SCOLYTID PESTS IN FRUIT TREE ORCHARDS

by

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Scolytid Pests In Fruit Tree Orchards

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ABSTRACT

Beetles of the family Scolytidae are minor pests in fruit tree orchards throughout the world. The primary pest species worldwide are the shothole borer, Scolytus rugulosus Ratzeburg, and the ambrosia beetle, Xyleborus dispar (F.). In addition, beetles belonging to four other species are occasional pests. The basic biology of these beetles is known, but large gaps in knowledge still exist. There have been no pheromones isolated for any fruit tree scolytids, but evidence suggests that they will be found with further research. Host selection and host reaction to attack are poorly understood. There is some evidence to suggest that S. rugulosus could be a vector of the fungal pathogen which causes Leucostoma canker, and this hypothesis could be tested experimentally. Current control methods consist primarily of cultural practises, especially proper orchard sanitation.

In 1991 and 1992, experiments were conducted in Creston, B.C. to determine whether ethanol-baited funnel traps could be used to monitor populations of S. rugulosus and X. dispar in orchards. Multiple funnel traps releasing ethanol at 108 mg/day were found to be more effective than those baited with ethanol at lower and higher rates. A comparison between multiple funnel traps and vane traps was inconclusive, due to low beetle numbers. X. dispar emerged in late March and early April, while S. rugulosus did not appear until June. S. rugulosus had one flight period from June to Sept., while X. dispar had two peaks, one in April, and a second in July. These findings differ from those reported by other investigators, probably due to climatic conditions. I conclude that ethanol-baited traps could be used to monitor for these pests, and there is a possibility that mass trapping could be effective at reducing the levels of local populations.

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INTRODUCTION

Members of the family Scolytidae (Coleoptera) are economic pests of forest trees throughout the world. A few members of this family are economically important in fruit tree orchards. These species usually cause minor economic damage, but in some years can be major pests. There is also a possibility that the beetles could be acting as vectors of plant pathogens. Chemical control of these beetles is often very difficult, mainly because most sprays do not penetrate to the inner bark or wood, where the beetles breed. The most important method of control seems to be proper sanitation in the orchard, but this is often neglected.

Herein I review the biology and impact of fruit tree scolytid pests in Part I, and in Part II, I describe two experiments testing their response to attractive chemical baits.

PART I

BIONOMICS

The two species of primary concern throughout the world, and also in British Columbia, are the shothole borer, Scolytus rugulosus Ratzeburg, and the ambrosia beetle, Xyleborus dispar (F.). Other species mentioned as being minor pests of orchards are Xyleborus saxeseni (Ratzeburg), Scolytus mali (Beschtein), Phloeotribus liminaris (Harris), and Xylosandrus crassiusculus (Motschulsky). The bionomics of all of these species are discussed below.

Scolytus rugulosus Ratzeburg

This species was originally described from Germany (Ratzeburg 1837), and is found throughout the Holarctic and Neotropical regions of the world (Bright and Stark 1973). It was believed to have been introduced into North America some time prior to 1877. By 1916, the shothole borer was well established throughout the eastern U.S. and

Canada. Blackman (1934) mentions it as a pest in Mississippi in the early 1920s, and it was first recorded on the west coast of North America in 1910 in Ventura County, California. It was well established in most of California by the 1930s (Smith 1932), and had reached Oregon by 1935 (Chamberlin 1939). The shothole borer apparently was not a problem in B.C. until the late 1950s, as there is no mention of it in a 1956 list of fruit tree pests in B.C. (Downing et al. 1956). S. rugulosus is now found in most fruit-growing areas of North America and Europe.

The host plants of S. rugulosus possibly include most deciduous species in it's range, and it has been recorded in North America from Amelanchier (Juneberry), Crataegus (hawthorn), Cydonia (quince), Eriobotrya (loquat), Malus (apple), Prunus (almond, apricot, cherry, choke cherry, nectarine, peach, plum, and prune), Pyrus (pear), Sorbus (mountain ash), and Ulmus (elm) (Chamberlin 1958; Wood 1982). This beetle ranges in length from 1.8-2.4 mm, and in colour from wholly black to reddish brown, with intermediate forms. The male's frons is slightly flatter and is more pubescent than the female's. This species is easily distinguished from other species of Scolytus by its size, the large, deep pronotal punctures, and the gradually ascending abdominal sternites. Complete morphological descriptions are given in Ratzeburg (1837), Chamberlin (1958) and Wood (1982). A summary of current biological knowledge is given below.

Adult beetles emerge in early spring, from late March to May, depending on the locality. There is a period of maturation feeding, common to all species of Scolytus (Rudinsky 1962). This feeding has been reported at the base of buds (Jacklin and Yonce 1968), and probably occurs in other thin-barked areas as well. Females initiate attacks on trees, boring 1.3 mm diameter holes through the bark, commonly in the area of lenticels. The shothole borer seems to attack trees which are under stress. Once the initial hole is drilled, the female begins to construct the main parent gallery. This gallery is usually from 1 to 5 cm long, usually runs parallel to the direction of the branch, is uniramous and lacks a nuptial chamber. The parent gallery is primarily in the cambium, but slightly enscribes the sapwood. Lindeman (1978) has reported that this species produces two distinct types of parent galleries, depending on the vigour of the tree. In slightly weakened trees, the galleries are shorter and contain fewer eggs than in dying trees. If successful, this reproductive strategy may allow the beetles to spread out their eggs over a greater area in living trees, allowing some of the eggs to develop. This behaviour may also increase the number of inoculation points for a symbiotic fungi that could predispose the tree to beetle attack. Such associations between bark beetles and fungi are common in the Scolytidae (Whitney 1982), but remain unverified for S. rugulosus. It takes anywhere from 1.5 - 4 h for the female to burrow a distance equivalent to the length of her body (Chamberlin 1939). The female is often helped in the tunnel building task by the male's removal of excavated frass (Wood 1982).

The arrival time of the male is unknown, but is probably shortly after the female starts the parent gallery. The males wander over the surface of the tree, and seem attracted to the entrance holes bored by the females (pers. obs.). The female protrudes her abdomen out of the entrance to the gallery and the male copulates with her. The male remains outside on the bark of the tree, and the two beetles remain *in copulo* for up to 20 min (Chamberlin 1939). Mating and copulation appear to be very similar to that of S. mali described below.

After mating, the female begins to lay white, spherical eggs singly in niches along the side of the parent gallery. These niches are 0.35-0.5 mm in diameter, and are 0.2-0.3 mm apart (Zhao 1984). The number of eggs laid varies from 20 to 163 (Chamberlin 1939). When all the eggs are laid, the female backs up into the original entrance burrow and dies with the abdomen blocking the tunnel entrance. Smith (1932) believes that this action helps reduce the chance of predation on the eggs and larvae. The male leaves after oviposition is complete (Kirkendall 1983).

The eggs hatch in a few days, and the first instars burrow in the cambium, at right angles to the parent gallery. These larval mines can vary greatly in length and shape, depending on the intensity of the attack, but commonly they are 2.5 - 10 cm long. The mature larvae burrow into the sapwood, toward the centre of the limb for about 1.5 cm, then pupate in rounded cells lined with chewed wood. The total duration of the larval stage varies, depending on the climate of the area, but Bright (1976) states that the larval stage lasts a little longer than a month. The different life stages have the following durations: egg, 3-4 days; larvae, 30 days; and pupae, 7-10 days (Jack 1962). In California, it is believed that three generations are completed in one summer, with a partial fourth generation possible, while in British Columbia, it seems that two complete generations are normal.

Shothole borers overwinter primarily as late instar larvae, or rarely as pupa. The earliest emergence of adults in the spring of the next year noted in California by Smith (1932) was March 27, while Chamberlin (1939) states that emergence occurs between May and June in the central United States. From personal observation and observations by Jack (1962), it is more likely that late April to mid-May is the earliest emergence in British Columbia.

