix, Picea, Pinus*	O	Turgeon and de Groot 1992
Dioructria resinosella Mutuura		*Pinus*	U	de Groot et al. 1994
Herculia thymetusalis (Walker)		*Picea*	L	Prévost et al. 1988
Tortricidae				
Acleris vaiona (Fernald)	Eastern blackheaded bud worm	*Picea*	L	Prévost et al. 1998
Archips packardiana (Fernald)	Spring spruce needle moth	*Picea*	L	Prévost et al. 1998
Archips alberta (McDonnough)		*Picea*	L	Prévost et al. 1998
Barbara mappana Freeman		*Abies, Picea*	L	Syme and Nystrom 1988, de Groot et al. 1994
Choristoneura fumiferana (Clemens)	Spruce bud worm	*Larix, Picea*	O	Churcher et al. 1985, Prévost et al. 1988
Choristoneura pinus pinus Freeman	Jack pine bud worm	*Pinus*	O	Turgeon and de Groot 1992
Choristoneura rosaceana (Harris)	Oblique banded leafroller	*Larix, Picea*	L	Prévost et al. 1988
Cydia strobilella (L.)	Spruce seed moth	*Picea*	O	Churcher er al. 1985, Turgeon and de Groot 1992
Cydia toreuto (Grote)	Eastern pine seed moth	*Pinus*	O	Turgeon and de Groot 1992
Eucosma monitorano Heinrich	Red pine cone borer	*Pinus*	O	Turgeon and de Groot 1992
Eucosma tocullionana Heinrich	White pine cone borer	*Pinus*	L	Turgeon and de Groot 1992
Spilonata lariciano Heinrich	Brown larch	*Larix*	L	Prévost 1995
Zeiraphera canadensis Mutuura and Freeman	Spruce bud moth	*Picea*	L	Churcher er al. 1985
Zeiraphera destitutana (Walker)	Purple striped shoot worm	*Picea*	L	Churcher et al. 1985
Zeriaphera improbana (Walker)	Larch bud moth	*Larix*	U	Prévost 1995

a As given by P. Benoit (1985) in *Insect Names in Canada* or in other published material.
b The impact of this insect is either of low (L), significant (S), occasionally significant (otherwise low) (O), and unknown or undetermined (U) importance.

23.2.2 Pest Damage and Impact

Several keys describing insect damage are available to aid in identifying insects that attack seed crops of conifers (Hedlin et al. 1980; Turgeon and de Groot 1992) and hardwoods (Rose and Lindquist 1982). If it is impossible to identify an insect with these keys, specimens may be sent to the taxonomic laboratory of the Canadian Forest Service. A copy of the submission form, together with instructions, is provided in Turgeon and de Groot (1992).

Damage by most insects that specialize in attacking conifer or hardwood seeds is often difficult to detect because infested structures cannot always be separated from healthy ones by outward appearances (de Groot et al. 1994). The symptoms of attack are often not visible before harvest (Rose and Lindquist 1982; Turgeon and de Groot 1992; de Groot et al. 1994). Symptoms of attack by other insects are visible only when the infestations are heavy enough to kill the cones or parts of them (Hedlin et al. 1980). In most instances, damage by defoliators to seeds or seed cones is easy to see because it takes the form of surface feeding.

The number of seeds destroyed per insect varies (see de Groot et al. 1994, Table 2). In some species (e.g., seed chalcids (*Megastigmus*) or spruce seed midge (*Mayetiola*), each larva consumes one seed during its development. Conversely, a single cone maggot or seed moth larva will mine most of the cone it infests, even though it rarely kills all the viable seeds (Tripp and Hedlin 1956; Prévost et al. 1988; J.J. Turgeon, unpublished data). At the other extreme, one cone beetle adult destroys all the seeds of several cones (Turgeon and de Groot 1992). The individual impact of most defoliators on seed production is usually small, unless it occurs during outbreaks of pests such as budworms. The combined effects of all defoliators, however, can be significant (Prévost et al. 1988). The most destructive and economically important specialists that attack conifers are cone beetles, cone maggots, seed moths (*Cydia*), cone worms, and cone borers (*Eucosma*) (Table 23.1). The budworms are undoubtedly the most devastating generalists. Significant damage has been reported occasionally for hardwoods, but only for a few species (Table 23.2).

Table 23.2 Insects damaging hardwood seeds in Ontario

Species	Common name[a]	Host(s) genus	Impact[b]	References
Coleoptera				
Curculionidae				
Apion nigrun Herbst	Black locust: see weevil	*Robinia*	L	Syme and Nystrom 1988
Apion simil Kirby	Birch catkin weevil	*Betula*	L	Rose and Lindquist 1982, Syme and Nystrom 1988
Conotracheus juglandis Le Conte	Butternut curculio	*Juglans*	O	Rose and Lindquist 1982, Syme and Nystrom 1988
Conotracheus spp.		*Quercus*	U	Rose and Lindquist 1982
Curculio spp.		*Quercus*	U	Rose and Lindquist 1982
Thysanocnenis spp.		*Fraxinus*	L	Osborn et al. (Unpublished data)
Diptera				
Tephritidae				
Rhagoletis sompleta Cresson		*Juglans*	O	Osborn et al. (Unpublished data)
Rhagoletis uavis (Loew)		*Juglans*	O	Osborn et al. (Unpublished data)
Hemiptera				
Lygeidae				
Kleidocerysresedae geminatus (Say)	Birch catkin bug	*Betula*	L	Rose and Lindquist 1982, Syme and Nystrom 1988
Pentatomidae				
Meadorus hteralis (Say)	Mottled stink bug	*Betula*	L	Rose and Lindquist 1982, Syme and Nystrom 1988
Rhopalidae				
Leptocoris rivittatus (Say)	Box elder bug	*Acer, Fraxinus*	L	Rose and Lindquist 1982, Syme and Nystrom 1988
Hymenoptera				
Cynipidae				
Callirhytis nuercus operator (Osten Sacken)	Wolly blossom gall wasp	*Quercus*	O	Rose and Linquist 1982, Syme and Nystrom 1988
Lepidoptera				
Blastobasidae				
Valentinia dandulella (Riley)	Acorn moth	*Quyercus, Carya, Castanea*	L	Rose and Linquist 1982, Syme and Nystrom 1988
Tortricidae				
Cydia caryna (Fitch)	Hickory shuckworm	*Carya*	O	Rose and Lindquist 1982, Syme and Nystrom 1988
Epinotia transmissana (Walker)	Birch catkin moth	*Betula*	L	Syme and Nystrom 1988
Gretchena lelicatana Heinrich	Ironwood fruitworm	*Ostreya*	L	Rose and Lindquist 1982, Syme and Nystrom 1988
Melissopus latiferreanus (Walsingham)	Filberworm	*Corylus, Quercus, Fagus*	L	Rose and Lindquist 1982, Syme and Nystrom 1988
Proteoteras aesculana Riley	Maple twig borer	*Acer, Aesculus*	O	Rose and Lindquist 1982, Syme and Nystrom 1988

a As given by P. Benoit (1985) in *Insect Names in Canada* or in other published material.
b the impact of this insect is either of low (L), significant (S), occasionally significant (otherwise low) (O), and unknown or undetermined (U) importance.

