PHENOLOGY OF THE IMPORTANT COLEOPTEROUS PESTS OF PINE FORESTS IN THE WESTERN CAPE, SOUTH AFRICA

THESIS

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6. TRIBE, G.D. 1991. Phenology of Oosomus varius (Curculionidae) and Prasoidea sericea (Chrysomelidae) on Pinus radiata in the south-western Cape Province. South African Forestry Journal 157: 47-51.

ABSTRACT

The phenology of the three exotic pine bark beetles present in South Africa was determined in the south-western Cape Province. Results from weekly trapping of adult beetles using trap-logs over a period of five years showed that the different species had activity peaks at different times of the year. Hylastes angustatus was the most consistent with 95% of the beetles captured in September and October. The Orthotomicus erosus activity peak was more variable but always occurred in the summer months (October to February) when 84% of the beetles were captured. Hylurgus ligniperda was the most variable, being found in every month of the year, although an autumn peak representing 37% of the beetles occurred in April/May. Activity peaks of each species coincided with distinct climatic conditions.

Buried and partially-buried pine logs placed vertically in the soil to simulate roots and stems of seedlings were used to determine the colonisation sites of the three bark beetle species. Ninety-eight percent of O. erosus beetles were found in the protruding parts of the logs while 86% of H. ligniperda beetles were found mainly below soil level. H. angustatus were intermediate, entering the logs at or just below the soil interface but colonising mainly the buried parts in which 64% of the beetles were found. Both H. angustatus and H. ligniperda were able to detect and colonise logs buried horizontally

at depths of 400mm, but O. erosus beetles were unable to do so. For adequate protection of seedlings from bark beetles, insecticide should be applied to both stems and roots.

The phenology of the indigenous pine needle feeders Oosomus varius (Curculionidae) and Prasoidea sericea (Chrysomelidae) was determined by counting, at weekly intervals, the number of beetles present on 10 young pine trees. The O. varius activity peak occurred in August where 42% of all beetles were active, with 87% of the beetles present in July, August and September. P. sericea also had their activity peak in August when 60% of all beetles were active, but with August and September alone accounting for 87% of the beetles. The occurrence of the activity peaks was consistent each year over the five-year study period. This information facilitates the correct timing of prophylactic insecticide sprays.

CONTENTS

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PHENOLOGY OF THE IMPORTANT COLEOPTEROUS PESTS OF PINE FORESTS IN THE WESTERN CAPE, SOUTH AFRICA.

INTRODUCTION

South Africa is a country poorly endowed with natural forests which are confined to a narrow strip along the wetter south-eastern coast extending into the Eastern Transvaal. Indigenous forests such as those in the Southern Cape are moreover situated on shallow soils and are thus very sensitive to external influences (Dept. of Forestry 1978). Exploitation of these indigenous forests began in the Cape Peninsula after the arrival of Jan van Riebeeck's party in 1652, which needed timber to build dwellings, including a fort, and for firewood (Dept. of Forestry 1980). The following brief history of forestry in South Africa was derived from the Department of Forestry's (1980) booklet entitled "Forestry in South Africa":

As the local forests became exhausted, the quest for timber extended gradually eastwards from Cape Town to the small scattered forests between Swellendam and Heidelberg. When these sources were exhausted the search for timber spread to the George-Knysna region where a woodcutters post was established in 1776. In 1812 the British naval authorities took over the forests between Knysna and Plettenberg Bay to meet timber requirements of the Simonstown dockyard. The Great Trek in 1836 caused an increased demand for wagon wood and structural timber. By 1847 the destruction of the forests had reached such a stage that all Crown Forests in the southern Cape were closed and a Conservator of Forests appointed to protect them. These forests were re-opened in 1856. Further fresh demands were made for sleepers and poles for the railway and telegraph line to Kimberley in the 1870's.

Although the indigenous forest played a vital role in the development of the settlement, the early Cape governors realised the necessity for the importation of fast-growing exotic tree species. The common oak (Quercus robur Linnaeus) was among the first introductions followed by cluster pine (Pinus pinaster Aiton) and stone pine (Pinus pinea Linnaeus). In 1876 the first commercial plantation consisting of fast-growing eucalypts was established at Worcester to provide firewood for railway locomotives but it was sold to De Beers between 1892 - 1894 at a large profit which gave the first indication of the potential value of commercial afforestation.

The planting of exotic conifers was extended from 1916 by providing white-labour forestry settlements in the Cape, Natal and Transvaal during the great depression. Up to the outbreak of the Second World War there was little interest in forestry in the private sector. It was only during the war when imports of timber were interrupted and prices escalated that privately owned sawmills mushroomed throughout the country. After the war there was an unprecedented boom in afforestation by the State and the private sector followed suit. In addition to conifers, extensive planting of hardwoods took place in sub-tropical areas for production of mining timber and later for sawtimber and pulpwood.

Even with the upsurge in forestry, by 1989 only 1,1 % of South Africa's total area had been afforested, mostly under man-made plantations. The forest and timber industry is one of the largest and fastest growing sectors of the South African economy with a total investment of R5995 million (Dept. of Forestry 1990). The forests represent a renewable resource which for convenience is divided into softwoods, mainly Pinus spp. (658 684 ha), Eucalyptus spp. (501 918 ha), wattle (122 055 ha), and others (7440 ha). The State owns 27,4 % (328 091 ha) of the plantations while the private sector owns 72,6 % (869 759 ha). In 1989 sawn timber in South Africa represented 1 801 000 m^3 in volume sold (R588,9 million); pulp represented 1 765 000 tons (R3054,6 million) and mining timber 1 618 000 tons (R290,6 million)(Dept. of Forestry 1990).

