Insects may attack conifer reproductive structures at any time from cone bud initiation through to cone collection and seed extraction. Insects that seriously damage cones and seeds are problematic, for the most part, during the pollination period and early cone development. However, some are likely to be encountered during cone collection and processing. This chapter discusses identification of these important insects and the practical significance of their actions to seedlots (Table 1, page 14). For information on other cone and seed insects, refer to Hedlin et al. (1980), Portlock (1996), and Turgeon and de Groot (1992). For insects of importance to conifer nurseries, see Hamm et al. (1990), Finck et al. (1990) or Sutherland et al. (1989).

Insects are natural, integral components of forest ecosystems. However, because of the human interest in wood products, many species of insects become our major competitors in the utilization of forest resources. Understanding the biology of these insects and learning how to live and deal with them is the challenge of forest insect management.

Forest insects that feed directly on conifer cones and/or seeds are termed **conophytes** (Turgeon et al. 1994) and are in direct competition with us for these resources. Only about 100 of the 50 000 species of insects known in Canada are **conophytic.** Of these conophytes, only a small number have an economic impact on our crops (de Groot et al. 1994). Although conifer hosts and conophytic insects coexist, certain conophytes can destroy entire cone crops in some years, particularly when crops are small following a previous year of large crops (de Groot et al. 1994). Conophytes can be readily divided into two categories. Obligate conophytes are those insects that *must* complete some part of their life cycle within conifer reproductive structures (Figures 12–14), while **heteroconophytes** (or facultative conophytes) do not require cones and

Obligate conophytes are those insects that must complete some part of their life cycle within conifer reproductive structures, while heteroconophytes do not require cones and seeds but feed upon them when they are available