23.2.3 Assessing Pest Abundance and Seed Losses

Seed losses vary greatly among sites and years (de Groot et al. 1994). The management of these losses requires sampling and monitoring techniques for predicting seed loss before there is serious damage, and for timing the control measures and assessing their efficacy (Sweeney et al. 1990). At present such methods are available only for conifer pests. Although egg sampling at specific stages of cone development is probably the most accurate method of predicting seed loss (Turgeon et al. 1994), the sampling process is extremely labour-intensive, the eggs are often difficult to detect (Turgeon and de Groot 1992), and the time available to make management decisions is usually short. Thus, other methods of assessing population densities or predicting damage are required. The usefulness, reliability, and accuracy of traps that imitate the visual cues used by insects or that are baited with sex pheromones or other semio-chemicals are being investigated. The primary use of traps is to detect adult populations or monitor the initiation, duration, and population density of several species on conifer seeds (Grant 1990; Chau 1993). There are three methods of detecting and monitoring most seed cone pests found in Ontario: cone dissection, pheromone traps, and colour traps (Turgeon and de Groot 1992). Practical considerations for using pheromones in seed orchards, such as design, position, and number of traps, as well as source of traps and lures, are discussed by Grant (1994).

One way of assessing the effects of abiotic and biotic mortality agents is to construct cohort life tables for the cone crop (DeBarr and Barber 1975; Rauf et al. 1985; Katovich et al. 1989; Schowalter and Sexton 1989; de Groot and Fleming 1994). Life tables have been combined with mortality analysis of seeds to produce cone crop inventory and monitoring systems (Bramlett 1987; Dombrosky and Schowalter 1988; Huffman 1988; Fatzinger et al. 1990; de Groot et al. 1996; 1998).

23.2.4 Management of Seed Losses

Eventually most seeds (Chap. 13) required for the production of bareroot stock (Chap. 14) and container stock (Chap. 15) used for reforestation in Ontario will probably come from first-generation seed orchards (Rauter 1984). The pest management strategies that will be used in these orchards will depend on the insects involved; their life histories, habits, and population dynamics; location of the seed orchard; tree species; the tactics available; and the value and quantity of seed produced that year (de Groot and Turgeon 1992; de Groot et al. 1994; 1996; 1998). Although insecticides are currently the only practical tools available for operational insect control in the year of attack, more emphasis is now being placed on silvicultural and crop management practices that prevent the buildup of insect populations in orchards.

These include the removal and destruction of easily harvestable and abundant seed crops (Turgeon and de Groot 1992; de Groot et al. 1994); the removal and destruction (e.g., by prescribed fire) of mature cones (Wade et al. 1989) or seeds (Wright 1986) left on the tree or the ground; early collection of cones and quick extraction of seed; and destruction of unwanted cone crops before they mature. Other practices, such as delaying reproductive bud burst and tree topping, are aimed primarily at other objectives, but can have benefits in pest management. On the other hand, pest problems can be aggravated by certain practices that stimulate crop production (e.g., increased tree spacing, fertilization or hormonal treatments, girdling, and top or root pruning) in otherwise poor crop production years (de Groot et al. 1994). Turgeon and de Groot (1992) and de Groot et al. (1994) reviewed other practices and biological control agents tested in Canada and commented on their operational use. A world-wide overview is found in Turgeon et al. (1994).

Numerous systemic and contact insecticides have been tested against conifer seed pests in Canada (de Groot et al. 1994, Table 4). Most of the materials tested are not likely to be registered for use solely against seed insects. The only one registered for use against white spruce cone and seed insects is dimethoate, a systemic insecticide.

In Canadian seed orchards, all pesticides have been applied from the ground, although aerial application, common in the southeastern United States when trees become too tall for efficient treatment with ground spray equipment, is effective in protecting the seed crop. It also provides a quick and timely application. Because very few direct comparisons of application technologies (e.g., sprays versus injections, implants, topical applications, and soil incorporation) have been made in Canada, it is impossible to develop recommendations for their use (de Groot et al. 1994).

Turgeon and de Groot (1992) summarize the advantages and disadvantages of the equipment that is used from the ground for suppressing insects attacking conifers in seed orchards (e.g., backpack sprayers, hydraulic sprayers, airblast sprayers, and mist blowers). Fogal and Lopushanski (1988) discuss equipment which incorporates granular and liquid formulations into the soil. Other factors that contribute to the efficacy of chemical control, such as the method of application, timing, formulation, and dosage, have also been reviewed (de Groot et al. 1994).

23.3 Nursery Production

In the production of container and bareroot nursery stock (Chaps. 14 and 15), insects are of minor importance, accounting for about 20% to 25% of the damage observed in any year (Greifenhagen et al. 1992; 1993). The temporary nature of these nursery production systems discourages the buildup of high pest densities (Sutherland and Van Eerden 1980). Severe winters in open-grown fields also reduce the extent to which insect populations can reach damaging levels on bareroot stock. Many insects must re-invade seedling production areas each spring during their mobile life stages. This invasion is influenced by year-to-year seasonal variation in such factors as weather, which can result in unpredictable buildups of pest populations.

For the most part, insects which attack nursery seedlings are generalists that prefer young, succulent plant growth (Sutherland 1984). Slightly less than half the major pests feed on seedlings from below ground; the remaining species feed on above-ground plant parts (Landis 1990). This feeding results in seedling mortality or reduced seedling quality. Mortality is caused by defoliation, cutting of the stem, or injection of toxins. Quality loss results from the discoloration of foliage, stunting, the production of multiple or crooked leaders, and contamination of the foliage by insect webbing.

The importance of particular insect pests has changed over the years as the emphasis in nursery production has changed from bareroot to container stock (Sutherland et al. 1990). Containerized seedlings usually suffer less damage from insect pests than bareroot stock because they are grown in the nursery for a shorter period and in more controlled environments (Landis 1990). Considerable information is available about insect pests in nursery production on the west coast (Sutherland and Van Eerden 1980; Sutherland 1984; Landis 1990), but very little has been published in this area for Ontario (Brandt 1989; Sutherland et al. 1990; Greifenhagen et al. 1992; 1993). Information is also available on insect pests of nursery and landscape plants, but it does not deal with seedling growth during the first three years (Ont., MAFRA 1997).

23.3.1 Insects That Attack Seedlings Below Ground

Although seeds in the ground are rarely attacked by insects, young plants become susceptible shortly after germination. Because this damage cannot be seen, its extent is difficult to determine until it is too late to save the seedling (Landis 1990). Furthermore, the fact that these insects live in the soil makes them hard to control. This type of damage, therefore, is often greater than that which occurs above ground.

Insects in the soil are more serious in containerized systems than when bareroot stock is used, possibly because of the higher humidity and temperature (Sutherland 1984). Several species, such as fungus gnats, are sporadic pests in container seedlings (Greifenhagen et al. 1992; 1993), but because they are secondary feeders on the roots of seedlings, they can be controlled easily with cultural practices that result in healthy root systems (Landis 1990).

Root weevils (e.g., strawberry root weevil); the black vine weevil; European weevil (e.g., dark-sided cutworm); black cutworm; and variegated cutworm can be problems on a wide variety of plant species, especially in bareroot stock (Greifenhagen et al. 1992; 1993). The damage is caused by larvae feeding at night from the surface of the soil and is most noticeable on the edges of nursery plantings of either container or bareroot stock.