Further afforestation is continuing with an increase of 30 057 ha planted in 1989, of which 19 399 ha (or 65 %) was planted to eucalypts (Dept. of Forestry 1990). Because land suitable for afforestation in South Africa is rather limited, silvicultural research has been concentrated on increasing the productivity of existing plantations by matching species to site and producing superior clones and other similar improvements (Poynton 1979a).

Insect and fungal pests represent a minor component in the many other considerations involved in the production of timber. Yet due to the large input costs involved in forestry from the preparation of the ground for planting through to the clearfelling and removal of trees, insects and pathogens can have an important impact on the final profit margin. Forestry is different to other agricultural crops in that the trees may remain in the soil for up to 35 years before being harvested and any additional costs such as aerial insecticide sprays become accumulative. Many plantations have been planted where trees never grew originally, some areas being grassveld previously. Such areas are historically free of both indigenous forest insects and their natural enemies, including an array of general predators usually associated with a forest biome. This has relevance in the event of the appearance of exotic pests, especially aphids, in these plantations where there is no natural reservoir of predators readily available to feed on them. For instance, the pine woolly aphid, Pineus pini (L.), has a negligible pest status in Western Australia where outbreaks of this aphid are quickly brought under control by numerous predators. These Pinus radiata D. Don plantations are surrounded by natural indigenous eucalypt forests which retain a large reservoir of natural enemies. The contiguous nature of South African plantations, which are sometimes monospecific monocultures, predisposes them to severe damage in the event of an exotic pest becoming established.

The recommendations of forest entomologists have always had to be evaluated with regard to the needs of the silviculturalists because the costs of establishment are so great. For example, the planting of P. pinaster in the western and southern Cape could eliminate the pine emperor moth, Imbrasia cytherea (Fabricius), as a pest in this region because their tough needles are unpalatable. However, the superior wood properties of P. radiata determines that this highly susceptible species is planted wherever suitable despite the threat from the pine emperor moth whose cyclical peaks of damage are then neutralised by aerial insecticide sprays where necessary. Similarly, the immediate replanting of a clearfelled pine plantation predisposes the seedlings to attack by the pine bark beetle, Hylastes angustatus (Herbst), which emanate from the surrounding stumps and commence maturation feeding on the green bark of the seedlings (Du Toit 1975). The damage caused by H. angustatus could be much reduced if replanting was delayed for about a year. However, economic factors cannot allow this land to remain fallow for any length of time and hence replanting commences immediately after clearfelling despite the threat of H. angustatus beetles.

As the planting of vulnerable or resistant tree species, varieties and clones will affect different insect pests in various ways which could lead either to an upsurge or drop in pest status, so too could various silvicultural practices have a similar effect. This could be an insidious effect due to the natural accumulation of debris and the resultant humus as plantations enter their second or more rotations, or by the artificial fertilisation of trees. The application of fertilisers to commercial forest species in southern Africa is gaining ground (eg. Donald et al. 1987; Herbert & Schönau 1989, 1990). Increased resistance due to increased host vigour is valid for certain insect pests but not for others (Van Rensburg 1984). Certain forest pests are known to favour vigorously growing trees while others are secondary pests only attacking dead or stressed trees. The secondary behaviour of bark beetles, which are able to use aggregation pheromones to overcome both trees with a slight physiological disequilibrium or to colonise dead trees, is well known (eg. Wood 1982). However, in the western Cape it is the healthy P. radiata leaders which are most susceptible to the deodar weevil Pissodes nemorensis Germar (Cillié, pers. comm.). Van Rensburg (1988) has shown that the black pine aphid Cinara cronartii Tissot & Pepper colonises the more vigorously growing trees while the pine woolly aphid (P. pini) is found on slower growing trees. Similarly the pine needle aphid, Eulachnus rileyi (Williams) is found mostly on the senescent needles (Odendaal 1980). This behaviour appears to be associated with the availability of free nitrogen. Senescence brings about a breakdown of protein to soluble amino acids in the senescing tissues and the translocation of this soluble nitrogen via the phloem to sites of storage or new growth (White 1984). Hence "flush feeding" herbivores are adapted to feed on this nutritious sap as it flows into new growth, while "senescence feeders" tap it at its source as it flows away from senescing tissue (White 1984). In addition host defences also play a role in regulating insect attacks and they too are affected by the physiological condition of the tree. Van Rensburg

(1984) gives further examples of the effect of host vigour on both insect populations and the defence ability of the tree.

Trees may fluctuate in their resistance to insects during their life span and these fluctuations may be as a result of changing environmental influences which may predispose trees to attack. Changes in the physical environment may affect the relative resistance or attractiveness of a tree species to some pests, but these changes will not necessarily affect all pest species in the same way (Van Rensburg 1988a).