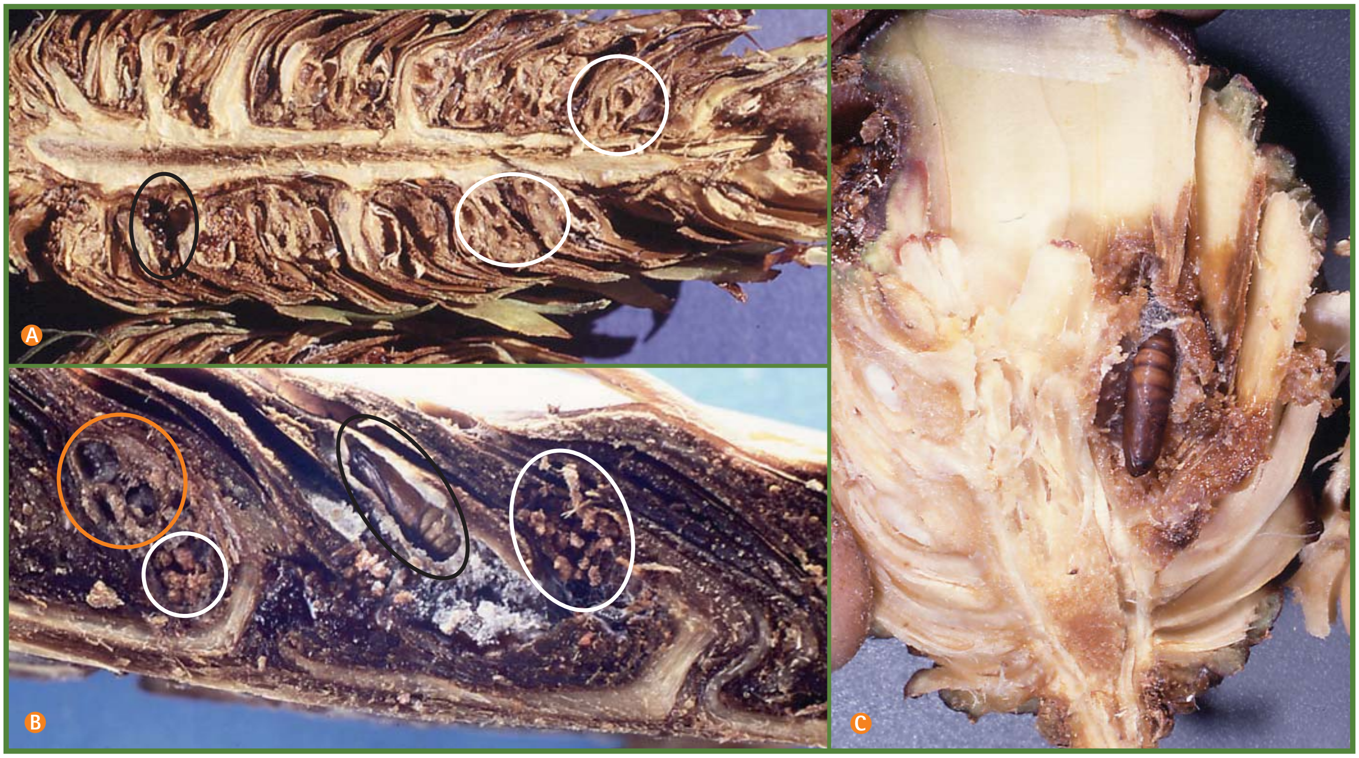

Figure 12 Obligate conophytes within conifer cones – moth and cone gall midge: a) damage caused by larvae of Douglas-fir cone moth (black circle) and cone gall midge (white circles) in Douglas-fir cone; b) cone moth pupa (black circle) and damage (white circles) and cone gall midge larvae and damage (orange circle) in Douglas-fir cone; and c) moth pupa and damage in pine cone.