Weevil larvae are small, white grubs (2 to 10 mm), whereas cutworm larvae are large grey-brown caterpillars (10 to 20 mm), (Sutherland and Van Eerden 1980; Landis 1990). Both groups attack a wide range of plant species, cutting off the tops of seedlings or damaging the stems or needles at ground level. Cutworm damage is apparent in spring and early summer; weevil damage tends to appear in late summer or early fall (Sutherland and Van Eerden 1980). The clipped tops caused by cutworms are more noticeable, whereas weevils can feed for some time before the foliage becomes chlorotic and the seedlings die. Damage by both groups can be reduced by avoiding fallow fields or by controlling weeds. If this is not possible, then monitoring for the presence of adults (with light traps and pheromone traps for cutworms and direct observation and pitfall or shaded ground traps for adult weevils) will identify problem areas before damage occurs. Brandt et al. (1995) report a method for estimating larval densities of root weevils in order to assess the need for weed control. As direct control options, larvae can be hand-picked from containerized material, or chemicals or nematodes can be applied to the soil.

Leather jackets are a consistent, but limited, problem in bareroot and containerized seedling production (Greifenhagen et al. 1992; 1993). Like other root-feeding pests, they are generalists that eat a variety of vegetation (Sutherland and Van Eerden 1980; Landis 1990). Girdling (which is similar to root weevil damage) occurs on seedlings at the soil level, leading to wilting, browning, and death. In Ontario nurseries, damage has occurred primarily to conifers (Greifenhagen et al. 1992; 1993). Control is similar to that used for root weevils (Landis 1990).

White grubs are sporadic pests of bareroot stock but can cause serious damage in fields that were recently left fallow or planted to grasses or in fields surrounded by large areas of turf grass. White grubs are larvae of either the June beetle or the Japanese beetle. The former requires up to three years to complete a life cycle; the latter usually completes its cycle in one year (Sutherland and Van Eerden 1980; Ont., MAFRA 1997). The June beetle is a frequent pest in some nurseries, whereas the Japanese beetle is only a recent introduction to Canada but has the potential to become a problem. June beetles are most damaging in their second and third years of growth, feeding on seedlings of all species, especially pines and spruces, throughout the summer. The initial symptoms of a problem are patches of wilting and yellowing seedlings, followed quickly by localized seedling mortality. Control (recommended at > 3 to 5 grubs per 30 cm^2) is best achieved by prevention: avoid planting stock where grass is or has recently been growing. If this is not possible, chemical insecticide controls are available. Nematodes are being developed for this purpose, and although more expensive, they may be an option in the future. Light traps should be used to monitor for adult insects and to predict damaging populations (Sutherland and Van Eerden 1980; Greifenhagen et al. 1993).

23.3.2 Insects That Attack Seedlings Above Ground

The most commonly observed insects in the nursery are those that feed above ground; however, they are highly mobile and therefore difficult to detect. Unlike insects that feed in the soil, those above the ground move relatively quickly between compartments. This mobility can make detection and control difficult.

A wide number of insects attack the shoots of nursery stock in Ontario. Most are important only sporadically, such as pales weevil on pines and spruces; oblique-banded leafroller on red pine; and European pine shoot moth on red pine. Others, such as the defoliators, are incidental pests that move into seedling areas from adjacent older stands or plantings. Methods for their control are found in Ont., MAFRA (1997) and below in the section on young plantations.

Springtails and thrips are common problems of container and bareroot stock and may cause loss of seedling vigour and mortality (Sutherland and Van Eerden 1980). They have often been reported in Ontario nurseries; however, their significance is unknown and, at least for container stock, biological control agents are available (Hunter 1994).

Spider mites (e.g., spruce spider mite) have been reported on red pine and occasionally Norway spruce and white pine (Greifenhagen et al. 1992; 1993). All stages of mites feed and cause yellowing, mottling, and drying of the foliage. They are usually detected by webbing on the needles (Sutherland et al. 1990). The greatest damage is to seedlings in dry soils in arid regions of the nursery or during late summer or early fall (Sutherland and Van Eerden 1980). Spider mite damage is rarely observed in container stock. Control is achieved initially through increased irrigation and pressure washing of the foliage during the spring (Sutherland et al. 1990). Attention also should be paid to areas surrounding the beds because populations can be blown in from older trees. In severe infestations it may be necessary to apply miticides.

Both container and bareroot stock are attacked by adults and nymphs of plant bugs, such as *Lygus* bugs. These small sucking insects (2 to 10 mm long), which have two to three generations a year, feed on succulent young tips of seedlings (Sutherland et al. 1990). In Ontario *Lygus* species have been reported on seedlings of pines (jack, red, and white) and spruces (black and Norway). Damage occurs to all age classes of seedlings, although first-year bareroot stock appears to be most susceptible. Generally, there is more damage around the edges of the nursery, where adults fly in from adjacent agricultural fields (especially those containing alfalfa, clover, or wildflowers) (Sutherland et al. 1990). Often, damage caused by *Lygus* bugs is difficult to identify because the adults move into the compartments during the early morning or late evening but fly to adjacent agricultural fields during midday. The subsequent chlorosis, twisting and stunting of shoots, and multiple leaders are not observed until several weeks after actual attack. If *Lygus* is thought to be the problem, it is important to monitor for adults with large sticky traps. Although not always successful, this approach will help to determine if and when adults are moving into the fields (Sutherland et al. 1990; Landis 1990). The more stationary nymphs can be controlled with insecticides, applied approximately every two to four weeks.

Other sucking insects (e.g., aphids, adelgids, leafhoppers, and whiteflies) are also widespread on nursery stock, often originating from agricultural areas. All feed on seedlings both as adults and immature nymphs (wingless forms of the adults), have many generations a year, and cause similar damage (Sutherland and Van Eerden 1980). In Ontario, aphids have been reported mostly on container stock of white, jack, and red pine (white pine aphid and pine bark adelgid) and Norway and white spruce (balsam twig aphid, spruce aphid, spruce gall adelgid, and woolly adelgids) (Greifenhagen et al. 1992; 1993). Leafhoppers (e.g., potato leafhopper), can cause "hopper burn" on bareroot willow, poplar, and red oak. Whiteflies have been reported in container stock of several broadleaf species.

Feeding by aphids and adelgids causes leaf or needle twisting or curling, or the formation of galls; feeding by leafhoppers results in chlorosis and, in extreme cases, death. Although aphids can be very common, control is rarely necessary because they do not kill the seedlings (Sutherland et al. 1990). Careful observation of seedling beds will ensure that the populations can be kept low through manual removal of infested plants. A number of natural enemies (predators and parasitoids) can be purchased for biological control in container stock (Hunter 1994). If these measures are not sufficient, insecticidal soaps, horticultural oils, and chemical insecticides can be used. Leafhoppers can cause severe damage, especially towards the end of the season after their populations build up. Here again, monitoring is important for predicting high infestations before damage is observed. Chemical insecticides can be used if necessary.

Defoliators (e.g., hymenopteran sawfly and lepidopteran moth larvae) can cause sporadic but significant damage, especially when compartments are adjacent to older stands. The important species include gypsy moth on red oak, jack pine budworm on red pine, spruce budworm on white and black spruce, red-headed pine sawfly on red pine, and yellow-headed spruce sawfly on white spruce (Greifenhagen 1994). Specific life cycles and control options are described in the following section, as well as by Armstrong and Ives 1995; Rose and Linquist (1980; 1982; 1984; 1985), and USDA (1985).

23.4 Young Plantations

Plantation insect pests come and go at different times in the life of the stand. Some arrive at the seedling stage and disappear within a year, whereas others arrive at flower production and disappear at crown closure. In Ontario, few insects regularly have a significant effect on the establishment and survival of trees in plantations. With the exception of the white pine weevil, most pests cause only occasional, localized damage. When damage does occur, however, it can result in the complete failure of a plantation.