Although several hundred indigenous insect species have been recorded feeding on forest trees in South Africa, only a small percentage of these have become pests (Geertsema 1982). Many of the native insect species which are today major pests in South African plantations (Table 1.) were relatively rare before the introduction of exotic eucalypt and pine trees. Except for the termites which destroy eucalypt seedlings, all the major indigenous pests are defoliators of pine trees. All had previously been recorded from a wide range of indigenous hosts and were by nature polyphagous (eg. Grobler 1957; Van den Berg 1971; Geertsema 1975). Several inconspicuous indigenous insect species have from time to time suddenly defoliated pine plantations and then just as abruptly returned to obscurity. The best example is that of the pine owl Tolna limula (Moschler), a noctuid which defoliated 80 ha of P. radiata near Humansdorp in 1977 (Geertsema 1979). Prior to this they were known only from seven

Table 1. The major insect pests of Eucalyptus and Pinus plantations in South Africa.

HOST	PEST SOURCE	PEST SPECIES	FAMILY	DAMAGE	ORIGIN	ARRIVAL DATE
PINES	INDIGENOUS	FUNGUS-GROWING TERMITES	Termitidae	Cellulose feeders	South Africa	-
		IMBRASIA (NUDAURELIA) CYTHEREA (Fabri.)	Saturniidae	Defoliator	Cape/Natal	-
		EUPROCTIS TERMINALIS Walker	Lymantriidae	Defoliator	Tvl/Natal	-
		PACHYPASA CAPENSIS Linnaeus	Lasiocampidae	Defoliator	Cape/Natal/Tvl	-
		PRASOIDEA SERICEA (Gyllenhal)	Chrysomelidae	Defoliator	Cape	-
		OOSOMUS VARIUS Boheman	Curculionidae	Defoliator	Cape	-
	EXOTIC	HYLURGUS LIGNIPERDA (Fabricius)	Scolytidae	Bark-beetle	Europe	1885
		HYLASTES ANGUSTATUS (Herbst)	Scolytidae	Bark-beetle	Europe	1930
		ORTHOTOMICUS EROSUS (Wollaston)	Scolytidae	Bark-beetle	Europe/Medit.	1968
		XYLEBORUS SAXESENI (Ratzeburg)	Scolytidae	Bark-beetle	Europe	1925
		PISSODES NEMORENSIS Germar	Curculionidae	Borer	N. America	1942
		CINARA CRONARTII Tissot & Pepper	Aphididae	Sap-sucker	N. America	1974
		PINEUS PINI (Linnaeus)	Adelgidae	Sap-sucker	Europe?	1978
		EULACHNUS RILEYI (Williams)	Aphididae	Sap-sucker	Europe	1980
EUCALYPTS	EXOTIC	PHORACANTHA SEMIPUNCTATA Fabricius	Cerambycidae	Borer	Australia	1906
		PHORACANTHA RECURVA Newman	Cerambycidae	Borer	Australia	1906
		GONIPTERUS SCUTELLATUS Gyllenhal	Curculionidae	Defoliator	Australia	1916
		TRACHYMELA TINCTICOLLIS Blackburn	Chrysomelidae	Defoliator	Australia	1982
		DROSOPHILA FLAVOHIRTA Malloch	Drosophilidae	Nectariferous	Australia	1976

specimens housed in museums. Other lepidopteran examples include the lasciocampid Nadiasa concolor Walker, Psycharium pellucens, Orgyia dregei, and Cleora herbuloti (Fletcher) (Hepburn & Loedolff 1964) which are all defoliators of Pinus spp. Erratic population increases of stick insects (Phasmatidae) and the glasshouse thrips, Heliothrips haemorrhoidalis (Bouche) are also responsible for damage to pine plantations. The unexpected upsurges in the numbers of indigenous pests have been ascribed to a temporary failure of natural enemies to constrain their hosts (Geertsema 1979).

Despite having comprehensive natural enemy complexes, there are several indigenous pests of pine trees which cause damage during cyclical upsurges in numbers. This results from an inability of their natural enemies to effectively regulate their numbers when conditions are made highly favourable to their host. One such cause is the availability of contiguous even-aged stands of trees. The biology and ecology of several of these pests, such as the pine emperor moth (Imbrasia cytherea) (Geertsema 1975), the pine brown tail moth (Euproctis terminalis Walker) (Grobler 1957) and the wattle lappet moth (Pachypasa capensis Linnaeus) (Du Toit 1975), have been fully described. In addition, a method of predicting the defoliation threat of I. cytherea to pine trees by counting the dead moths on the forest floor has been formulated (Geertsema 1980) which allows pre-emptive insecticide sprays on young larvae before any damage is incurred. Review articles on forest entomology in South Africa have been published by Webb (1974), Van den Berg (1979) and Geertsema (1979, 1982).

Because South African plantations consist of exotic tree species, a far greater danger lies in the arrival of pests from the trees' countries of origin. Tooke (1935) warned of the danger of planting large areas with a single species of tree and the possible arrival of an insect pest of primary importance whose effect he predicted would be "calamitous" to the industry. In the last 97 years since pines and eucalypts were planted in South Africa, there have been 13 major pest species which have arrived from overseas. The records show that on average an exotic forest pest arrives in South Africa every nine years with an interval of between 2 and 26 years (Table 2). Over the last 10 years the average time between arrivals of new forest pests has risen sharply. This is probably due to the greater mobility of people and goods today which will continue to increase the chances of further inadvertent introductions. Due to a greater phytosanitary awareness there is less likelihood of insects being introduced on legitimately imported plant material. A greater danger lies in the arrival of pests in containers, camping equipment and other cargo, or with illegal imports of plant material. South Africa in particular may have more to fear from pests initially introduced into countries to her north and it is for mutual protection from alien pests and diseases that the countries of sub-saharan Africa have a phytosanitary arrangement. The two aphid species, Pineus pini and Eulachnus rileyi, for example, first appeared in countries to the north.