Nickle (1971) reported a parasitic nematode found in association with S. rugulosus in Maryland. Neoparasitylenchus rugulosi Schvester causes the female shothole borer to produce abnormal egg galleries. Parasitized female beetles produce no eggs, and die within a week of completing their gallery. Nematodes then leave the dead host through its "headend". These nematodes mate, and the gravid females enter shothole borer larvae in nearby galleries. These nematodes lay their eggs just as the beetles are becoming adults. The larval nematodes mature within the beetle's haemolymph, and are then transported by the adult beetles to new trees to continue their lifecycle. This nematode was not found in beetle populations in California, Georgia or Eastern Canada by Nickle (1971), and I have seen no other records of N. rugulosi. It would be of interest to study this nematode more, as it may have the potential to control populations of S. rugulosus, or possibly other species of Scolytus.

Information on insect parasites of S. rugulosus in North America is limited. All recorded parasites of the shothole borer are hymenoptera. The bethylid wasp, Cephalonomia utahensis Brues, is listed as a parasite in the United States south of Idaho (Halstead 1990). This species may be conspecific with C. hyalinipennis Ashmead, which is found in Europe, South America, southern Canada and the entire United States. Grissell (1981) lists the Holarctic pteromalid wasp, Cerocephala eccoptogastri Masi, as a parasite in Ohio, Michigan, Colorado and California, as well as being found in Libya, Egypt, Spain, Greece, France, Turkey and Israel. The following species are listed from North America by Krombein et al. (1979): Spathius benefactor Matthews (Ichneumonidae); Roptrocerus xylophagorum (Ratz.) (Torymidae); Heydenia unica Cook and Davis, Rhaphitelus maculatus Walker, Cheiropachus quadrum (F.) (Pteromalidae); Eurytoma abatos Walker (Eurytomidae); Eupelmus juglandis Ashmead (Eupelmidae); Tetrastichus scolyti Ashmead, Entedon leucogramma (Ratz.) (Eulophidae); and Sclerodermus macrogaster Ashmead (Bethylidae).

The European and Middle Eastern parasite fauna are documented more thoroughly. The following species are listed from Israel in addition to Cerocephala eccoptogastri: Cephalonomia hypobori and Sclerodermus domesticus Latreille (Bethylidae); Ecphylus silesiacus (Ratz.) and Dendrosoter protuberans (Nees) (Braconidae); Eupelmus sp. (Eupelmidae); Entedon ergias (Eulophidae); Eurytoma maura and E. morio (Eurytomidae); and Cheiropachus quadrum, Heydenia pretiosa Foerster and Rhaphitelus maculatus (Pteromalidae) (Mendel and Gurevitz 1985). Other species include Cheiropachus colon (L.), Entedon leucogramma, Eurytoma fraxinicola Hedqvist, and Euhecabolodes minutus Tobias. The percentage of parasitism reached 90% in suitable conditions in Israel, but no other parasitism levels have been reported. When I reared shothole borers from an area that had been under attack for at least two years, parasitism by pteromalid wasps was approximately 30-40%.

No specific predators are mentioned anywhere in the literature, but beetles in the family Cleridae could be as important as they are to other bark beetles. I noticed that trees infested with S. rugulosus had large numbers of ants on them, but whether or not these were preying on the beetles was not ascertained. There is no information published about microorganisms associated with the shothole borer in North America, but Pignal (1973) mentions two species of yeasts, Hansenula holstii Wickerham and Candida diddensii, as being regularly found in shothole borer galleries in France.

Obviously much of the biology of S. rugulosus is still poorly understood. There are no known pheromones, host selection and mating behaviour have been incompletely studied, and the host reaction to shothole borer attack is also not known. These areas must all be studied in more detail for a full understanding of this pest.

Xyleborus dispar (F.)

This species was first described as Apate dispar by Fabricius in 1792, and had been most recently placed in the genus Anisandrus (Wood 1961). X. dispar is found throughout boreal and temperate zones around the world, and was introduced into the fruit-growing areas of North America from Europe. This introduction was likely on nursery stock. The less stringent quarantine procedures at the turn of the century probably allowed both this species and S. rugulosus to become established in North America. X. dispar was first seen in Western North America in 1901 in Washington state, and was reported from B.C. in 1922 (Hopping 1922).

Host plants seem to include most deciduous trees in it's range, and it has been infrequently collected from some conifers. Host genera from which X. dispar has been collected in North America include Acacia (wattle), Acer (maple) Aesculus (horse chestnut), Alnus (alder), Betula (birch), Castanea (sweet chestnut), Celtis (hackberry), Corylus (hazelnut), Crataegus (hawthorn), Diervilla (bush honeysuckle), Fagus (beech), Fraxinus (ash), Gleditsia (honey locust), Ilex (holly), Juglans (walnut), Liriodendron (tulip tree), Malus (apple), Pinus (pine), Platanus (sycamore), Populus (poplar), Prunus (almond, apricot, cherry, peach, and plum), Punica (pomegranate), Quercus (oak), Rosa (rose), Sambucus (elderberry), Salix (willow) and Tsuga (hemlock) (Mathers 1940; Chamberlin 1958; Bright 1968).

Physiologically, this species shows marked sexual dimorphism, with the females and males ranging in length from 3.2-3.7 and 1.8-2.1 mm, respectively. The two sexes are also quite different in other respects, most important of which is that only the females can fly. Complete taxonomic descriptions of X. dispar can be found in Chamberlin (1939), Bright (1968), Bright (1976) and Wood (1982). Females are distinguished from others in the genus by the stout body, the coarsely asperate front of the pronotum, and the large size (Bright 1968).

Adult X. dispar emerge earlier in the year than S. rugulosus, probably due to the fact that they overwinter as adults. Mathers (1940) noted adults emerging between mid-March and the beginning of April when the temperature was >15.6° C on the coast of British Columbia. No other emergence dates are recorded for North America. Emergence was noted in Europe once daily maximal temperatures reached 18-20° C (Mani et al. 1990). These observations are substantiated by my trap catches in early 1992, when large numbers of beetles were captured after two consecutive days of >20° C The first beetles emerged in Creston, B.C. in 1992 on March 19.

Females initiate attacks primarily on lenticular tissue (French and Roeper 1975). X. dispar seems to prefer weakened or dying trees, but apparently healthy trees are also attacked. In contrast to the shothole borer, the females bore into the sapwood of the tree. The tunnel is at right angles to the branch and is usually preceded by the female burrowing “test” tunnels. After burrowing into the substrate for twice her body length, if she finds the substrate unsuitable, she will stop and start a new gallery elsewhere. The tunnels are usually simply branched. In small trees or branches, the tunnel may be corkscrew shaped, while in bigger trees, it usually runs with the rings of growth (Chamberlin 1939). Total length of the tunnel averages 12.95 cm (Egger 1973).

The eggs are laid free along the wall of the gallery, and over the course of two weeks, an average of 28 eggs is laid by each female (Egger 1973). The eggs hatch in 2-3 days, and the larvae wander about, feeding on an ambrosial fungus, Ambrosiella hartigii Batra, which is introduced into the tree host by the female (Norris 1979). This fungus is transported by the females in mycangia located between the pro- and mesonotum. The mycangia are intersegmental pouches which nourish the fungus. They are lined with tall, secretory cells, which resemble many other insect exocrine gland cells, and the mycangial walls are minutely corrugated, which probably assists in their retention of fungal propagules (Happ et al. 1976). It is hypothesized that the beetle secretes soluble amino acid-nitrogen to nourish the fungus in the mycangium (Roeper and French 1981).

The relationship between X. dispar and A. hartigii is a true symbiosis. The fungus requires the beetle for transportation to a plant host, and both adult and larval beetles feed on the fungus. The fungus has two forms, a mycelial and an ambrosial form. The beetles require the ambrosial form for oviposition and pupation, and the change from mycelial to ambrosial form is induced by the beetle. This induction may involve a substance secreted by the pupae and postdiapause beetles (French and Roeper 1972).

The larvae feed exclusively on the ambrosia fungus until mature. The adult female stays and tends the larvae, often pushing them into the ambrosial fungus (French and Roeper 1975). The maternal female crops other fungi and releases substances to ensure that the ambrosial fungus is dominant in the gallery. If this female dies, her brood will die, most commonly by invasion of foreign fungi and bacteria (Norris 1979). After approximately two weeks of feeding, mature larvae pupate along the sides of the parental gallery.