23.4.1 White Pine Weevil

The most damaging insect pest of white pine plantations in Ontario is the white pine weevil. Along with white pine blister rust, it limits the regeneration of white pine throughout the province. It can also affect the regeneration of jack pine and Norway spruce.

The biology of the weevil has been described by Wallace and Sullivan (1985). The adults lay eggs in the tree leaders, and the larvae feed down the leader during the early summer. This damage girdles the stem, causing the terminal shoot to wilt and die. The result is lateral branching, loss of two to three years of tree height growth, crooked stems (Fig. 23.1), and poor timber quality (Gross 1985). In severe cases, growth is retarded to the point where the tree is out-competed by adjacent trees, and dies. Damage is recognized during the summer by a terminal that is bent in the form of a shepherd's crook and exhibits copious resin flow; later in the season dead tops are symptomatic of an infestation (Wallace and Sullivan 1985). The damage can be confused with that of the eastern pine shoot borer, but the borer almost always attacks laterals as well as the leader and feeds down the centre of the shoot, rather than in the cambium. The weevil mainly attacks trees 1 to 5 m in height (Szuba and Pinto 1991).

The weevil is best managed by integrating strategies to reduce its abundance into the silviculture prescriptions for white pine. On productive sites, where white pine does not compete well with other species, a clearcut system can be used: the stand is harvested and densely replanted to white pine. On poorer sites, a uniform shelterwood system is used to perpetuate the white pine component (Hodge et al. 1989). Specific treatments should avoid stand conditions beneficial to the weevil, such as

- leaders with diameters > 4 mm
- open-grown trees in stands with < 40% crown closure
- leaders with thick bark
- leaders exposed to full sunlight
- dry sites for successful overwintering

Thus, weevil populations can be reduced by growing an overstorey of either conifers (e.g., mature white pine) or early-flushing hardwoods (e.g., aspen) until the plantation trees reach 6 m (Szuba and Pinto 1991). This slows tree growth, thereby reducing leader diameter, as well as reducing the amount of sunlight available (Chap. 21). Another way of keeping the stands relatively shaded is to increase the density of the regeneration, although this is not an option if blister rust is present. The increased density keeps the leaders slender and promotes recovery of lost form in trees that are damaged.

Figure 23.1 Crooked stem of young white pine, following recovery from white pine weevil attack. *(Photo by T. Scarr)*

If possible, the dead leader and the buds of all but one of the laterals in the whorl immediately below it should be pruned in August before the weevils emerge in order to reduce subsequent weevil populations and to correct the form of the tree (Hodge et al. 1989). Placing the cut leaders in screened containers that allow parasites to emerge but prevent the escape of weevils, and leaving the containers in the stand will help to retain natural enemies (Szuba and Pinto 1991). Current insecticides provide poor control against the larvae because they feed under the bark. Insecticides (e.g., methoxychlor) are used against adult weevils in the spring to prevent them from laying eggs. The adults emerge soon after the snow has disappeared from the base of the trees and air temperatures reach 15° C. Insecticides should be applied about one week after the adults emerge, i.e., when 10% to 20% of the leaders show small round holes resulting from feeding by the adults. Since egg laying may be extended by cool spring temperatures, it is important to continue monitoring for three to six weeks after the first application.

23.4.2 Shoot and Bud Moths

Although numerous lepidopteran insects feed on the shoots of plantation trees, only a few species cause appreciable damage. Serious infestations are often associated with poor site conditions and open-grown trees in exposed or understocked stands. The more important species are outlined below. Their detailed biologies are described in Rose and Lindquist (1984) and USDA (1985).

The European pine shoot moth is a small grey-brown moth introduced into Ontario in 1925. Damage appears during the summer as larvae feed in the buds of red and Scots pine, although the major injury to terminal and lateral tips occurs during the following spring when the larvae move into the expanding new shoots. The shoot moth tends to become established on trees which, because of low vigour on poor sites, cannot produce sufficient resin to kill the larvae. Although pruning trees below the snow line reduces overwintering survival of larvae by eliminating the prime overwintering sites, better control is achieved by applying insecticides during the spring to kill the larvae as they move between shoots.

The eastern pine shoot borer feeds on all species of pine; it can reach damaging levels in understocked and open-grown plantations of pure pine. Damage is most common on trees 1 to 3 m tall and is similar to that of white pine weevil except that the laterals are also attacked. One of the best ways to recognize borer damage is by shaking the trees: infested leaders will break where the borer has tunnelled into the pith. No controls are known for this pest; however, maintaining good stocking in mixed stands may reduce its incidence.

The spruce budmoth is another shoot insect that feeds on conifers, primarily white spruce. As yet, no major damage has been detected in the province, probably because the greatest impact is in pure plantations of white spruce, which are uncommon in Ontario. Trees are susceptible from the time they reach 1 m until crown closure. Although they may be deformed and stunted, they are very rarely killed. Control measures include encouraging early crown closure and growing spruce with other species. Chemical insecticides are available against the adults, but there is only a very short period in which they can be used.

The spruce budworm can also be a serious pest in young plantations, although outbreaks are more common in mature stands. Though budworm populations occasionally reach high levels in young plantations, they rarely cause mortality until the stands are over 20 or 25 years of age. The effects are discussed in section 23.5.1. Management is aimed at reducing the balsam fir component in the stand and regenerating the stand to less susceptible species such as black spruce. If control becomes necessary in order to protect the foliage and keep the trees alive, insecticides (e.g., Btk) are available as either ground or aerial applications (Armstrong and Ives 1995).

The jack pine budworm damages plantations of young jack pine; it also feeds on white and red pine growing in association with jack pine. It has also damaged white pine regeneration in white pine stands being managed under the uniform shelterwood system (see section 23.5.2). Although high densities of this insect may occur in plantations younger than 40 years, whole-tree mortality is uncommon, appearing only after three or four years of severe defoliation. However, there may be as much as 50% mortality in stands on thin soils or with a pine overstorey (Howse 1986). The insecticides available for controlling jack pine budworm are similar to those for spruce budworm. But because of the short duration of most outbreaks of jack pine budworm and the fact that much of the effects are due to the first year of defoliation, control must begin sooner than for spruce budworm, preferably in the first year of severe defoliation. This requires good monitoring to detect growing populations, combined with good estimates of overwintering populations to determine which specific stands will be defoliated and when the first year of defoliation will occur (Scarr 1995). On sites where groups of jack pine are interspersed with rock outcrops, regeneration after outbreaks can be achieved by leaving seed trees during harvest, and then conducting a light prescribed burn and aerial seeding.

23.4.3 Sawflies

Sawflies are one of the more destructive groups of insects in young conifer plantations. A member of the Hymenoptera order, they are related to bees and wasps, although their immature stages can be mistaken for moth larvae. The two groups can be differentiated by the number of abdominal prolegs (fleshy, unjointed, leg-like structures along the abdomen): sawfly larvae have more than five pairs, whereas moth larvae have five or fewer pairs.

Sawfly species are differentiated by feeding habit: *Diprion* spp. feed singly; *Neodiprion* spp. are gregarious.

The latter feed primarily on pine, whereas *Diprion* and other genera have a wider selection of host plants. Most sawflies have only one generation a year in Ontario, although a few may complete a second in the south.