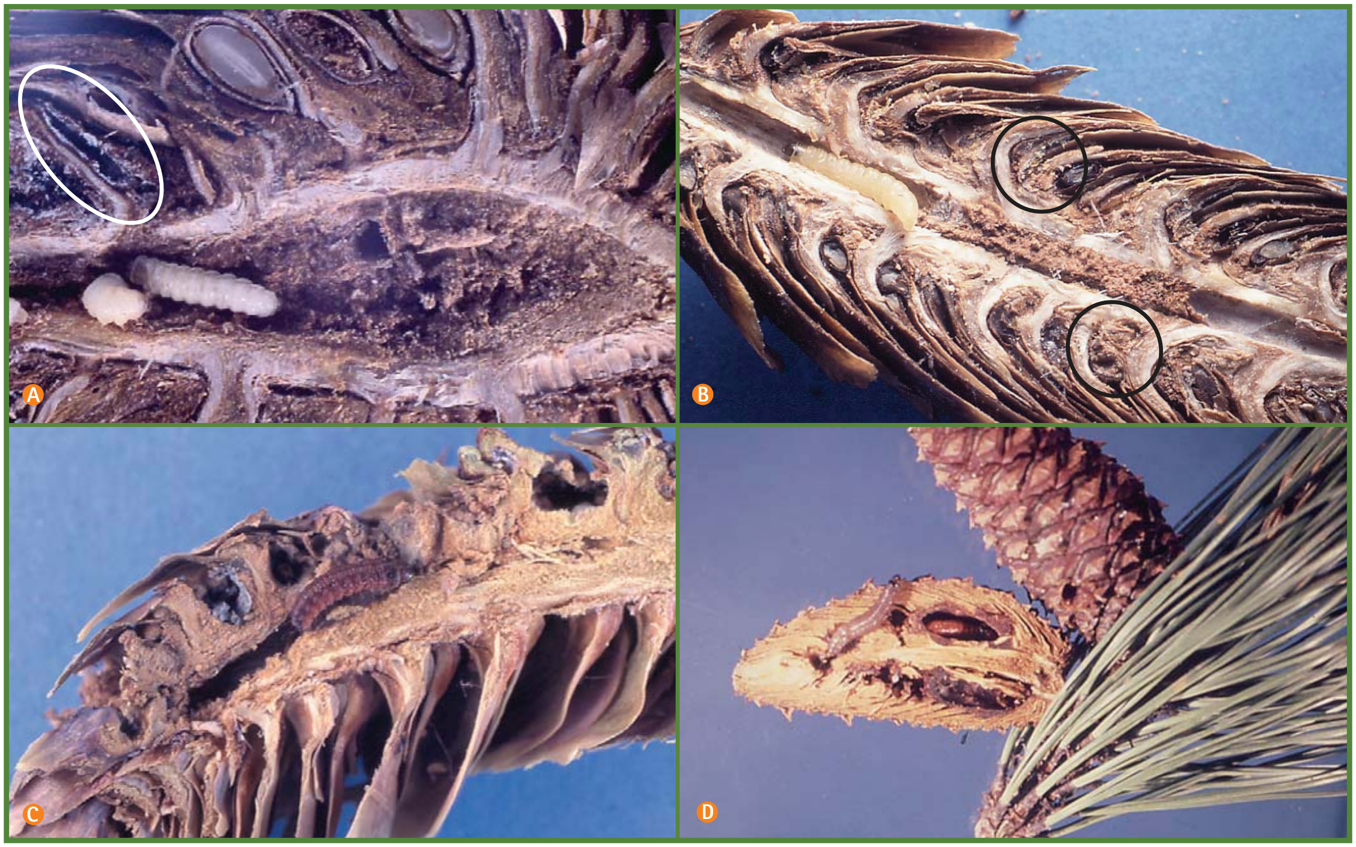

Figure 13 Obligate conophytes within conifer cones – seedworms and coneworms: a) ponderosa pine seedworm seed damage (white circle) and overwintering caterpillars in ponderosa pine cone; b) spruce seedworm seed damage (black circles) and overwintering caterpillars in interior spruce cone; c) coneworm caterpillar and damage in interior spruce cone; and d) ponderosa pine coneworm caterpillar, pupa and damage in ponderosa pine cone.

seeds but feed upon them when they are available (after de Groot et al. 1994, Turgeon et al. 1994).

Heteroconophytic insects are unlikely to impact the activities of seed handlers and are not dealt with in detail here. In British Columbia, western spruce budworm is a common and well-known heteroconophyte. Contorted, mature cones (especially of Douglas-fir or spruce) with some amount of surface damage *may* have been fed upon by western spruce budworm in early spring. Typically, it is impossible or difficult to extract seeds from such cones. Insect activity not only damages or destroys seeds but can reduce yield by limiting cone opening illustrating that losses from insects may be indirect through the reduction in seed yield.

Obligate conophytic insects are often host-species and host-cone tissue specific

Obligate conophytic insects are often host-species and host-cone tissue specific. For instance, the larvae of the Douglas-fir seed wasp are found only in Douglas-fir seeds (**Figure 14c, d**); larvae of a closely related species only in seeds of western and mountain hemlocks; larvae of the Douglas-fir cone gall midge only in Douglas-fir cone scales (**Figure 12a, b**). For many other examples, see Hedlin et al. 1980.

In conifer seed orchards, which are normally managed to produce cone crops on a more regular basis, conophytic insects tend to be more consistently present and damaging

Natural stands of conifers often bear large cone crops in one year, then grow for several years producing few or no cones. Obligate conophytic insects have developed various biological strategies to survive the cone drought years and avoid over-exploitation of resources (see Turgeon et al. 1994). For seed and cone collectors and processing technicians, the most noticeable effect of these strategies is that obligate conophytes seem to disappear for several years only to re-appear unexpectedly in large numbers, often destroying an entire cone crop. This is especially true for cone crops in natural stands. In conifer seed orchards, which are normally managed to produce cone crops on a more regular basis, conophytic insects tend to be more consistently present and damaging (Finck et al. 1990).

Figure 14 Obligate conophytes within conifer seeds: a) seed midge larva (circled) in *Abies* seed; b) seed midge (white circles) and seed wasp larvae (orange circle) in seeds in sub-alpine fir cone; c) radiograph showing three Douglas-fir seed wasp larvae (circled) in Douglas-fir seeds; and d) Douglas-fir seed wasp larva in seed in Douglas-fir cone.

The damage caused by obligate conophytic insects is often not readily apparent. For instance, ponderosa pine coneworm caterpillars may destroy the contents of conifer seed cones while leaving little or no external evidence of their activities (**Figure 13d**). Likewise, seeds destroyed by seed wasps are indistinguishable from undamaged seeds without dissection or the use of x-ray techniques (**Figure 14c, d**).