The pupal stage lasts approximately two weeks, and the sex ratio of eclosing adults averages 1 male: 2 females (Egger 1973). These beetles overwinter in the gallery. Beetles mate in the gallery, and copulation lasts from 10-20 min. Males mate more than once, and even though they are mating with their sisters, excellent genetic vigour seems to be maintained (Norris 1979). This system of reproduction is known as inbreeding polygyny (Kirkendall 1983).

Inbreeding has advantages over both parthenogenesis and outbreeding. When a mutation occurs in parthenogenetic animals, that mutation is assured in all of its offspring. Given normal mutation rates, asexuality cannot be expected to conserve a successful genome for more than one generation (Shields 1982). Inbreeding combines very similar parental genomes, allowing for the removal of harmful mutations during gametogenesis. Outbreeding has the disadvantages of reducing, by meiosis, the amount of genetic material passed on to offspring, and breaking down successful combinations of alleles by recombination. Inbreeding greatly reduces the meiotic loss of genetic material, especially if the mating individuals are closely related, as they are in X. dispar. Successful combinations of genes are passed on to offspring in inbreeding populations virtually unchanged (Shields 1982).

The mated beetles apparently stay within the gallery system for the rest of the summer and winter, as there is only one generation of X. dispar per year in both Europe and North America. The initial entrance hole is used by the mated females to disperse in the following spring. The entrance hole is often plugged with the ambrosial fungus, and it is believed that in boring through this plug, the females load their mycangia with fungal spores (French and Roeper 1975). The males are flightless, and remain behind in the tunnel, presumably to die. There is a possibility that males could move between galleries in close proximity in order to outbreed, but there is no record of this occurring. The maternal female dies after her brood leaves.

No predators or parasites are recorded for X. dispar in North America. There is one species of Hymenoptera listed as a parasite in Europe, the pteromalid Perniphora robusta Ruschka (Eichhorn and Graf 1974). The observation by Norris (1979) that maternal females eat or entomb dead or weak progeny, may explain the lack of parasites. Parasitized larvae, if recognized, could be destroyed before the parasite has a chance to fully develop.

However, parasitism of ambrosia beetles, e.g. Trypodendron lineatum (Olivier) (Borden 1988) is generally rare, possibly because of their cryptic habits and advanced degree of parental care.

X. dispar succeeds in reproducing by living in symbiosis with a fungal partner. While the shothole borer depends on internal digestion of plant materials, the ambrosia beetle acquires all of its required nutrients from the fungus it introduces into tree hosts. The ability of A. hartigii to survive on many different tree species, allows X. dispar to survive in these trees as well. Unlike ambrosia beetles in the genera Trypodendron and Gnathotrichus, X. dispar and other species in this genus have flightless males. The drawbacks of this system include the reduction of males to short-lived, non-flying, non-dispersing inseminators of their sisters, and the loss of most outbreeding of the genome. Advantages of having fewer, flightless males include increased reproductive potential due to the larger percentage of female progeny per brood, greater nutrition for the larger female larvae, and the ability of females to colonize a sparsely distributed resource without needing to attract males for reproduction. The two different systems of reproduction of the shothole borer and the ambrosia beetle have allowed these two species to exploit similar habitats, but in entirely different ways.

Xyleborus saxeseni (Ratzeburg)

This species is closely related to X. dispar, and was described by Ratzeburg (1837). It may have been introduced into North America, but there is also evidence that it is native (Chamberlin 1939). X. saxeseni is found throughout most of North America, as well as Europe, North Africa and northern Asia (Fischer 1954). The polyphagous nature of this species has accelerated its spread. Hosts in North America include most species of hardwoods, with Acer (maple), Betula (birch), Carya (hickory and pecan), Cornus (dogwood), Diospyrus (persimmon), Fagus (beech), Gleditsia (honey locust), Ilex (holly), Juglans (walnut), Liquidamber (sweetgum), Populus (poplar), and Quercus (oak) being mentioned by Baker (1972). This species also attacks some conifers (*Libocedrus*, *Pinus*, *Tsuga*) as well, and Bright and Stark (1973) suggest that no species of tree may be exempt from attack.

Though quite closely related to *X. dispar*, *X. saxeseni* is smaller; females average 2-2.2 mm long, and males 1.5 mm. The body is more slender than that of *X. dispar*, with finer asperities on the pronotum. The elytral declivity is characterized by a series of pointed tubercles. The most characteristic feature of this species is the conical scutellum.

The biology of *X. saxeseni* has not been extensively studied in North America, but a general overview of the lifecycle is possible, especially after the work of Kovach (1986). *X. saxeseni* usually attacks large trees which are dying, or trees which are stressed in some other way. The female tunnels into the heartwood of the tree, with the tunnels varying in shape depending on the tree species attacked (Chamberlin 1958). A typical tunnel runs fairly straight into the heartwood, and then takes a turn in the radial direction, before culminating in a relatively large chamber. The female lays her eggs freely in batches of 8-12 along the walls of the tunnel and chamber (Fischer 1954). The total number of eggs laid by each female has been reported as 48 by Bright and Stark (1973), but Egger (1973) reports an average of 73 offspring from each hatching site. The larvae that develop move throughout the chamber and tunnel, sometimes helping to enlarge the chamber (Bright and Stark 1973). There are three larval instars, as determined by head capsule size (Fischer 1954). The larvae feed exclusively on an ambrosia fungus which covers the entire surface of the chamber.

The species of fungus cultivated was identified only as a "yellow moniloid fungus" in Norris (1979), but Batra (1967) earlier described it as *Ambrosiella sulphurea* Batra. The mycangia of *X. saxeseni* are sclerotized pouches in the bases of the elytra. There is very little else reported about the relationship between *X. saxeseni* and the fungus on which it feeds.

The life cycle of this beetle is known to take an average of 24.7 days to complete on artificial diet (Kovach 1986), and Baker (1972) states that only two months are needed under natural conditions. Like X. dispar, the females and flightless males overwinter as adults in the host tree. The female to male ratio is reported as averaging 20:1 (Fischer 1954), or 26:1 (Kovach 1986). Mating occurs in the tunnel before the females disperse. The males then die and are ejected from the entry hole. The females emerge in early spring, when the temperature exceeds 21° C for two consecutive days (Kovach 1986). This species is multivoltine in South Carolina, with adult emergence peaks occurring every 57 days. There are no reports of parasites or predators of X. saxeseni, and more research must be done on this beetle, especially with regard to its relationship to its ambrosial fungus.

This beetle is usually a very minor pest of fruit trees, where it is often found in association with X. dispar. Kovach (1986) reported it as being the most numerous beetle captured in peach orchards, while most other authors consider it to be far less damaging than X. dispar.

Scolytus mali (Beschtein)

The range of S. mali includes central Europe, the British Isles and the eastern United States and Canada (Rudinsky et al. 1978). It has been recorded in North America from southern Ontario and Quebec, Connecticut, New York and New Jersey (Bright 1976). S. mali is quite closely related to S. rugulosus, and is distinguished from it by its length (3 mm vs. 2.5 mm), the finer, more widely separated elytral punctures, and the glabrous region on the elytra (Bright 1976). The hosts listed for North America include Malus (apple), Prunus (peach, plum), Pyrus (pear), Sorbus (mountain ash) and Ulmus (elm).

The biology of S. mali has not been investigated in North America (Bright 1976), but Rudinsky et al. (1978) studied it in central Europe. There are two generations per year in Europe at lower elevations, with the first flight occurring in May and June, and the second flight in July and August. Rudinsky et al. (1978) state that only one generation occurs at higher elevations, and in more northerly countries. The emerging male and female beetles have a brief period of maturation feeding.

The females initiate maturation feeding at crevices or wounds in the bark on weakened trees, and after three or four days, the males join them to mate. Males run over the surface of the attacked tree and are attracted to females which protrude their abdomens out of the entrance of their feeding burrow. The males then swing their abdomen over the entrance hole and copulate for 1.0-1.5 min. Stridulation appears to play some part in courtship behaviour, as it was observed in males at the entrance to female galleries. The male leaves after copulation is completed. Most of the beetles leave the maturation feeding site to find other breeding material, but some females remain and initiate egg galleries. There is some evidence to suggest that pheromones may be produced by the female of S. mali when galleries are initiated (Rudinsky et al. 1978), but not enough material was available for confirmation of specific compounds.