Table 2. Exotic pests of Eucalyptus and Pinus and their date of arrival in South Africa.

PEST SPECIES	ARRIVAL DATE	INTERVAL (Years)
Hylurgus ligniperda	1885	
Phoracantha semipunctata	1906	21
Phoracantha recurva	1906	
Gonipterus scutellatus	1916	10
Xyleborus saxeseni	1925	9
Hylastes angustatus	1930	5
Pissodes nemorensis	1942	12
Orthotomicus erosus	1968	26
Cinara cronartii	1974	6
Drosophila flavohirta	1976	2
Pineus pini	1978	2
Eulachnus rileyi	1980	2
Trachymela tincticollis	1982	2
13 Species	97 years	m = 8.8yrs

The first forest insect pest to arrive in South Africa was the red-haired pine bark beetle *Hylurgus ligniperda* (Fabricius) in 1885. This secondary bark beetle which colonises ailing or dead *Pinus* spp. in Europe had little impact on the forest industry. This was followed by the arrival of the two Australian longicorn beetles *Phoracantha semipunctata* and *P. recurva* in 1906. It was only with the arrival of the eucalyptus snout beetle *Gonipterus scutellatus* Gyllenhal in 1916 and the subsequent massive defoliation of trees throughout South Africa that the industry was forced to make drastic changes. The eucalypt species grown commercially at the time of arrival of the snout beetle were also the most susceptible (Richardson & Meakins 1986). They were replaced countrywide by the more resistant *Eucalyptus grandis* Hill ex Maiden which accounts for 80 % of all commercially grown eucalypts today (Poynton 1979b).

As yet no pests of pine or eucalypt seeds have appeared in South Africa which is a considerable advantage not enjoyed by many countries. Protecting seed banks can be very costly, especially in the trees' country of origin. The arrival of the Australian eucalyptus nectar fly *Drosophila flavohirta* Malloch in 1976 was thus initially of concern to the forestry industry in its possible disruption of pollination which is effected mainly by honeybees, and the possible consequences to seed formation. Eucalyptus trees today supply 80 % of South Africa's honey production (Johannsmeier 1976) and the nectar fly remains a major concern for beekeepers. The eucalyptus nectar-flow also forms the basis for the maintenance of honeybee colonies for the pollination of a wide variety of commercial crops from sunflowers to apples with a value of about R800 million per year (Anonymous 1991).

The distribution of both exotic and indigenous forest pests is not always uniform throughout the forest regions of South Africa and neither is the severity of the damage always consistent throughout the region. For instance, the diamond-back snout beetle Oosomus varius Boheman which is an indigenous beetle which feeds on the needles of young pine trees is restricted to the south-western Cape Province. Similarly, the indigenous chrysomelid known as the fruit nibbler because of the damage it inflicts on pome fruit, Prasoidea serica (Gyllenhal), is found only in the western and southern Cape where it feeds on Pinus radiata needles and is able to cause mortality. The indigenous pine brown tail moth Euproctis terminalis occurs in the eastern Transvaal and Natal but even within this distribution range only certain plantations (such as in the Jessievale area from Carolina to Nelshoogte near Barbarton) are regularly and severely defoliated by the larvae of this moth. Termites again are mainly a pest of young eucalypt plantations in Zululand and Natal (eg. Atkinson 1989; Atkinson & Govender 1991). The exotic ambrosia bark beetle Xyleborus saxeseni (Ratzeburg) is restricted largely to fire damaged pine trees in hot and humid localities in Natal. It has not been able to become established in the winter rainfall areas of the western and southern Cape (Tribe 1985). In New Zealand X. saxeseni attacks both logs and freshly sawn timber (Milligan 1969; Hosking 1972).

No indigenous parasites or predators have adapted to any of the exotic forest pests in South Africa although some general predation does take place. This predation occurs only when the pest species is encountered (usually during their seasonal peak in numbers) and the predator does not actively search for a certain pest species. The eucalyptus tortoise beetle Trachymela tincticollis Blackburn is prey for at least five species of indigenous spiders and its larvae were fed on by the pentatomid Macrorhalphis leprosa Germar in February 1985 at Kommetjie. T. tincticollis elytra have also been found in bird droppings on occasions. Another predator, believed to be the small grey mongoose Galerella pulverulenta (Wagner), removes the bark from dead eucalyptus logs and feeds on the Phoracantha larvae beneath. This, however, occurs only within the Phoracantha experimental site in Tokai State Forest and has not been observed elsewhere. None of these predators have any effect on the regulation of the pest populations in general except the coccinellid species which feed on P. pini infestations, in particular Exochomus spp. (Van Rensburg, pers. comm.)

From the beginning there has always been a strong biological control approach to forestry entomology in South Africa although insecticides have played an important role and continue to do so where necessary (eg. Van den Berg 1979). The first biological control attempt was the highly successful introduction of the egg parasitoid Anaphes nitens (Girault) by Tooke (1955) in 1926 to control the eucalyptus snout beetle. The mean parasitism rate in the western Cape remains at 89% some 65 years later (Tribe 1991). Then followed various investigations into the biology and control of the major indigenous defoliators of pine trees. Euproctis terminalis was studied by Tooke (1938) and Grobler (1957), Pachypasa capensis Linnaeus by Van Dyk (1969) and Du Toit (1975b), and Imbrasia cytherea by Tooke & Hubbard (1941), Van den Berg (1971) and Geertsema (1975). The poplar emperor moth Pseudobunaea irius (F.) and the pine-bark emperor moth Holocerina smilax (Westw.) were also studied by Van den Berg (1974; 1975).