Sawflies are often present in plantations, but usually their numbers are low and damage is slight. Occasionally, however, they can become numerous enough to cause tree mortality and plantation failure. Btk is not effective for controlling these defoliators; thus, protection must be achieved through chemical insecticides or viruses (where they have been developed). One of the keys to controlling sawflies is frequent inspections of stands during susceptible periods. In this way, isolated pockets can be controlled (either with pruning or insecticide) before there is extensive damage in the plantation.

Redheaded pine sawfly is the most serious pest of red pine plantations in southern Ontario, causing poor growth and mortality. It also attacks jack pine, Scots pine, and white pine (Rose and Lindquist 1984). Outbreaks last two to three years and are associated with dry weather. The larvae feed during early summer, preferring older foliage. Pockets of high sawfly density can occur in the plantations where trees are under stress from low moisture, competition (from adjacent pines or bracken fern), frost, or shallow soils or where trees are at the stand edge. The degree of damage depends on the extent of defoliation, tree size, and severity of other stresses; trees shorter than 6 m are most susceptible. Defoliation levels of 90% usually result in tree mortality, and a single colony can kill a tree. The most effective way of controlling this insect is to select a proper site for establishing the plantation and to suppress competing vegetation (Chaps. 12 and 21). Monitoring of population densities is important in order to determine whether insecticides are necessary. Chemical insecticides are available, but the viral product Lecontvirus is more selective and can achieve the same results with either ground or aerial applications. It is available only in limited supplies, however, from the Canadian Forest Service.

The European pine sawfly is an introduced species that feeds on red and Scots pine, as well as many other pine species, occasionally causing defoliation of plantations and Christmas trees. The larvae feed on older foliage from spring until mid-July. Natural enemies have been successfully introduced for control of this insect over the past 50 years (Kelleher and Hulme 1984). Insecticides can be used if outbreaks occur, but the Sertifer virus is not yet registered in Canada.

The introduced pine sawfly is another non-native species that attacks white, Scots, and other pines. Both immature and mature white pine are susceptible, particularly when growing on thin, rocky soils. There are two overlapping generations each year, the larvae of the first one consuming older foliage from early to mid-summer, those of the second one consuming current-year foliage from mid-summer to fall. In years of warm fall weather, there may also be a third generation. Trees can be killed after only one year of defoliation, especially from feeding by the second generation. Thus, surveys must be conducted throughout the summer and fall to detect populations and to anticipate damage. Usually natural enemies maintain populations below damage thresholds, but insecticides may be necessary in severe infestations.

Swaine jack pine sawfly damages primarily jack pine but can also be found on red, Scots, and white pine. Outbreaks occur in intervals of eight years and can be extensive. Feeding occurs throughout the summer, first on the old foliage and then on the new foliage. Control can be achieved through the aerial or ground application of a chemical insecticide. A nuclear polyhedrosis virus has been developed by the Canadian Forest Service, but it is not yet available commercially.

Yellowheaded spruce sawfly is a relatively common pest of white, red, black, blue, and Norway spruce. It feeds in early summer, preferring new foliage, but it will feed on old foliage if it has eaten all the current year's foliage before the larvae reach maturity. Total defoliation results in the tree's death (Fig. 23.2), requiring re-establishment of severely affected plantations (de Groot 1995). When natural enemies fail to contain this insect, it may be nec-

Figure 23.2 Top-kill and tree mortality in black spruce plantation caused by yellowheaded spruce sawfly. The plantation was replanted twice. *(Photo by T. Scarr)*

essary to use the botanical insecticide neem or chemical insecticides.

Pine false webworm is an introduced pest of Scots, red, jack, and white pine. Defoliation levels of 90% and higher have been recorded. The damage results in deformed branches, reduced market value for Christmas trees, and in extreme cases the tree's death. Feeding occurs in spring and early summer with preference for the new foliage (USDA 1985; Lyons et al. 1993). Although traditionally considered a pest of young plantations, since the early 1990s it has caused severe defoliation in semi-mature and mature pines in south-central Ontario, including plantation trees and mature overstorey white pine in mixed stands. Chemical insecticides are effective against this pest. Recent tests have shown the botanical insecticide neem to provide effective control, although it is not currently registered for this use. Some population control can be achieved by clearcutting heavily damaged plantations of trees of merchantable size in autumn and leaving the slash on the ground. The adults emerge from the soil in spring and lay eggs in the needles of the slash; the needles then dry out before the larvae reach maturity.

Several other species of sawflies periodically reach outbreak numbers in young plantations; they include the jack pine sawfly on jack, red, and Scots pine; the red pine sawfly on red, jack, and white pine; the balsam fir sawfly on balsam fir, black, and white spruce; and the larch sawfly on larch. These species are usually unimportant in Ontario, either because they attack species that are not regenerated extensively or because they cause only localized damage. See Rose and Linquist (1980; 1982; 1984; 1985), USDA (1985), and Armstrong and Ives (1995) for more information.

23.5 Maturing Forests, Including Natural Regeneration

Hundreds of insect species attack maturing forests, but the most important are those that defoliate and reach outbreak densities. These include spruce budworm, jack pine budworm, forest tent caterpillar, gypsy moth, spruce spanworm, large aspen tortrix, birch leafminer, balsam fir sawfly, birch skeletonizer, early aspen leafcurler, and spearmarked black moth. There are also hundreds of other defoliating insects that occur at high numbers periodically throughout the province, but any damage they cause has not been quantified. Only the first four species will be discussed in detail here because their effect is better established and the tree species they attack have higher economic value in Ontario. All are probably cyclic species, although the gypsy moth has too short a history in the province to confirm this; their biology is outlined in USDA (1985) and Rose and Lindquist (1982; 1984; 1995). The following section examines their effects on natural regeneration and stand succession.

23.5.1 Spruce Budworm

Since the early 1700s, 10 major outbreaks of spruce budworm have occurred in Ontario. Although quite variable, the interval between outbreaks and their extent and duration has changed over the last 75 years. Before 1910 outbreaks were fewer and shorter than in recent years, and more or less local. Since 1920, there have been only six years when Ontario has not had significant budworm infestations (Fig. 23.3). The current outbreak has been under way since 1967 and is the largest (with a peak of 18.85 million infested ha), the longest-lasting, and the most damaging (Fig. 23.3). This change has coincided with our increasingly intensive forest management and protection of forests from fire. It has also been suggested that the warming of the climate is a factor. Although difficult to predict, the geographic shifting of the area infested over time suggests that budworm infestations will continue to occur fairly constantly, in one place or another, throughout the province in the foreseeable future.

The primary hosts of the spruce budworm are balsam fir and white and black spruce, although it also feeds on larch and hemlock. Balsam fir is the most vulnerable host species (i.e., the most likely to suffer damage as a result of infestation), followed by white and then black spruce. In sustained infestations, though, 100% of the balsam fir and half or more of the merchantable volume of the spruce may be lost.