The female produces galleries 3-4 cm long, with a turning niche or nuptial chamber at the entrance. Apparently, males may come back and enter the gallery, and even mate with the females again. It is not clear if this is the same male that originally mated with the female. The male may also help in enlarging the gallery. No data are given on the number of eggs laid. The first generation larvae mature and emerge from the parental gallery, but the second generation larvae overwinter in the gallery.

This species is considered a fairly important pest of apple orchards in Europe, but is not much of a problem in North America. It is mentioned as a pest of fruit trees in Austria by Rupf (1980). The attacking beetles weaken, and within 1-4 years may kill small apple trees (Rudinsky et al. 1978). Baker (1972) states that this species is capable of transmitting the Dutch Elm disease pathogen during its maturation feeding.

Phloeotribus liminaris (Harris)

This native species, commonly called the peach bark beetle, is found in eastern and central Canada, and the eastern U. S. It is considered a minor pest of peach orchards, but it is also recorded from Morus (mulberry), Prunus (cherry and plum), Sorbus (mountain ash) and Ulmus (elm) (Baker 1972; Bright 1976). This species is easily distinguished from any other fruit tree scolytids by its antennal club, which is deeply divided into three independently movable parts (Bright 1976).

P. liminaris breeds primarily in stressed trees. Females initiate attack in the spring, with the males joining shortly afterwards. The gallery is short, transverse, and usually consists of one short and one long tunnel, extending in either direction from the entrance hole, and deeply engraving the wood (Baker 1972). The short tunnel is considered a turning niche, or mating chamber. The males die in the gallery after copulation.

The female lays between 80 and 160 eggs in niches along the walls of the main gallery (Slingerland and Crosby 1914). The larvae feed at right angles away from the egg gallery, with the grain of the wood (Bright 1976). The eggs of the first generation hatch in about 20 days, and the larval stage lasts approximately 25-30 days. Pupation occurs in enlarged cells at the ends of the larval galleries. The pupal stage lasts from 4-6 days, after which the adults remain in the tree for another week or two before emerging (Slingerland and Crosby 1914). There are two generations per year, with the broods of the later generations overlapping.

The young second generation adults emerge in the fall, and burrow into the bark of trees to overwinter. These burrows sometimes extend into the living outer bark, causing irritation and possibly affecting normal growth patterns. These trees may be more suitable for attack the following spring. The peach bark beetle usually does not kill the trees it attacks, but the trees can be severely stressed. This species is reported by Baker (1972) as occasionally being a severe pest in peach orchards.

Xylosandrus crassiusculus (Motschulsky)

This species is a recent introduction from east Africa and southern Asia, first recorded from the continental United States in South Carolina in 1974 (Kovach and Gorsuch 1985). X. crassiusculus attacks a wide variety of hosts in its native range, but has only been reported from Cornus (dogwood), Prunus (cherry and peach) and Liquidamber (sweetgum) in South Carolina (Kovach 1986).

X. crassiusculus females range in length from 2.1-2.9 mm, and are 1.5 times as wide as long (Wood 1982). They are easily distinguished from other North American ambrosia beetles by their widely separated procoxae and dull elytral declivity surface. Males are smaller than females, appear deformed when viewed laterally, and are flightless (Kovach 1986). They remain in the parental gallery to inseminate their mothers and sisters.

The only work on this species in North America was carried out by Kovach (1986). X. crassiusculus had one generation per year in South Carolina, with peak emergence occurring in early March. Females attack apparently healthy peach trees in areas of high humidity. Kovach (1986) noted the greatest trap catch in an orchard located near a swamp. The females burrow into the host sapwood, and galleries are branched, with cave-like depressions where the eggs are laid. Each female lays from 1-6 eggs per depression over a prolonged period. The female also inoculates the tree host with an ambrosial fungus, identified as Monilia sp. (Wu et al. 1978). The fungus isolated by Kovach (1986) was a Fusarium species, which Kovach believes is an auxiliary ambrosial fungus. Positive identification and a complete description of the primary ambrosial fungus is obviously still required.

There are probably three larvae instars, and the adults eclose from 48-62 days after parental gallery initiation (Kovach 1986). The average number of offspring per gallery is 8, with 70% of the galleries failing to produce offspring. After emergence, Kovach (1986) suggests that an obligatory diapause is required in South Carolina, as this species has up to 4 generations per year in Taiwan (Wu et al. 1978).

There are obviously many areas of the biology of X. crassiusculus which remain to be studied, particularly the relationship between the beetle and its ambrosial fungus, diapause and why it may be required, and the potential geographic and host ranges of this beetle in North America.

Other Species

There are other species of scolytids mentioned as attacking peach trees, but these are not considered as pests. Kovach and Gorsuch (1985) list Ambrosiodmus rubricollis (Eichhoff), A. tachygraphus (Zimmerman) and Monarthum fasciatum (Say) as additional species infesting peach wood in North Carolina. No other species of scolytids attacking any other fruit trees are mentioned in the literature.

HOST-INSECT INTERACTION AND IMPACT OF INFESTATION

The impact of scolytid beetles in fruit tree orchards can be both direct and indirect. Direct impacts include the loss of limbs, or sometimes whole trees, due to the tunneling of the larvae and adults. These beetles seem to attack already physiologically weakened trees, but these trees may not show this weakness externally. The tunnelling of larvae of S. rugulosus can girdle limbs, and cause severe stress to the trees. The advantage of this girdling action to the beetles is that it disrupts translocation in the tree, and therefore, provides areas where the beetle larvae have a much higher chance of survival. Jack (1962) believes that the mechanical damage caused by the adults of X. dispar would be enough to kill small trees. Kovach (1986) did experiments to test the effect of mechanical injury on peach trees. He found that young, healthy peach trees were able to withstand a simulated attack of up to 100 small (2 mm diameter) borers, without reduced growth or flower set.

This simulated injury actually caused increased growth as a response. This suggests that other agents, such as the ambrosial fungus, may be involved if trees are being killed.

Once an adult shothole borer starts to bore into the bark of the tree, the tree responds by producing large amounts of sap. This sometimes succeeds in killing the beetles, but puts even more stress on the trees. The production of sap requires a large amount of energy, and may represent a significant loss of carbohydrates that the tree could require (Wisniewski et al. 1984). This stress, in turn, may cause increased beetle attack. Gum secretion is most common in stone fruit trees, but does occur in all trees to a certain extent. Gum is produced by gum ducts, which originate as unlignified xylem tissue (Stösser 1978). The defensive role of gum comes from its ability to infiltrate intercellular spaces and the cells surrounding the wound quickly, thereby sealing off the area of infection (Agrios 1978).

The production of gum and its effect on the beetles may be equivalent to the role of secondary resinosus in coniferous trees in response to symbiotic fungi introduced by bark beetles (Berryman 1972). The ability of fruit trees to produce large amounts of sap or gum raises the question of the efficiency of this hypothesized defense mechanism against invading beetles. There is no literature on this subject, and a study that could elucidate the effect of fruit tree sap on invading beetles would be important.

The possibility that gum exudation may somehow inhibit the hypothesized pheromone system of S. rugulosus should also be examined. It has been suggested that the resin of lodgepole pine, Pinus contorta var. latifolia Englemann, is capable of obstructing the production or release of pheromones of Dendroctonus ponderosae Hopkins (Raffa and Berryman 1983). If stone fruit tree sap has the same effect, it could be an important way in which healthy fruit trees defend themselves against attack.

The second form of direct impact is caused by the maturation feeding of the adult beetles in the genus Scolytus. S. rugulosus adults emerging in the spring often feed at the bases of young buds (Smith 1932). This type of damage may continue throughout the summer, and up to 90% of buds may be damaged in bad years (Jacklin and Yonce 1968).

This type of feeding damage may decrease fruit production, and may cause more stress to the trees, through loss of photosynthetic area.