These basic biological studies largely determined the season and cyclical fluctuations of each pest species and revealed the most opportune time to spray them. Further research led to an even more accurate method of predicting the defoliation threat to pines by I. cytherea by counting dead moths on the forest floor and entering this figure in a formula (Geertsema 1980). If the predicted defoliation was above the economic threshold, aerial sprays of cypermethrin would be carried out during the early larval instars before much damage was done. Not all the earlier studies were concerned with insecticide application and several novel approaches at control were made. The training of feral pigs to root out and feed on I. cytherea pupae was successful in many plantations (Van den Berg 1969) and is still partially in operation today (Botha 1989).

Of the exotic forest pests only four species have been thoroughly studied:

G. scutellatus (Tooke 1926; 1955), Phoracantha semipunctata and P. recurva (Drinkwater 1973; 1975) and H. angustatus (Du Toit 1975a). Although successful biological control of G. scutellatus was achieved by the introduction of the egg parasitoid Anaphes nitens (Girault), there still remains a problem in the highveld areas where control is erratic (Tooke 1955; Annecke & Moran 1982). New egg parasitoids of G. scutellatus have been located in Tasmania (Huber & Prinsloo 1991) and it is proposed to introduce them to the colder highveld areas in South Africa (Tribe 1991). The attempt at biological control of Phoracantha spp. by the larval parasite Syngaster lepidus Brullé was not successful as the wasp failed to become established (Drinkwater 1975). Phoracantha spp. remain erratic pests which are able to colonise and kill drought-stressed eucalypts. A method of trapping Phoracantha spp. egg batches has been devised which has promise in the location of possible egg parasites in Australia for introduction to South Africa (Cillié & Tribe 1991). The pine bark beetle, H. angustatus, remains a major pest of pine seedlings since its arrival in South Africa in 1930. Under plantation conditions, H. angustatus is not regarded as a suitable candidate for biological control and so the emphasis still remains today on the prophylactic chemical protection of seedlings (Forestry Commission 1946; Du Toit 1975). Because no insecticides are registered against H. angustatus, control measures implemented by forest managers when the beetle is discovered ranges from Lindane sprays to dusting seedlings with Bexadust. Current research by Kirsten & Goss (1991) involves the relating of clearfelling dates with H.

angustatus activity peaks and the prediction of high risk periods to seedlings.

Two recent attempts at the biological control of exotic forest pests were highly successful. The introduction of the parasitoid Pauesia cinaravora Marsh against the black pine aphid Cinara cronartii in 1983 (Kfir et al. 1985) virtually eliminated the aphid as a pest of pine plantations (Van Rensburg 1988b, 1989). The aphid had been linked to the formation of reaction wood in Pinus taeda (Raubenheimer & Shaw 1987). From the once plentiful aphids which posed a serious threat to pine plantations (Van Rensburg 1978; 1981) it is rare to locate colonies today and these are invariably parasitised. Similar success was achieved with the introduction of the egg parasitoid Enoggera reticulata Naumann for the control of the eucalyptus tortoise beetle, Trachymela tincticollis Blackburn, in 1986 (Tribe 1988; Tribe & Cillié 1989). T. tincticollis originates from Western Australia and is a defoliator of eucalypt species, including E. grandis. After its discovery in Cape Town in 1982 it had spread as far as Lambert's Bay and East London before biological control measures were introduced. Through weekly trapping of T. tincticollis larvae (Tribe & Cillié 1985) it was possible to show a phenomenal decrease in population due to the 93 % parasitism rate achieved by E. reticulata. The dispersal of E. reticulata throughout all regions where T. tincticollis occurred was very rapid, being achieved within a year after release in Cape Town (Urban et al. 1987).

Several studies on the biology of recently arrived forest pests have been made. The pine woolly aphid, Pineus pini (L.) is a northern hemisphere adelgid which arrived in Zimbabwe via Australia (Barnes et al. 1976). It was found almost simultaneously in Kenya (Odera 1974; Mailu et al. 1980) and by 1978 had reached South Africa (Bruzas 1983). Infestation causes trees to become suppressed resulting in reduced tree diameter and both the shedding of needles and stunting of those remaining (Tanton & Alder 1977; Zwolinski 1989, 1990). Both cone development and seed production are adversely affected by the aphid (Zwolinski et al. 1989) although there appears to be some resistance within and between pine species (Donald 1989). Several indigenous coccinellid predators now occur in P. pini infested plantations and have considerably reduced the severity of the aphid attacks (eg. Barnes et al. 1976; Bruzas 1983; Zwolinski 1989). Besides the immediate damage to the tree through sap removal and needle drop, the tree undergoes physiological changes which results in a stem covered in rough bark, with only the present year's needles retained and they are short and clumped (unpublished data). These symptoms persist and the trees remain stunted even after the aphids have been eliminated. Thus P. pini remains an important pest in South Africa despite the predators now present. If P. pini can conclusively be shown to cause the symptoms described, then any breeding for resistance programme will have to take into account that a single aphid attack is able to cause permanent damage to the trees.