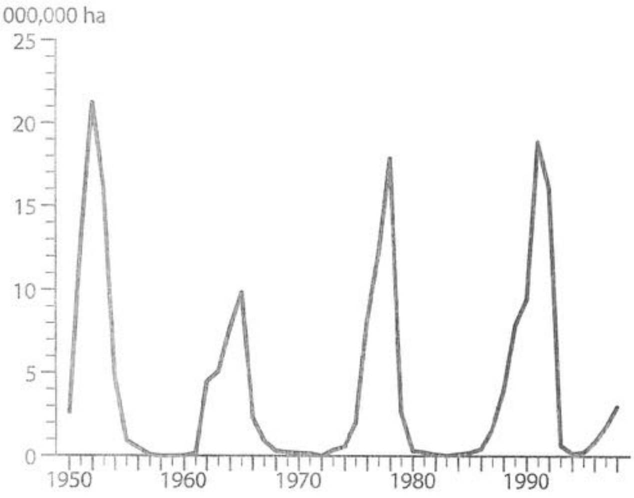

Figure 23.3 Area of Ontario with moderate to severe defoliation caused by the spruce budworm, 1950–1998

Injury to trees is cumulative in that all or part of the new foliage produced on an infested tree is consumed each year. In light or moderate infestations, the damage consists of partial loss of new foliage in the upper portion of the crown. If the infestation collapses after a few years, trees seldom exhibit lasting harm and resume normal growth. In severe, persistent infestations, all new foliage may be consumed for several successive years. Diameter growth is reduced during the first year of appreciable defoliation and continues in relation to the degree of defoliation and the number of consecutive years of attack. Top killing of balsam fir usually occurs after three or four years of severe defoliation, and some suppressed trees may die. Complete mortality of balsam fir usually begins after about five years of severe infestation, and nearly all of the merchantable volume is dead by the ninth or tenth year.

White spruce starts to die after six or eight years of repeated severe defoliation, whereas the mortality of black spruce is quite variable. Pure stands of black spruce or mixed stands of black spruce and jack pine are not susceptible. Isolated or dominant white spruce trees will generally survive an attack although, like all hosts, they will suffer reduced diameter and height growth and may be predisposed to disease and bark beetles.

The long-term effect of spruce budworm outbreaks on the succession of naturally regenerating forests is unknown. Normally, the understorey of mature fir-spruce stands (i.e., more than 40 years old) contains a large number of shade-tolerant balsam fir and white spruce seedlings, of which the balsam fir outnumber the spruce by as much as 30:1 or more (Fye and Thomas 1963). These suppressed seedlings will survive for a long time, waiting to be released when the overstorey is removed. By defoliating and killing older trees, a budworm outbreak opens up the canopy and allows for regeneration; however, it is not certain which tree species regenerates. Two studies have examined the type of forest that regenerates after a spruce budworm outbreak.

The first study used permanent plots established in the 1940s and 1950s in three locations in northern Ontario (Lake Timiskaming, Black Sturgeon Lake, and Cedar Lake near Dryden) to study forest succession 15 years after an infestation (Prebble 1948, 1949; Ghent et al. 1957; Ghent 1963). It was found that (1) balsam fir seedlings accumulated for 20 to 30 years before the budworm infestation (Ghent 1958b); (2) defoliation caused the overstorey balsam fir to stop the production of female flowers (cones) early (Ghent 1958b); and (3) the ratio of spruce:fir regeneration varied considerably, but there was a general trend towards a higher proportion of balsam fir in the regeneration than in the original stand (Ghent et al. 1957; Fye and Thomas 1963). This research suggests that balsam fir tends to predominate in the regeneration after a budworm outbreak (Fye and Thomas 1963), either as mature trees that survived the outbreak or as seedlings released by the outbreak. The fact that these stands were vulnerable and severely attacked by spruce budworm again in the late 1980s suggests that the balsam fir component did indeed remain high.

The second study, which examined the structure and dynamics of spruce-fir forests, concluded that the perpetuation of spruce in these stands could be partly due to budworm outbreaks in both boreal forests (white spruce forests in northern Ontario) and north-temperate forests (red spruce forests in southern Ontario) (Gordon 1985). Indeed, Gordon (1985) argued that spruce budworm is essential in maintaining spruce in these stands and that there is evidence that the insect has evolved with the spruce-fir forest.

Neither of the studies described above includes fire: stands of trees killed by spruce budworm are more susceptible to fire, which tends to favour spruce regeneration over balsam fir.

Until more data are available, these two studies suggest that we cannot be certain whether balsam fir or spruce will dominate natural regeneration after a spruce budworm outbreak. This information is essential, however, because managers cannot make the right decisions about controlling spruce budworm outbreaks without knowing the consequences for species regeneration. For example, if spruce will predominate in the regeneration and this is the preferred species, then the outbreak could be allowed to run its course; if balsam fir will predominate and spruce is still the management objective, then the outbreak could be suppressed.

Extensive studies have dealt with the suppression of spruce budworm outbreaks (Prebble 1975; Sanders et al. 1985). Considerable information is available on the development and application of both chemical and biological agents (Cunningham 1988; van Frankenhuyzen 1990; Smith et al. 1990; Helson 1992). Spruce budworm outbreaks are usually on such a large scale that they can be suppressed only through aerial application of insecticides at the early stages of an outbreak. Once an outbreak is fully under way, suppression is no longer feasible. Then the main objective is to retain the foliage on mature trees, keeping them alive until harvest, or to protect other values, such as recreation.

23.5.2 Jack Pine Budworm

Widespread and damaging outbreaks of the jack pine budworm have occurred in northwestern Ontario since the early 1930s (Fig. 23.4). Since 1967, there have also been outbreaks in northeastern and central Ontario, the most recent being in the northeast between 1983 and 1986, in the northwest between 1984 and 1989, and in the north-central part of the province from 1993 to 1996. Outbreaks have occurred on average every 8 to 10 years, although the periodicity has been variable, probably depending upon climate or weather (Fig. 23.4). The outbreaks usually last only two to four years, beginning and ending abruptly.

The principal species attacked by this budworm in Ontario is jack pine, although red pine, Scots pine, and eastern white pine can also be fed upon. In the 1990s outbreak there was severe damage to white pine, including mature trees and regeneration in stands managed under the uniform shelterwood system (Scarr 1995; see also Chap. 9).

Figure 23.4 Area of Ontario with moderate to severe defoliation caused by the jack pine budworm, 1950–1998

As with spruce budworm, the damage is caused by larvae feeding on new foliage, but it is very difficult to predict tree mortality. If populations of jack pine budworm are very high for two or more consecutive years, the trees may or may not be killed. Top killing, crooked or multiple leaders, and increment reduction are more common initially, although Howse (1986) did find that stands of pole-sized jack pine in the Algonquin Park District suffered 25% tree mortality and 30% top kill after only two or three years of light to severe defoliation. The damage can be more severe in low-density stands of large-crowned flowering trees or in intermediate or suppressed trees of low vigour on poor sites or during droughts (Benzie 1977). Mortality of suppressed trees or trees on poor sites can be high, ranging from 13% to 60% (Gross and Meating 1994; Hopkin and Howse 1995).

The effect of jack pine budworm on a stand is relatively subtle in comparison to that of spruce budworm. Generally, the suppressed or intermediate jack pine trees are the first to die when defoliated, but these trees are of low vigour and are unlikely to contribute significantly to future stand development. Unlike the situation in fir-spruce forests, there is little young jack pine regeneration in maturing stands, and thus jack pine budworm is not considered to have a long-term influence on stand succession. If there is young regrowth, it may be severely defoliated by larvae dropping from overstorey trees. Young open-grown jack pine regeneration, natural or artificial, is seldom infested or severely damaged even if it is beside or amongst mature stands until the trees reach 7 to 8 m in height.

The role of jack pine budworm in regeneration and species composition is uncertain. The typical damage pattern – individual trees with a dead top but an intact lower crown – may favour jack pine as the dominant tree species by making the stand more susceptible to fire. The greater penetration of light dries out the ground, increasing the chances of a ground fire. The fire opens the serotinous cones in the upper part of the tree, while the absence of foliage in the upper crown prevents the fire from burning so hot as to destroy the cones.