The different types of damage caused by the adults of S. rugulosus and X. dispar both involve injury to the bark of the trees. The bark of a tree is an extremely important barrier to fungal infection (Agrios 1978). Bark tissues shield the xylem from the environment, and the containment of infectious microorganisms is also a primary function of the bark (Biggs et al. 1984). In the case of X. dispar, the adults inoculate the tree with A. hartigii, but other fungi, including species of Ceratocystis, Schizophyllum, Aspergillus, Penicillium and Trichoderma, have also been found in the galleries of infested trees (French and Roeper 1975). The last three species are common saprophytic fungi, but many Ceratocystis spp. associated with bark beetles are pathogenic (Whitney 1982), the most notable being C. ulmi (Buism.) C. Moreau, the causal organism of Dutch Elm disease. C. ulmi is carried to elm trees primarily by Scolytus multistriatus Marsham (Carter 1973) in North America.

There are numerous examples of scolytids inoculating trees with pathogenic fungi to help overcome the tree's defense mechanisms. The most studied interactions include Dendroctonus ponderosae and the fungus Europhium clavigerum Robinson (Raffa and Berryman 1983), Scolytus ventralis LeConte and Trichasporium symbioticum Wright (Bright 1976), Ips typographus L. and Ceratocystis polonica (Siem.) C. Moreau (Christiansen and Horntvedt 1983), and Pseudopityophthorus pruinosus (Eichhoff) and Ceratocystis fagacearum (Rexrode et al. 1965). There is also some evidence to suggest that an ambrosia beetle, Xylosandrus germanus Bland. may be implicated in the transmission of Fusarium to black walnut trees (Weber and McPherson 1984).

There is a possibility that S. rugulosus may also be a vector of fungal pathogens in B.C. There are reports from Europe that S. rugulosus is involved in transmitting Verticillium dahliae Kleb. to apricots (Popushoi and Kylik 1976), and Agrios (1980) mentions S. rugulosus as a minor vector of Ceratocystis fimbriata Ell. & Halst., the causal organism of a canker disease of stone fruits. Jack (1962) suggested that there could be a relationship between an unidentified disease in fruit trees in B.C. and beetle attack. He could not conclude whether the beetles were acting as vectors, or simply attacking trees already diseased. From personal observation, I have also noticed trees that are diseased and are also attacked by shothole borer. The most common diseases seen on peach trees were the cankers caused by *Leucostoma persooni* Höhnel and *L. cincta* (Fr.) Höhnel, previously known as *Cytospora leucostoma* and *C. cincta*, respectively.

A relationship between *S. rugulosus* and *L. persooni* was suggested as long ago as 1937. Willison (1937) noted cankers forming around the boring activity of *S. rugulosus*, while Luepschen et al. (1979) reported that <1% of cankers were associated with insect damage. Sinclair (1987) also lists *S. rugulosus* as one species which provides entry sites for *Leucostoma*. These researchers do not suggest that the beetle actually transports the fungus, only that it provides entrance holes.

Leucostoma produces easily visible "threads" of conidiospores from it's pycnidia. Agrios (1978) states that the fungus is spread primarily by spores being splashed by water, but also mentions insects as possible vectors. There is evidence to show that *L. persooni* conidiospores can be dispersed by wind-blown rain as far as 77 m from a source tree (Bertrand and English 1976). The interior of British Columbia is very dry throughout most of the year, so the transmission of this fungus by water alone seems unlikely, unless it could be promoted by some types of sprinkler systems. The spores of *Leucostoma* are sticky, and they require a wound in order for inoculation to take place. These characteristics support the hypothesis that the spores of *Leucostoma* are ideal for transport by insects. Female and male *S. rugulosus* walking on infested branches could quite conceivably pick up these spores on their cuticle, allowing for mechanical vectoring to occur.

The hypothesis of pathogen vectoring by *S. rugulosus* adults was investigated by examining 60 terminal branches in a peach orchard in Keremeos, B.C. which was devastated by *Leucostoma* . However, I found no adult feeding damage. This does not rule out the possibility that trees in other areas have been inoculated with Leucostoma by S. rugulosus. Even if direct vectoring is not found, the injury caused by the adult beetles to the bark of the tree, plus the extra stress caused by the beetle attack, must surely make the tree more vulnerable to fungal invasion. Pathogen vectoring by S. rugulosus is only a hypothesis, but one which should be considered, as some horticulturists are quite concerned about the spread of Leucostoma in orchards, especially since no control method is currently available.

The experiments required to substantiate the hypothesis of pathogen vectoring could be similar to those carried out by Witcosky et al. (1986) working with the beetles Hylastes nigrinus (Mannerheim), Pissodes fasciatus LeConte and Steremnius carinatus (Boheman), and their vectoring of Leptographium wageneri Kendrick. The criteria set out by Leach (1940) to prove that a specific insect is a pathogen vector are the following: 1) the insect must be associated with diseased hosts; 2) the insect must visit healthy hosts under conditions suitable for transmission of the pathogen; 3) the insect must carry inoculum of the pathogen in the field, and; 4) the insect must successfully transmit the pathogen to hosts under laboratory conditions. The first two criteria have been met for S. rugulosus and Leucostoma. I have observed trees which had both Leucostoma canker and had shothole borer damage. The flight periods of S. rugulosus occur at times when Leucostoma is producing spores for dispersal. The primary spore production time in Leucostoma is in fall, when there are shothole borers flying. The last two criteria have yet to be experimentally proven.

The hypothesis that shothole borers carry Leucostoma spores could be easily tested. Living beetles could be captured in the field and examined for spores using an electron microscope, as was done with Ips sexdentatus Boerner (Levieux et al. 1989). Wild beetles can also be crushed onto nutrient media to see if they carry the fungus externally. The possibility of internal transport of spores can be checked by surface sterilization of the beetles before crushing. The ability of S. rugulosus to transmit Leucostoma in the lab could also be shown with a few simple experiments. Fruit trees of several different species could be kept in the lab. Shothole borers which have been exposed to the conidiospores of Leucostoma could then be introduced into the trees. The occurrence of cankers, or the ability to culture the fungus from the trees with S. rugulosus, would prove that the beetle transmits the fungus.

MONITORING

Observation of the damage caused by scolytid beetles is one way to monitor for their presence. A small entrance hole, often exuding pitch, is the first obvious sign of attack by Scolytus spp. Ambrosia beetle attack is often a little more difficult to detect, but the presence of small amounts of fine frass on the outside of the tree is usually the first sign that attack has occurred. Wilting of the leaves may occur later. Philip and Edwards (1991) suggest the use of tanglefoot applied to fruit tree trunks to trap adults and indicate their presence. The emergence holes of S. rugulosus are quite easy to see, as the adult beetles produce a "shot hole" effect in the bark, from which the common name was derived. The detection of these beetles visually has one major drawback; by the time these signs of attack are seen, it is too late to prevent attack.

Detection of the presence of the beetles before major attacks can occur would greatly enhance the ability of the grower to control the beetle. Researchers in forestry have been using semiochemicals (Nordlund 1981) to monitor, and in some cases to control, beetles of many different scolytid species (Borden 1990). Similar techniques have been used very successfully in orchards to monitor the codling moth, Cydia pomonella (L.), and new semiochemicals are being developed for monitoring of numerous other orchard pests.

Several studies suggest that semiochemical-baited traps could be used to monitor both S. rugulosus and X. dispar. It had been found by Graham (1968), Moeck (1970), and Kimmerer and Kozlowski (1982) that ethanol is one compound produced by trees that are freshly cut, or under stress. Graham (1968) showed that induced anaerobic conditions greatly increased the attractiveness of hemlock and Douglas-fir to Trypodendron lineatum.

The change from aerobic to anaerobic (fermentative) respiration produces primarily ethanol (Salisbury and Ross 1985). The ability of several different tree species to produce ethanol under anaerobic conditions was verified by Moeck (1970). Kimmerer and Kozlowski (1982) demonstrated, by gas-chromatographic measurement, the production of ethanol in plants stressed by sulphur dioxide, ozone, water stress, and freezing and crushing injury. Since the fruit tree scolytids are known to attack primarily stressed trees, it seemed likely that ethanol could be an attractant for them.