Because of these factors, cone crops must always be assessed for damage caused by conophytic insects. Preferably, this is carried out prior to harvest so that time and money are not wasted harvesting worthless crops. Insect assessments should also be carried out routinely at cone processing centres upon receipt of incoming cone crops or, at minimum, just prior to seed extraction. Refer to the first chapter in Portlock (1996) and Turgeon and de Groot (1992) for detailed discussions of pre-harvest cone crop monitoring, sampling, and damage assessment techniques.

Ideally, post-harvest assessments of cone crops should be based upon examination of 50 cones selected randomly from each seedlot. Operationally, due to the small size of some seedlots and timing constraints, random samples of 20 to 25 cones per seedlot are more practical and appear to provide satisfactory damage assessments.

Seed orchard seedlots usually have been subjected to rigorous assessment (typically involving dissection of 50 conelets per orchard) for the presence of economically important conophytes during the pollination period and through maturation. However, in seed orchards, certain conophytic insects are not routinely monitored (e.g., seed wasps) and others may become established or otherwise cause damage after the assessment (e.g., some coneworms and the western conifer seed bug). Therefore, it is important that all seedlots, regardless of origin, be assessed for insect damage at the processing centre prior to seed extraction.

While minimal post-harvest assessment includes the determination of average numbers of filled seed per cone (see chapter 1 in Portlock [1996] or Appendix 3), detailed assessment should also include identification and a tally of conophytic insects observed and, if feasible, some level of quantification of associated damage (e.g., estimate of percent of cones affected).

The following sections outline insect problems of direct relevance to conifer seed cone collection, and seed extraction and handling. For information on specific cone and seed insects, see Hedlin et al. (1980), and Furniss and Carolin (1980).

Moth Caterpillars in Stored Cones

Conophytic moth larvae (caterpillars – Figures 13, 15a) may continue feeding within stored cones until seeds are extracted. It is important to identify potential caterpillar problems and deal with them promptly to avoid unnecessary post-harvest loss of seeds. Caterpillars are the immature (usually actively feeding) stages of moths and butterflies. Prior to transforming into adult moths, caterpillars enter a dormant, usually inactive, pupal stage (Figures 12b, c; 13d; 15b). Seed handling technicians and cone collectors should be able to differentiate between moth larvae and pupae.

To differentiate between caterpillars and pupae, compare Figure 15a (caterpillar) and 15b (pupae) as well as the two life stages present in Figure 13d (caterpillar on surface of cut cone, pupa embedded in cone tissue). Caterpillars have a soft, cylindrical, elongated, and segmented body, a small but distinct head, three pairs of short walking legs near the head end, and a variable number of pairs of stubby prolegs nearer the hind end. Moth pupae are cylindrical but compact with a shiny covering and may or may not be enclosed in some sort of a cocoon. Close examination of a moth pupa with a handlens or microscope often will reveal legs, wings, antennae, and other appendages of the future adult, tightly bound up under the "skin" (Figure 15b).

Conophytic moth larvae may continue feeding within stored cones until seeds are extracted

Presence of caterpillar damage is indicated by bore holes (Figure 13d) or cavities on the surface of cones with associated **frass** and, often, webbing. Within cones, frass-filled tunnels through cone tissue (Figure 12b) indicate the presence of caterpillars. Many (but not all) conophytic moths overwinter within damaged cones as caterpillars or pupae. Efforts should be made to determine if pupae or caterpillars are present in stored cones. Pupae will cause no further damage to seeds but some types of caterpillars (especially coneworm caterpillars) may continue to feed.

Any brownish-coloured caterpillar, up to 15–20 mm long (Figures 13d, 15a) and found burrowing randomly through cone tissue (Figure 13c, d) at or post-harvest may be a coneworm caterpillar. Coneworms may occur in cones of virtually all BC conifers, especially Douglas-fir, true firs, pines, and spruces. In contrast, similar sized but whitish caterpillars found only in the cone axis and only in ponderosa pine (Figure 13a) and spruces (Figure 13b) are seedworm caterpillars. When found in mature cones, seedworm caterpillars have finished feeding and will cause no further damage to seeds.