Some semi-mature and mature white pine stands were affected during the 1990s outbreak of jack pine budworm in Ontario. Many of these stands were managed under the uniform shelterwood system. After two to four years of severe defoliation, both the overstorey trees and the regeneration were affected. Tree mortality averaged about 8% in the affected stands, top kill averaging 11.3% (Scarr, unpublished data).

The effects of jack pine budworm outbreaks can be reduced with either aerial or ground applications of Btk or chemical insecticides.

23.5.3 Forest Tent Caterpillar

There have been outbreaks of forest tent caterpillar somewhere in Ontario on average every 10 years. The oldest recorded outbreak dates from 1834 (Sippell 1962). The most recent outbreak began in the late 1990s; the previous outbreak peaked in 1991 at 18.87 million hectares (Fig. 23.5).

The primary host tree in Ontario is trembling aspen, although the larvae also feed on the foliage of other poplars, white birch, sugar maple, red oak, and numerous other deciduous species. Red maple appears to be immune from attack. In severe infestations, the larvae sometimes feed on coniferous trees intermixed with denuded deciduous trees. High populations persist for two to four years or sometimes even longer (Prebble 1975).

In high populations, much or all of the host foliage may be consumed by early or mid-June, but injury is not considered severe because deciduous trees can refoliate. This refoliation, though, can cause significant stress to the tree because it uses up starch reserves. Although some trees die as a result of repeated, severe defoliation, this loss is

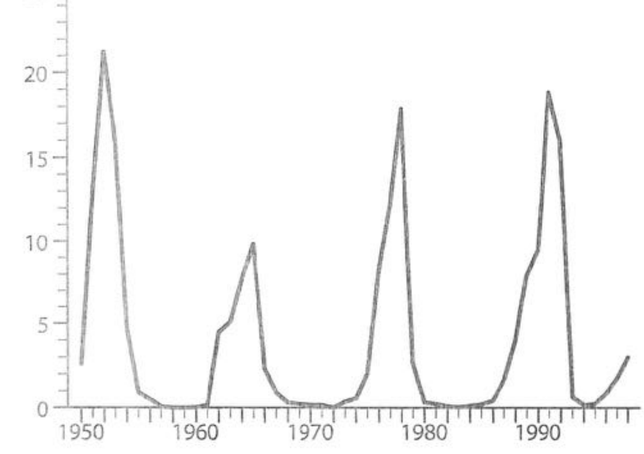

Figure 23.5 Area of Ontario with moderate to severe defoliation caused by the forest tent caterpillar, 1950–1998

usually considered insignificant (Howse 1981). In the early 1990s outbreak, the Canadian Forest Service recorded crown dieback and tree mortality over an area of 54,080 ha, including one plot in mature aspen that showed 32% mortality (Jones et al. 1996). The major effect of forest tent caterpillar is to weaken trees, thereby making them more susceptible to other pests, drought, and wind damage (Churcher and Howse 1989). Instances of tree mortality are confined largely to suppressed trees or those growing on poor sites, especially if the trees are exposed to drought after repeated defoliation (Prebble 1975). The major consequence of repeated annual defoliation is reduced increment growth (20% to 90% annually) during defoliation and for one to two years afterward (Howse 1981). The biology of forest tent caterpillar is described in Rose and Lindquist (1982).

The role of the forest tent caterpillar in aspen regeneration and succession is uncertain, but it may advance stand conversion. Trembling aspen is a shade-intolerant species requiring full sunlight for survival and growth. As an early-successional species trembling aspen is usually replaced by tolerant hardwoods on drier soils or by balsam fir, white spruce, or white pine on fertile soils (Chap. 20). In the absence of fire, it is succeeded by balsam fir, black spruce, or eastern white cedar on moist soils (Sims et al. 1990). Defoliation of the aspen overstorey by the forest tent caterpillar can speed up the succession by temporarily increasing light penetration, killing some of the aspen, and making others more vulnerable to attack by other insects and diseases.

Past studies suggest that the forest tent caterpillar may influence the succession of boreal forest stands and thus, indirectly, spruce budworm outbreaks. Wellington et al. (1950) found that several years before a budworm outbreak there were fewer storms, as well as droughts and outbreaks of forest tent caterpillars. They theorized that removal of the overmature, decadent poplar or birch overstorey was hastened by forest tent caterpillar, allowing the balsam fir understorey to dominate. By hastening this type of succession, they speculated, tent caterpillar outbreaks increased the susceptibility of these stands to spruce budworm. They also considered climatic fluctuations to increase the susceptibility of areas, particularly during times of drought.

In a follow-up study, Ghent (1958a) undertook to determine what influence aspen mortality might have on subsequent susceptibility to spruce budworm in understorey balsam fir and spruce trees. He examined aspen stands which had been defoliated by the forest tent caterpillar and found that the beginning of a budworm outbreak coincided with heavy aspen defoliation. Ghent, however, considered that the mortality of overstorey aspen was due primarily to wind breakage, not tent caterpillar defoliation, and concluded that the succession of conifers in these stands was not accelerated by defoliation.

Forest tent caterpillar has not been suppressed on productive forest stands in Ontario because of the low commercial value of aspen. Control of this insect has been directed to more valuable stands of oak and, for aesthetic reasons, to provincial parks. Populations of forest tent caterpillar can be effectively reduced with aerial and ground applications of Btk or chemical insecticides. Natural enemies, in particular, viruses and the larval and pupal parasitoid *Sarcophaga aldrichii* (Park.), usually cause outbreak populations to collapse in any one location in two to four years. Pheromones are also available for monitoring male moths and predicting areas of high infestation. With the increased emphasis on aspen production, it may become more important to monitor and control the forest tent caterpillar.

23.5.4 Gypsy Moth

The gypsy moth is an introduced defoliator of hardwoods. It was first detected in Ontario in 1969 near Kingston and has since established itself throughout southern Ontario, with northern limits from Sault Ste. Marie to North Bay, an area that coincides with the distribution of oak. The populations of gypsy moth are probably cyclical, although the outbreaks have been considerably smaller than those of the previous three species (Fig. 23.6). There have been two outbreaks in Ontario since 1981, and a third is expected soon. The introduced fungal pathogen *Entomaphaga maimaiga* Humber, Shimazu, and Soper, may alter this emerging outbreak pattern, although the history of this fungus in Ontario is so recent that its role in the population dynamics of gypsy moth cannot be predicted. Caterpillars of the gypsy moth are very similar to those of forest tent caterpillar in size, hairiness, trees attacked, life cycle, and damage (Rose and Lindquist 1982; USDA 1985).