It has been shown that ethanol is a primary attractant for the ambrosia beetles Gnathotrichus sulcatus (LeConte) (Cade et al. 1970) and Trypodendron lineatum (Moeck 1970). Norris and Baker (1969) have shown that ethanol acts as a biting stimulant for Xyleborus ferrugineus (F.), and there is similar evidence for ethanol as a boring stimulant for T. lineatum (MacConnell et al. 1977). Experiments carried out by Moeck (1971), Roling and Kearby (1975), Montgomery and Wargo (1983), Kovach and Gorsuch (1985) and Klimetzek et al. (1986) confirmed that ethanol was attractive to both S. rugulosus and X. dispar. All of these researchers used either sticky traps or barrier traps to conduct their experiments. The ethanol release rate varied greatly, from as low as 0.001 mg/h to as high as 1200 mg/h. The purity of the ethanol used ranged from 10 - 75%. One criticism of these studies, especially for their applicability to orchards, is that only Kovach and Gorsuch (1985) did their work in an orchard. The two earliest studies did not determine release rates, and the release rates and concentrations are highly variable in the other experiments. The data from all previous research is not consistent enough to draw any solid conclusions about ethanol as a practical monitoring tool for X. dispar and S. rugulosus.

The use of ethanol-baited traps as a monitoring tool for X. dispar was first suggested by Moeck (1971) when he captured many more individuals of this ambrosia beetle than any other species of scolytid in ethanol-baited sticky traps. Other investigators produced additional information about other semiochemicals. Schroeder and Lindelöw (1989) found that X. dispar was repelled by α-pinene, a compound found in the resin of many coniferous trees. Thus X. dispar would be able to use α-pinene to distinguish between conifers, and its preferred deciduous hosts. These investigators and Klimetzek et al. (1986) also found that the number of X. dispar captured increased as the amount of ethanol released increased. Montgomery and Wargo (1983) found that ethanol released at rates >420 mg/h did not catch significantly more beetles than at release rates of approximately 85 mg/h. The maximum release rates of ethanol in the studies by Klimetzek et al. (1986) and Schroeder and Lindelöw (1989) were 250 and 128.1 mg/h respectively, so it seems that a release rate of between 250 and 420 mg/h is probably optimum for X. dispar. This is much higher than the 400 nmol/g dry wt ethanol released by birch trees recorded by Kimmerer and Kozlowski (1982).

The amount of research on primary chemical attractants of S. rugulosus has been less extensive. Kovach and Gorsuch (1985) listed S. rugulosus as one of the eight scolytid species attacking peach wood that was attracted to barrier traps baited with 75% ethanol. The only other experiments on this species involved assessing the attractiveness of different tree species to adult females (Gurevitz and Ishaaya 1972; Gurevitz and Ascher 1973). It was found that the most attractive fruit tree species tested was apricot, followed by peach, almond, plum and apple, which was barely attractive. It was also found that this order of attractiveness was the same, regardless of the fruit tree host on which the beetles were reared.

Levy et al. (1974) listed three host flavonoid compounds (taxifolin, pinocembrin, and dihydrokaempferol) from apricot bark which increased the biting response in the beetles. These compounds were not tested against ethanol, so their relative attractiveness is unknown. These three compounds were only extracted from ground bark, not in the air surrounding the tree, as ethanol was in the experiments by Kimmerer and Kozlowski (1982). None of these compounds was field tested, so their ability to attract flying beetles is also unknown. It could well be that these compounds act only at short range to identify the plant as suitable to the beetles.

I hypothesize that beetle-produced pheromones may be involved in the attraction of S. rugulosus to their host trees, most likely in combination with host volatiles, especially ethanol. Levy et al. (1974) suggest that since shothole borer infested bark was more attractive than non-infested bark, beetle secretions, as well as host compounds, may be important in attraction. A more recent paper by Gurevitz and Ledoux (1981) also suggests that an aggregation pheromone is present. They found that frass extracts were also more attractive to females than ethanol alone. The elucidation of the pheromones of S. multistriatus may have significance in this case.

Results of initial experiments on S. multistriatus semiochemicals were interpreted to mean that a host compound acted as a primary attractant (Meyer and Norris 1967), but Peacock et al. (1971) demonstrated that a female-produced pheromone was also involved in attraction. Peacock et al. (1973) showed that frass extracts were attractive to beetles in the laboratory. These extracts failed to elicit field responses, so collection of the pheromones was done using Porapak Q, and these extracts proved to be effective in attracting beetles in the field (Peacock et al. 1975). Finally, it was discovered that a combination of two beetle-produced compounds and one host compound worked in synergy to attract beetles to freshly attacked trees (Pearce et al. 1975).

I think that similar experiments may be required to identify the pheromones of S. rugulosus. The possibility that ethanol, or one or all of the three host compounds found to be attractive by Levy et al. (1974), could be working in concert with beetle produced pheromones must be examined. The use of Porapak Q to collect pheromones of S. rugulosus would be feasible, especially using new microtechniques (Gries et al. 1988).

There has been no mention of a pheromone in X. dispar, but this may be due to a lack of research. Klimetzek et al. (1986) claim that the spanandrous Xyleborinae, which include X. dispar and X. saxeseni, seem to lack aggregation pheromones, but fail to substantiate this claim. There is a possibility that aggregation pheromones are not needed, as there is a strong primary attraction, and the females are mated when they leave the parent galleries, but it would be of adaptive advantage for the majority of females to respond to compounds released by pioneer beetles that have successfully attacked a vulnerable host.

The use of ethanol-baited traps would allow the fruit grower to assess the presence or absence of scolytids in an orchard. In the case of X. dispar, Mani et al. (1990) suggest that one or two traps per orchard would allow for effective monitoring, whereas eight traps per ha would be required for control. The number of traps required for control would depend on the type of trap used, as well as the numbers and release rates of semiochemicals. Mani et al. (1990) used the red cross trap "Rebell® rosso", which is not readily available in North America.

CONTROL

The most effective method of control of all scolytid pests of orchards is sanitation. The other important measure is to protect trees from attack by maintaining their vigour. The most important factor in this regard seems to be water. Gorsuch and Kovach (1985) showed that many trees infested with scolytids were under obvious stress. Many of the trees they observed to be attacked by scolytids were in soils with high populations of nematodes, and low pH. The ability of trees to resist attack by scolytids is probably seriously affected in drought stressed trees. Christiansen and Horntvedt (1983) suggest that the impaired photosynthesis and increased respiration which occur in drought stricken trees likely reduces the photosynthate content, which is essential to resist attack. Diseases are also encouraged by drought.

Drought stress has also been shown to predispose Picea pungens Engelm. to Cytospora kunzei Sacc. var. picea Waterman (Schoeneweiss 1983). The ability of Leucostoma persooni and L. cincta to invade trees is also enhanced by drought stress (Sinclair 1987). The possibility of global warming due to the greenhouse effect could increase the stress on trees in temperate areas of the world. Increased temperatures would increase water stress, especially in areas like the interior of B.C. which already have chronic water shortage problems. Water stress is not always immediately obvious, so sanitation is very important.

Smith (1932) pointed out the importance of rigorous orchard sanitation in reducing infestations. Many orchards have abandoned woodpiles near them, which are ideal breeding material for S. rugulosus. These woodpiles are sometimes made up of trees or branches removed because they were attacked by X. dispar or shothole borers. These piles must be moved into a building from which emerging beetles can't escape, or they must be destroyed. The easiest method of disposal is burning. If the piles are not completely burned however, beetles can often be found breeding in the unburnt bark, as I have observed in Keremeos, B.C.

A novel method of control for S. rugulosus is mentioned in Zhao (1984). This author suggested that branches be placed in the ground around trees which may be attacked. These freshly cut branches would act as "traps". These branches would be undergoing anaerobic respiration and therefore producing ethanol, which would attract the beetles. The branches can then be removed after they are attacked and burned to kill any beetles within them.

Jack (1962) described the first serious damage due to scolytid beetles in B.C. in the late 1950s; since then scolytids seem to have become much less of a problem. This reduction in damage seems to be mainly due to good orchard management, especially sanitation. It is now quite difficult to find growers in B.C. who have serious problems with either S. rugulosus or X. dispar. There are occasional outbreaks, but as long as the grower is conscientious and quickly removes and burns affected branches, the infestation usually is quite easily controlled. The most serious problems usually occur in orchards that have been abandoned, or in orchards that are for sale, and are not maintained properly. These neglected orchards can be reservoirs of beetles which can attack neighbouring orchards.