Figure 15 a) Fir coneworm caterpillar and b) pupae.

Stored conelots harbouring coneworm caterpillars should be kept cool, to slow feeding activity, and processed as quickly as possible to minimize further damage. Collect suspected coneworm caterpillars and send them alive (preferably) or preserved in ethanol to a cone and seed entomologist for identification.

Disposal of Insect-infested Cones

Whenever feasible, make an effort to identify damaging insects found in cones. Some conophytic insects found in harvested cones will survive within spent cones or associated debris after kilning and seed extraction (Ministry of Forests unpublished data). These insects can mature and emerge later to cause problems in future cone crops. Of particular concern are seedworm caterpillars in the axes of ponderosa pine (Figure 13a) and spruce (Figure 13b) cones, Douglas-fir cone gall midge larvae in Douglas-fir cone scales (Figure 12a), and any conophytic moth pupae (Figures 12c, d; 13d; 15b).

Note that larvae of spruce cone axis midges are often common in the axis of spruce seed cones (Figure 16) and may be confused with seedworm caterpillars. Spruce cone axis midges differ from seedworm caterpillars in being smaller, pinkish, legless, and enclosed within white, papery cocoons. Spruce cone axis midges apparently cause little or no damage to conifer seeds (Hedlin et al. 1980; Turgeon and de Groot 1992) and are not considered to be economically important.

Figure 16 Spruce cone axis midge cocoons (circled) in interior spruce cones.

If possible, burn insect infested spent cones and processing debris (small amounts of material can be "cooked" in microwave or other ovens). This option may not be feasible for large-scale seed extraction facilities. In such cases, do not discard spent cones and debris in areas where future cone harvesting may occur. To avoid exporting insect problems to other areas, do not offer insect infested spent cones to landscapers, ornament dealers, or other commercial cone dealers.

Insects Within Seeds

Certain conophytic insects spend most of their lives entirely enclosed within, and consuming the contents of, otherwise healthy looking seeds. Adult seed wasps and seed midges lay their eggs on, in, or close to developing seeds in young cones (Hedlin et al. 1980). Larvae develop individually to maturity within seeds (seed wasp – Figure 14b, c, d; seed midge – Figure 14a, b) and overwinter there. The contents of infested seeds are completely consumed. Adult seed wasps and midges exit from seeds in spring, mate and lay eggs for a new generation of larvae. Until adult emergence, infested seeds show no external sign of insect inhabitants. Seed midge larvae are found in *Abies* and spruce seeds whereas seed wasp larvae are associated with most, if not all species of Pinaceae (de Groot et al. 1994, Hedlin et al. 1980).

Seed midges are not well known but seed wasps have been extensively studied. Seed wasps usually are present at some level in most uncleaned seedlots of susceptible conifers and may be responsible for considerable seed destruction. Some proportion of infested seeds may be removed during seed cleaning but levels of seed wasp or midge larvae in cleaned seedlots should always be determined (infested seeds will not germinate). This is easily carried out through standard radiography (Figure 14c) of a random sample of cleaned seeds (minimum 100 seeds). Alternatively, determine the presence of larvae in seeds by slicing open a random sample of seeds with scalpels or razor blades (see discussion on cutting tests in the chapter "Seed Condition").

Table 1 Scientific names of insects discussed in text

Common Name	Order	Family	Scientific Name
western conifer seed bug	HEMIPTERA	Coreidae	*Leptoglossus occidentalis* Heidemann
Douglas-fir cone moth	LEPIDOPTERA	Tortricidae	*Barbara colfaxiana* (Kearfott)
seedworm			*Cydia* spp.
ponderosa pine seedworm			*Cydia piperana* Kearfott
spruce seedworm			*Cydia strobilella* (Linnaeus)
coneworm		Pyralidae	*Dioryctria* spp.
fir coneworm			*Dioryctria abietivorella* (Grote)
ponderosa pine coneworm			*Dioryctria auranticella* (Grote)
Douglas-fir cone gall midge	DIPTERA	Cecidomyiidae	*Contarinia oregonensis* Foote
seed midge			*Dasineura* spp.
spruce cone axis midge			*Kaltenbachiola rachiphaga* (Tripp)
seed wasp (seed chalcid of others)	HYMENOPTERA	Torymidae	*Megastigmus* spp.
Douglas-fir seed wasp			*Megastigmus spermotrophus* Wachtl