The pine needle aphid Eulachnus rileyi, is a European species which appeared recently in Zambia (Löyttyniemi 1979) and Zimbabwe (Odendaal 1980) before moving to South Africa. This aphid is reputed to cause yellowish mottling of needles and eventual needle cast but mostly senescent needles are preferred and only in the heaviest infestations are the current years needles attacked (Odendaal 1980). An investigation in Natal concluded that no control measures were warranted because the aphid fed mainly on senescent needles which were about to be shed anyway (Marchant 1989). The presence of E. rileyi may possibly help augment the numbers of predators available in the plantations and so maintain a reservoir of natural enemies against the more virulent pine woolly aphid.

Over the past decades forest entomology in South Africa has had some exemplary successes in the control of various insect pests although several problems have yet to be resolved satisfactorily. Many of these past successes are now taken for granted by the forest industry and the accelerated arrival of exotic pests in the last few years indicates that forest protection is likely to be an ongoing process. This thesis should therefore be viewed as a section of the continuation of applied basic research presently being conducted in response to the needs of the industry.

EXOTIC BARK BEETLE PESTS OF PINUS:-

1. PHENOLOGY OF PINUS RADIATA LOG COLONISATION BY THE PINE BARK BEETLE HYLASTES ANGUSTATUS (HERBST) (COLEOPTERA: SCOLYTIDAE) IN THE SOUTH-WESTERN CAPE PROVINCE.

ABSTRACT

Phenology of Pinus radiata log colonisation by Hylastes angustatus was recorded at Grabouw by means of weekly trap logs. Over the five year study period, 95% of all beetles were captured in September and October. The timing of this activity peak was constant each year although beetle numbers varied between sites and years. Activity peaks coincided with distinct climatic conditions namely a mean temperature threshold of about 11,4°C occurring simultaneously with rainfall before flight activity. In the winter rainfall region, H. angustatus is inactive in summer mainly because of the lack of rain. The proportional width of the peak helps explain why H. angustatus is regarded as a major forestry pest in summer rainfall areas but not in the winter rainfall area. A distinction is also made between

the spring flight peak and those caused by the subsequent emergences of beetles from logs and stumps in thinned or clearfelled areas. This study facilitates correct timing of insecticide treatments to protect pine seedlings from attack.

INTRODUCTION

The pine bark beetle, *Hylastes angustatus* (Herbst), of European and southern Russian origin, feeds on the cambium and inner bark of conifers, mainly *Pinus* species (Schedl 1959; Schwenke 1974). It was first recorded in South Africa in 1930 in the southern Cape Province (Schedl 1959). Today it occurs wherever *Pinus* species are grown commercially (Du Toit 1975). A general account of *H. angustatus* in South Africa was given by Tribe (1984).

H. angustatus is commonly found in the roots and stumps of dead or dying conifers. It transmits root-pathogenic *Leptographium* fungi (Wingfield & Swart 1989). However, the major damage is caused when the beetles feed on the young green bark of roots and root-collars of seedlings before dispersing and constructing nests in stumps or logs (Forestry Commission 1946). It is during this maturation feeding phase that deaths of seedlings occur when their stems are girdled by under-bark feeding. Over

50% of pine seedlings in a newly planted stand may be killed by the beetles (Browne 1968; Du Toit 1975). The generally accepted loss rate is 15%, above which replacement is necessary (Bevan 1987).

Because H. angustatus feeds beneath the bark and mainly below ground, the beetles have already departed by the time the damage is first noticed (Du Toit 1975). Working in Jessievale State Forest near Chrissiesmeer (in the summer rainfall region of the eastern Transvaal highveld), Du Toit (1975) used various trapping methods to establish that their flight period lasts from mid-August to early April. He was also able to show that seedlings were most vulnerable up to one year after planting. Thereafter the trees became virtually immune from attack. There is generally only one generation per annum in Europe although there may be up to three generations of H. angustatus in the southern regions (Schwenke 1974). Du Toit (1975) calculated that there are four or possibly five generations per year at Jessievale.

Various natural enemies of Hylastes have been recorded (e.g. Zethner-Møller & Rudinsky 1967; Mills 1983) which serve to control endemic beetle numbers in natural coniferous forests (Forestry Commission 1946). These have however been considered of little use for commercial plantations. Hylastes control measures are primarily geared for the prevention of damage to seedlings (Forestry Commission 1946). Where newly established pines in commercial plantations are exposed to a high incidence of infestation, chemical protection is regarded as the only effective control measure (Bevan & Jones 1964; Du Toit 1975).

The present study attempts to predict the timing and duration of H. angustatus activity in the south-western Cape Province. A comparison of the climatic factors corresponding with these activity peaks could allow similar predictions to be made for pine growing areas in other parts of the country. The timing and number of prophylactic insecticide sprays needed for each climatic region could then be determined.

METHODS

Two permanent trapping sites were established within compartments G13a and J11 of mature Pinus radiata D. Don trees approximately five kilometres from each other in Lebanon State Forest near Grabouw (in the winter rainfall region of the south-western Cape Province). Trap logs, one metre long and 150 mm in diameter were cut from P. radiata trees. Two trap logs were always present at each locality and each log remained in the plantation for a fortnight. By initially placing first one log, and then a week later the second log on the ground, it was possible to collect at weekly intervals, one log from each site for analysis. Trap logs were placed in large plastic bags for removal to the laboratory. They were dissected and the number of beetles present was recorded and plotted against the week of log retrieval. Since freshly cut logs are not immediately attractive to secondary bark beetles, the number of H. angustatus beetles was therefore plotted against the second week of each two week log exposure period. The accumulative weekly totals of beetles over the five year trapping period were plotted using Julian weeks with an adjustment made for the leap year. Descriptions and a key to Hylastes species are given in Schwenke (1974) and Grüne (1979). The identity of H. angustatus was confirmed from samples which had been sent to the National Collection of Insects in Pretoria.