Despite the decrease of scolytid problems in North American orchards, there appears to be a continuing impact in Europe. The reasons for this are unclear. It seems that there are more small orchards placed near native forests, which would allow for easy immigration of beetles into the orchards. The fact that S. rugulosus and X. dispar are native to Europe, and may be adapted to European conditions, may also contribute to their continued success there. Although a large number of parasites and predators would likely be associated with these two species in Europe, these obviously can't control the beetles. The 90% parasitism rates mentioned by Mendel and Gurevitz (1985) in Israel shows that parasites could be a control factor, but these authors do not mention how long it took to achieve this level.

PART II

TRAPPING EXPERIMENTS

Introduction

The ability to capture scolytids in ethanol-baited traps is well documented. The possibility of using these traps to monitor, and possibly mass trap, two species of orchard scolytids in B.C. was the reason the following experiments were carried out. I proposed to test the hypothesis that ethanol-baited funnel traps could be used to monitor the presence of Xyleborus dispar and Scolytus rugulosus in orchards.

Methods and Materials

Experiments were designed to find an appropriate release rate, and to compare the efficacy of the multiple funnel trap (Lindgren 1983) and a plastic vane trap designed by J. Fournier (B.C. Ministry of Forests, 4595 Canada Way, Burnaby, B.C.). The vane traps were constructed of 3 vanes of plastic venetian blind material cut to size (30.7 cm long, 8.9 cm wide) and spray painted black. These vanes were joined together by plastic rings at three points. The vanes were attached to the top and bottom of the trap using window vane connectors. The top and bottom of the vane trap were made of the same parts as the funnel traps, so that the 3 vertical vanes were positioned immediately above a collecting funnel and receptacle. These experiments also allowed the study of flight periods of the two beetles in British Columbia.

Multiple-funnel traps (Phero Tech Inc., Delta, B.C.) baited with plastic dispensers releasing 97% ethanol at 27, 54, 108 and 216 mg/day (at 20° C) were placed at four locations between April 4 and October 5, 1991, two each in Cawston and Creston, B.C. The orchard in Creston consisted of 30-year old apple trees, with one site having a single row of peach trees along one edge. At each site, two traps of each of the four doses were placed at random around the perimeter of orchards, bringing the total number of traps to 32. Trap position was chosen by assigning each treatment with a number from one to four, and then placing them using a random number table. All traps were at least 30 m apart. Half of the traps in Creston were replaced by plastic vane traps at the end of June. The vane traps were baited with ethanol released at 54 mg/day as the traps could only accommodate dispensers that released ethanol at this rate. Traps were checked at intervals of 7 to 21 days. The beetles were preserved in alcohol, and identified later at the lab using Bright's (1976) key. There were several other types of insects captured, but these were not of interest, so they were discarded.

Multiple funnel traps baited with 108 mg/day ethanol were also placed in the same Creston orchard between March 10 and April 26, 1992. These traps were checked daily by the grower, in order to find earliest flight, and the influence of temperature on flight.

Results and Discussion

Most X. dispar were captured in traps from which ethanol was released at 108 or 216 mg/day (Fig. 1). A Fisher's Protected L.S.D. test showed that trap catches at the 108 and 216 mg/day release rate were significantly different from the other two release rates. At Creston, there were 130 and 1518 X. dispar captured in 1991 and 1992 respectively, and 29 S. rugulosus captured in 1991. The greater abundance of X. dispar is likely due to the previous occurrence of this species in this area.

Two different peaks of activity were apparent for the two species (Fig. 2). X. dispar was most active early in 1991, but there was some overlap with S. rugulosus, which was captured predominantly in July. There was a suggestion of two flight peaks for X. dispar in 1991, one in March-April, and a second in July. X. dispar were first captured in 1992 on March 19. This early emergence date and the high number of beetles captured was probably due to the very mild winter of 1991-1992, and the early spring of 1992, in which the daily maximum temperatures rose above 20° C at the beginning of April. The close relationship between temperature and trap catch in 1992 is clearly illustrated in Figure 3. Flight of X. dispar seems to occur when daily maximum temperatures rose above 15° C, and over 90% of the X. dispar were captured in 1992 when the temperature was above 18° C.

The numbers of beetles captured were quite low in the trap comparison study. The vane and funnel traps captured 7 and 4 X. dispar and 11 and 10 S. rugulosus, respectively, at equivalent ethanol release rates, indicating little difference in efficacy of the two traps.

The data presented in Fig. 1 show that it could be possible to monitor for the presence of X. dispar using Lindgren funnel traps baited with ethanol released at 108 mg/day. The data from 1992 using 108 mg/day showed that this release rate is sufficient to catch large numbers of beetles, if they are present. The orchard in which the traps were placed in Creston suffered minor damage in 1992 (4 small trees killed). The grower believes that it could have been much worse if the traps were not present, but the alternative hypothesis that the traps attracted X. dispar into the orchard must also be considered. Nonetheless, mass trapping of X. dispar on small acreages may be a viable possibility in B.C.

The response of S. rugulosus to ethanol in 1991 suggests that ethanol-baited traps could also be used to monitor for the presence of the shothole borer. The problem of low trap catches may be alleviated if pheromones are found which are involved in the attraction of S. rugulosus to its host. The flight periods of S. rugulosus and X. dispar are both different from those found by Jack (1962) in the Okanagan Valley. The later emergence dates in my study are probably due to cooler temperatures in the Creston area than in the Okanagan Valley. The emergence dates for X. dispar mentioned by Mathers (1940) are similar to those in 1992 in Creston. The large percentage of X. dispar captured at temperatures above 18° C confirms the conclusion of Mani et al. (1990) that this species emerges in spring once temperatures reach 18-20° C. There is a suggestion in the data of two flight periods for X. dispar, and only one for S. rugulosus. This is different from previous records in B.C. (Jack 1962; Philip and Edwards 1991).

Comparison of the plastic vane and funnel traps should be done again at a site and time when there are more beetles present. The funnel trap is commercially available, but is cumbersome. The vane trap is smaller and easier to use and appears to be as effective as the multiple funnel traps, but cannot accommodate the optimal size of ethanol dispenser. A change in design could allow for use of a large dispenser. In addition, the vane colour and the use of patterned vanes could also be examined.

Fig. 1. Catches of 118 X. dispar in multiple funnel traps baited with ethanol released at 4 rates, April 18 to October 5, 1991, in Cawston and Creston, B.C.

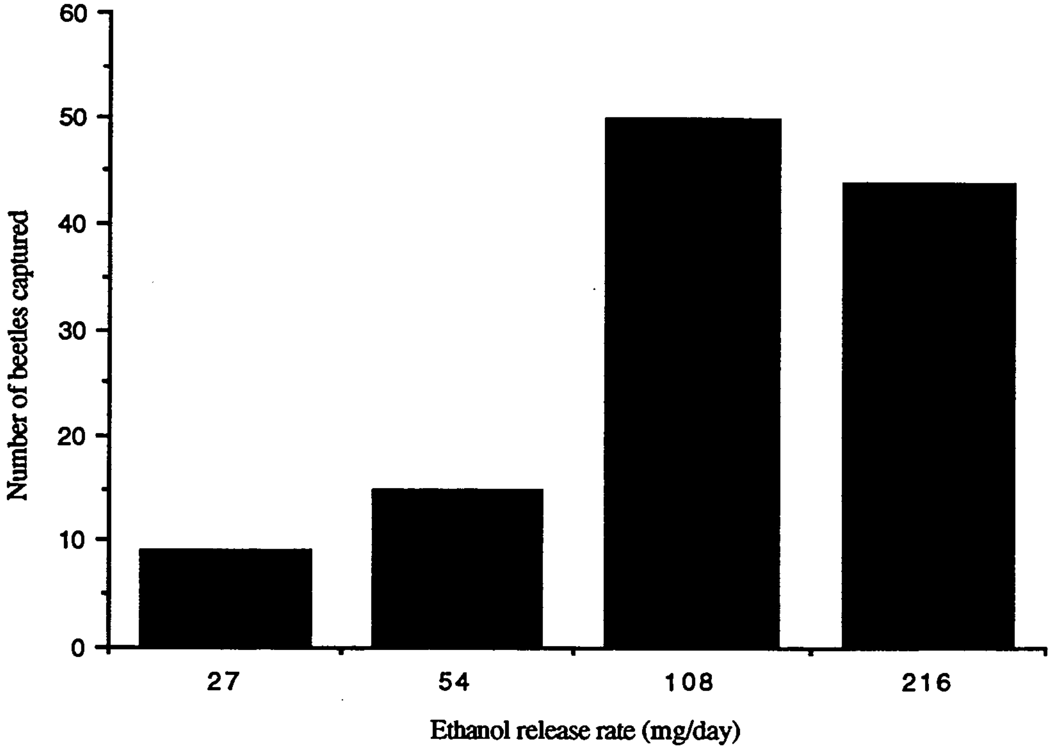

60
50
40
30
20
10
0
Number of beetles captured
27
54
108
216
Ethanol release rate (mg/day)

Fig. 2. Percentage of X. dispar and S. rugulosus captured in multiple funnel traps in 1991 and 1992 in Creston, B.C. N= 118 and 1518 for X. dispar in 1991 and 1992, respectively; N= 29 for S. rugulosus. (Note: Percentages reported for 1992 are slightly higher than those for the equivalent time period in 1991 because the whole flying population in 1992 was not captured).