Seed wasp infested seeds should not be exported. Douglas-fir seed wasp was introduced to Europe in seedlots imported from Canada early in the 20th century. Currently, regeneration of Douglas-fir in Europe is seriously hampered because of high levels of seed destruction attributable to this insect. Seed wasp levels in cleaned Douglas-fir seedlots can be reduced by using the "incubation drying separation" (IDS) method described by Sweeney et al. (1991) or through some type of specific gravity separation (see discussion in "Seed Processing"). Operationally, gravity table extraction is likely to be a more practical method than IDS to reduce seed wasp levels in large seedlots.

Identifying Western Conifer Seed Bug Damage

Western conifer seed bugs insert their syringe-like mouthparts deep into cones and feed upon developing and mature seeds during the growing season. The seed coat is left undamaged but seed contents are partially or completely consumed (Figure 17), or seeds may fuse to scales, especially when seed bug feeding has occurred early in seed development. Accurate identification of seed bug damage in extracted seeds is very difficult (Bates 1999; Bates et al. 2000). Damage is not visible externally on fed-upon seeds, and internal damage (revealed through seed dissection or radiography) may have been caused by weather, poor pollination, or other environmental factors rather than seed bug feeding. Partially depleted seed contents are likely to be the result of seed bug feeding but it is not possible at present to determine the cause of total depletion. Researchers at Simon Fraser University have developed a marker that will accurately identify the presence of western conifer seed bug saliva within seeds (Lait et. al 2001). In the near future we hope that this tool will enable seed technicians to assess seed bug damage with a high degree of accuracy.

Accurate identification of seed bug damage in extracted seeds is very difficult

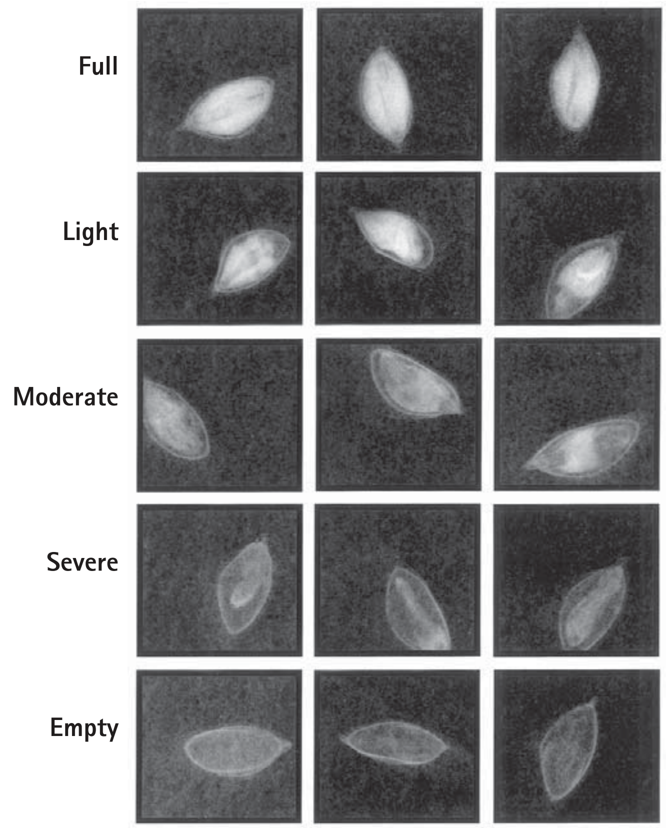

Figure 17 Radiographs of Douglas-fir seeds exposed to feeding by western conifer seed bug during cone development. Damage categories are: Full (no apparent damage), Light ($>2/3$ of seed contents remaining), Moderate ($1/3$–$2/3$ remaining), Severe ($<1/3$ remaining), and Empty (no contents remaining). Copied with permission from Bates (1999).