Weather data were supplied by Elgin Experimental Farm (courtesy of Winter Rainfall Region, Department of Agriculture and Water Supply), the weather station closest to Lebanon State Forest. These daily weather records were prepared as weekly means to coincide with the weekly trapping regime. The weather means and standard deviations were calculated for the periods when 80% of the beetles were active. Cape Hylastes activity weather ranges were then compared with pentads of long term averages of corresponding weather parameters at selected localities within the pine growing regions of South Africa. The number of pentads which fell within these Cape Hylastes activity weather ranges and the months in which they occurred was recorded. These served as a means of predicting potential H. angustatus injury periods in summer rainfall regions.

RESULTS

The phenology graphs showed that there was a single major peak for H. angustatus log colonizing activity which was seasonally constant each year at both trapping sites. However, beetle numbers varied between years and between sites (Fig. 1). The percentage of beetles captured during the peak months of September and October (actually Julian weeks 36-43) from the five year accumulative totals was 95% (Fig. 2). This percentage remained constant each year (Table 3).

Table 3. Number of Hylastes angustatus beetles captured in September & October and percentages of the total captured each year from 1981 to 1985 at two sites in Lebanon State Forest.

SITES 1 + 2 COMBINED

YEAR	ANNUAL TOTAL	SEPT. + OCT.	%
1981	594	555	93,43
1982	3 209	3 045	94,89
1983	1 222	1 174	96,07
1984	3 284	3 166	96,40
1985	1 962	1 864	95,01
TOTAL	10 271	9 804	95,46

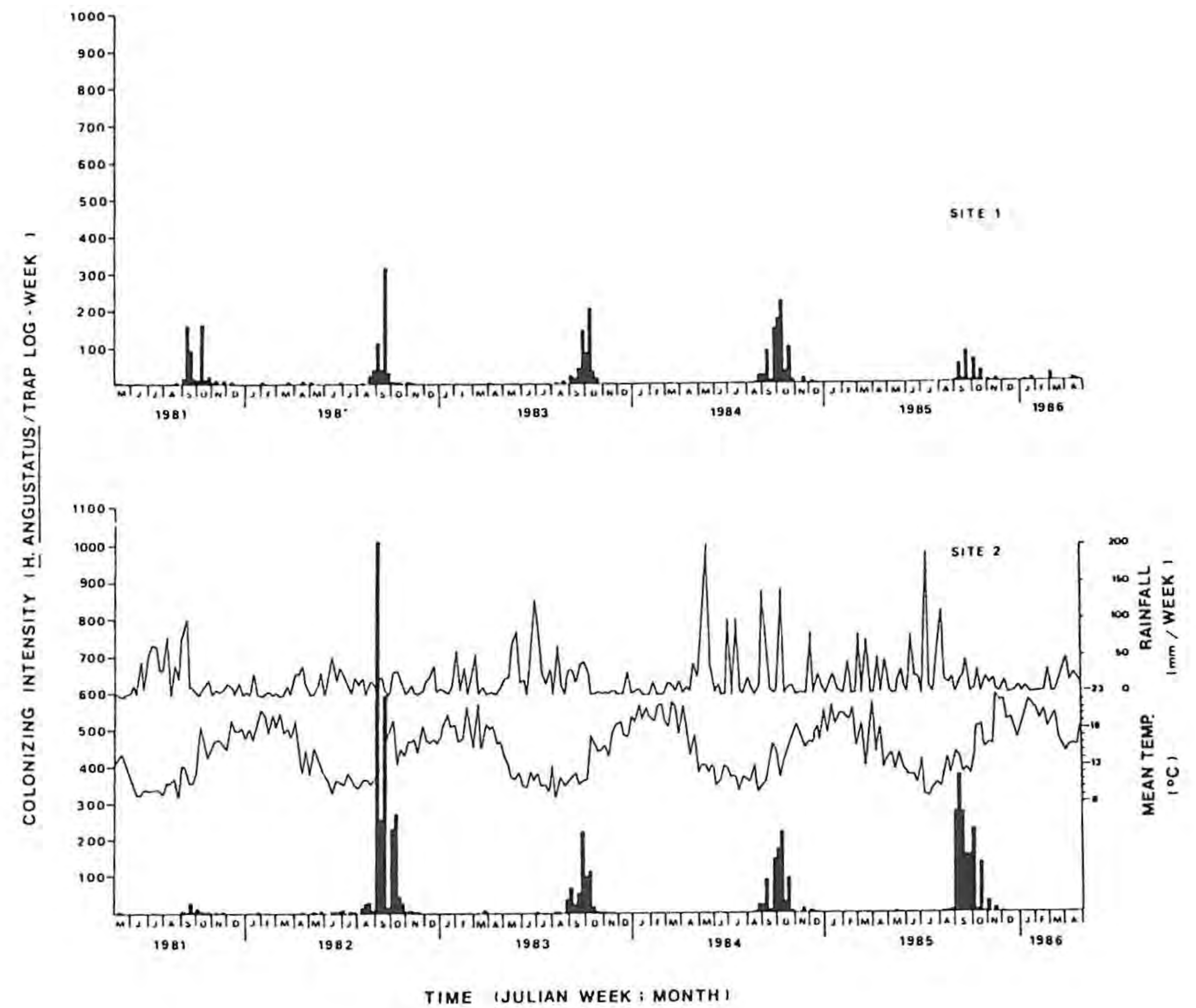

Fig. 1. The number of *Hylastes angustatus* beetles removed from weekly *Pinus radiata* trap logs at two sites (5 km apart) within Lebanon State Forest over a five year period, and the mean weekly temperature and rainfall.