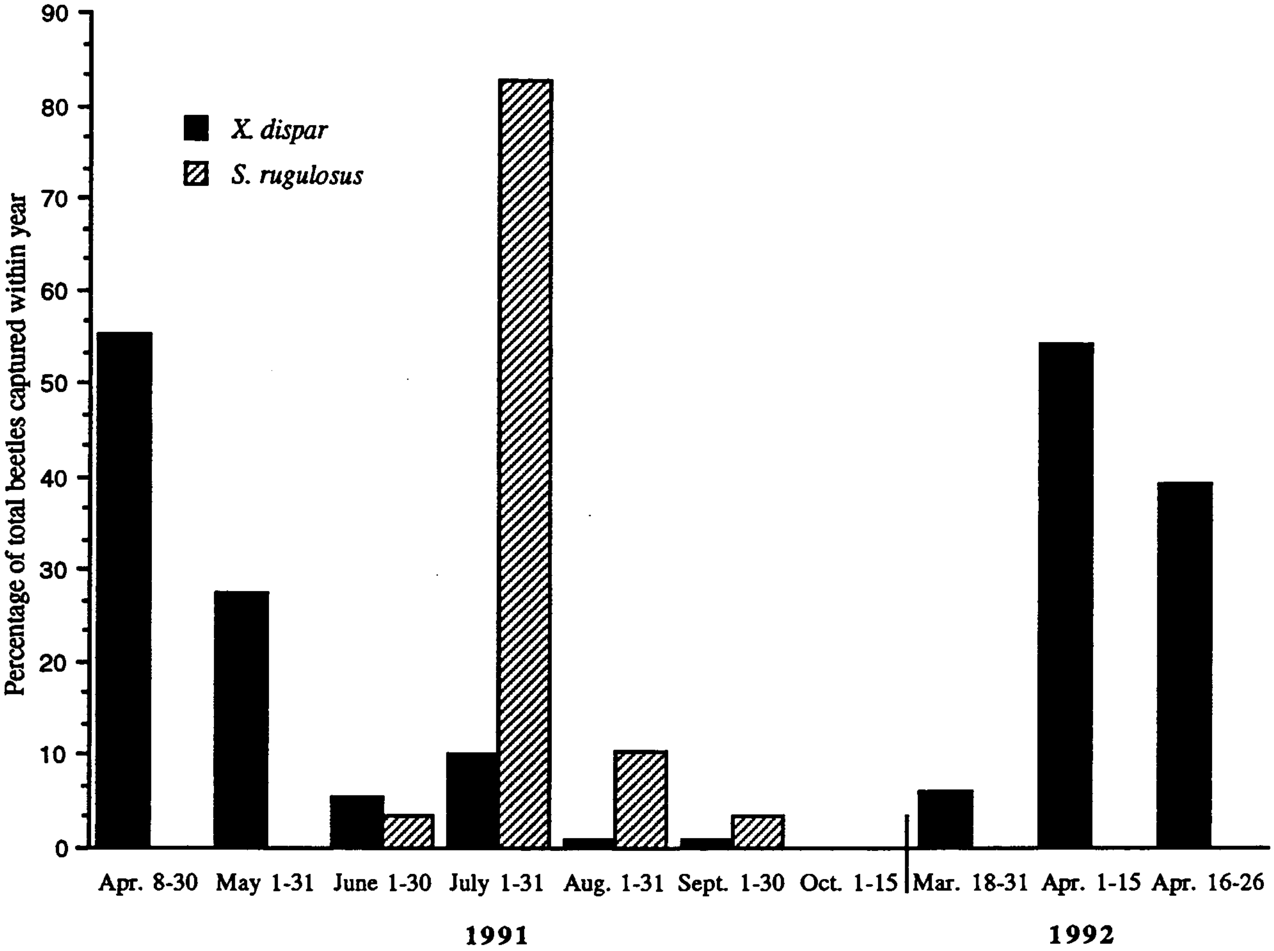
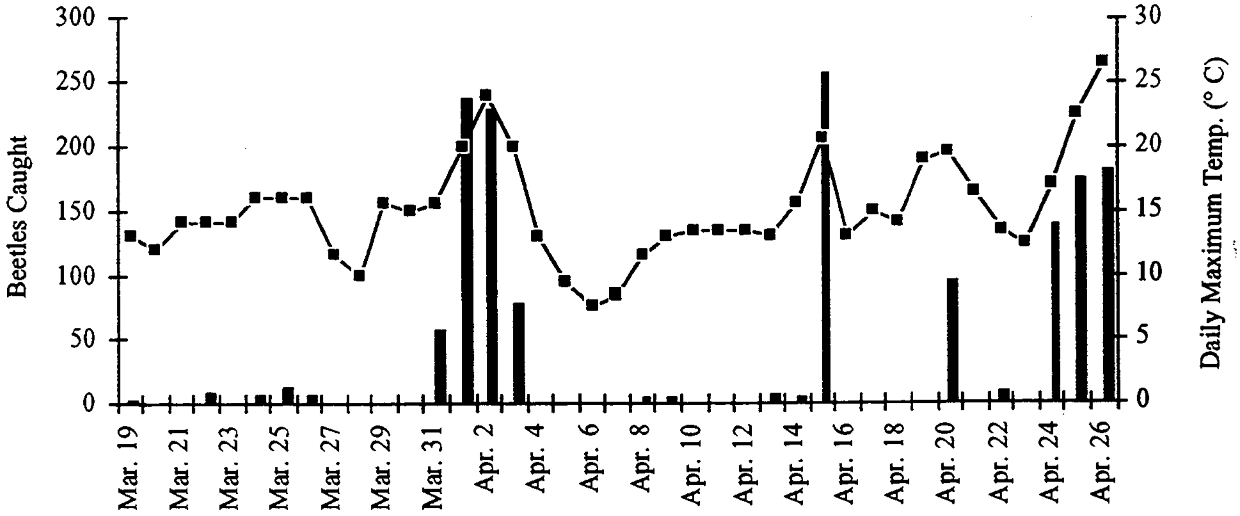

90
80
70
60
50
40
30
20
10
0
Percentage of total beetles captured within year
■ *X. dispar*
▨ *S. rugulosus*
Apr. 8-30
May 1-31
June 1-30
July 1-31
Aug. 1-31
Sept. 1-30
Oct. 1-15
Mar. 18-31
Apr. 1-15
Apr. 16-26
1991
1992

Fig 3. Comparison of catches of *X. dispar* in ethanol-baited traps (solid bars) and daily maximum temperatures in Creston, B.C. in 1992.


Beetles Caught
300
250
200
150
100
50
0
Daily Maximum Temp. (° C)
30
25
20
15
10
5
0
Mar. 19
Mar. 21
Mar. 23
Mar. 25
Mar. 27
Mar. 29
Mar. 31
Apr. 2
Apr. 4
Apr. 6
Apr. 8
Apr. 10
Apr. 12
Apr. 14
Apr. 16
Apr. 18
Apr. 20
Apr. 22
Apr. 24
Apr. 26

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