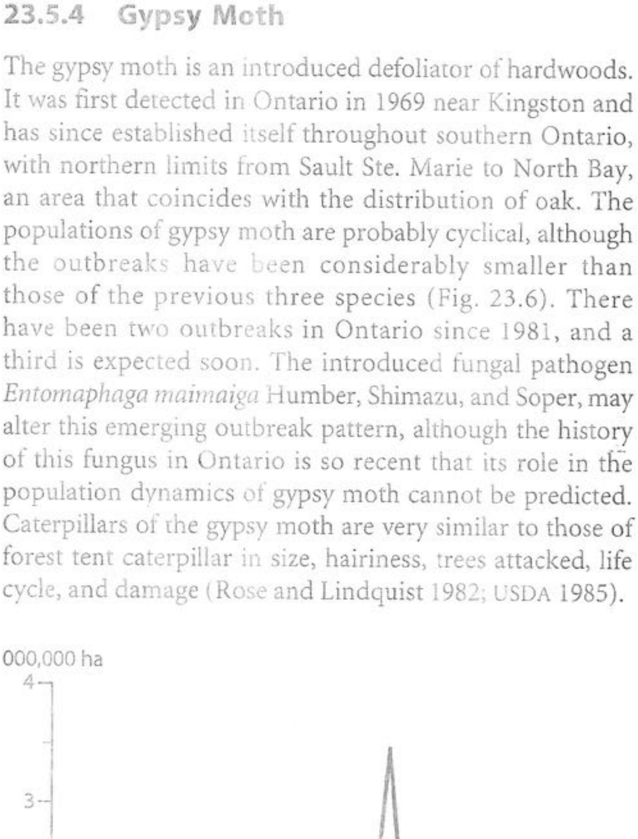

Figure 23.6 Area of Ontario with moderate to severe defoliation caused by the gypsy moth, 1981–1998

What has enabled the gypsy moth to spread so dramatically is the seemingly unlimited supply of host material. Gypsy moth larvae have been observed feeding on over 500 host species, although they prefer oak (all species), alder, apple, birch, larch, aspen, willow, basswood, and mountain ash. They will also eat beech, hemlock, and all species of pine and spruce. High populations of gypsy moth larvae will completely defoliate trees or infested forests by late June. Few trees have died, though, relative to the size of the outbreak, because oak can refoliate and high populations seldom last more than two years in any one location. Nonetheless, when forests are under stress, from drought for example, they can be more susceptible to mortality as well as attack by secondary insects and diseases. The combination of gypsy moth defoliation, drought, and other organisms has caused severe mortality - up to 50% after two or three years in some stands (Keizer 1992).

The effects of this insect on natural regeneration and stand succession in Ontario has not been studied. In the American northeastern states and Michigan, larval feeding on understorey hosts in stands dominated by oak not only reduces seed production and stump sprouting, but also kills advanced regeneration (Witter et al. 1992). After repeated defoliation of the overstorey, accelerated forest succession due to differential mortality among tree species has resulted in the development of stands of less susceptible species (Witter et al. 1992). The expectation in these areas of Michigan, as well as the New England states, is that oak will be replaced by red maple. Nealis and Erb (1993) state that in Ontario the thinning of densely stocked stands, release of understorey plant species, and acceleration of stand conversion to less vulnerable species as a result of infestations by the gypsy moth may be regarded as beneficial. From the manager's perspective, this may or may not be the case, depending on whether oak or maple is the desired species and what the specific biodiversity objectives are for the area.

To maintain the oak component in a stand and to reduce the potential for dieback and stress in a stand, gypsy moth populations can be controlled with aerial or ground applications of insecticides (Doane and McManus 1981; Nealis and Erb 1993). Both chemical insecticides and Btk are available, but before they are used it is important that sampling of egg masses on the ground or pheromone trapping for adult males be conducted in the late summer to determine which areas require treatment. There may be high overwintering mortality if egg masses are located above the snowline; the manager should be alert to this possibility in the spring to prevent needless interventions. Population levels of gypsy moth are also affected by a nuclear polyhedrosis virus, and several predators and parasites; the fungal pathogen *Entomophaga maimaiga* is probably responsible for keeping populations low for the last several years since 1993. The nuclear polyhedrosis virus has been registered for use against gypsy moth, but it is not commercially available.

23.6 Future Directions

In Ontario we have been managing and growing forests for only a short time. During this period, numerous insects have become a problem for sustained production, and it is likely that numerous other pests will arise over the next 20 to 50 years of regeneration. For example, some of the generalist insects that now attack agricultural crops will undoubtedly find young, intensively managed forests attractive. Where there are shortages in the wood supply, insects occurring at what were once considered acceptable levels will, without any actual population increases or changes in population dynamics, begin to have significant effects on production levels.

Effective management of these new pests will entail a sound knowledge of insect biology, sampling, impact, and control options. The biology of insects that currently damage Ontario forests is well documented both in this chapter and by others (USDA 1985; Rose and Lindquist 1980; 1982; 1984; 1985). Detailed sampling plans have been developed to predict population densities and damage for major forest pests such as the spruce budworm (Sanders et al. 1985) and gypsy moth (Nealis and Erb 1993). For most other common species, however, only rudimentary information is available. Essentially nothing is known about the "new" pests, especially those introduced from other parts of the world. Even if much is known about an insect in its country of origin, managers can only speculate on its biology and population dynamics if it becomes established in Ontario. These monitoring and sampling programs will become even more important for tracking the changes in population dynamics and pest status that are predicted as a result of global warming (Fleming and Volney 1995).

One of the subjects about which we have the least information, for both native and introduced insects, is impact. While the specific damage (e.g., extent of defoliation) caused by forest pests has been well described, surprisingly little has been done to quantify real losses or economic injury (Miller 1983). Instead, the acceptable injury level is often set by managers at an arbitrary threshold, usually near 0% or 10% for seed and cone production (Turgeon et al. 1994) and nursery production, and as high as 50% for young plantations and regenerating forests, depending on the type of feeding damage.

In contrast, there is considerable information about the various options for controlling forest pests on regeneration, and new knowledge is being added all the time. Although chemical insecticides are effective in some situations, these products will become less readily available as both environmental concerns and registration costs increase, and there are likely to be few new registrations. In many cases, the only means of registration in individual forestry markets will be through minor-use registration clauses in the Pest Control Products Act. The exception may be for environmentally safe novel insecticides that have high target specificity or new modes of action, or that are derived from plants, fungi, or other similar sources. A common problem, though, for the products with high target specificity (e.g., viruses) is to attract companies interested in producing them commercially in operational quantity.

Currently, although a number of chemical insecticides are registered and available for aerial control of forest insects in Ontario, government policy prefers biological agents (e.g., Btk), even if they are slightly more expensive and limited in efficacy. Although this policy was supported by the decision in the Class Environmental Assessment for Timber Management (Chaps. 1 and 4), it is not feasible for insects for which biological insecticides do not exist (e.g., most sawflies, bark beetles, and newly introduced species).

In the future, management of forest pests will emphasize prevention rather than control. One of the essential elements in this approach will be monitoring (Sutherland et al. 1990). Sampling techniques for predicting the movement of insects at the tree, stand, and forest level; information on the true consequences of insect damage; and an increased understanding of the population dynamics of pests and their natural enemies will all reduce our need for reactive approaches to pest management. The silvicultural approach, although limited in some respects, is the most desirable in terms of prevention. It requires relatively low technology, can be integrated into other aspects of the production systems, and in the long term can be the least costly approach. Reactive approaches will be restricted to relatively benign compounds which are targeted to specific pest situations. These include insecticidal soaps and natural plant products, such as neem (Helson 1992) and biological agents such as Btk (van Frankenhuyzen 1990), viruses (Cunningham 1988), nematodes (Eidt and Thurston 1994), and natural insect enemies like ladybird beetles, lacewing larvae, and parasitoids (Nealis 1991; Smith 1993). In the final analysis, significant demands will be made on forest managers, who will need to integrate insect management into ecosystem management, sustainable forest management, increased or changing fibre requirements, demands of users of the forest other than forest industry, and a changing world affected by global warming and by the introduction of new insects from other countries.

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