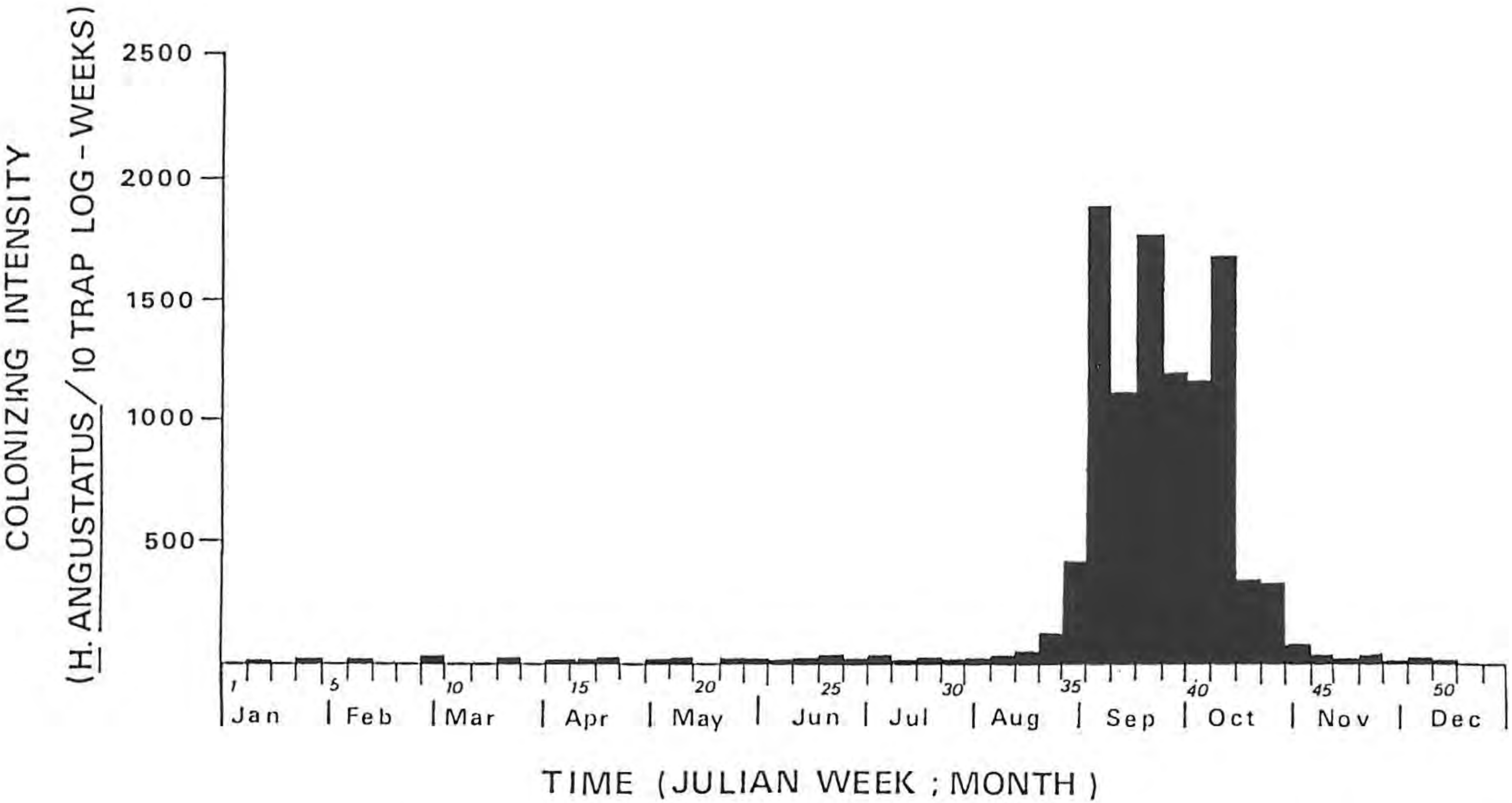

Fig. 2. The total number of Hylastes angustatus beetles captured weekly from both sites over a five year period from May 1982 to April 1986 in the winter rainfall region of the south-western Cape Province.

Table 4. Comparison of weather conditions before, during and after the main Hylastes angustatus activity periods at Lebanon State Forest from 6 May 1981 to 5 May 1986 in the winter rainfall region of the south-western Cape Province.

Period	Temperature °C			Evaporation (mm/week)	Sunlight (h/d)	Rainfall (mm/week)
	mean	min	max			
Winter (before)	17,7±1,7	6,1±1,9	17,5±3,5	1,8±0,6	5,5±1,2	30,3±36,9
Beetles active	13,6±2,2	8,1±1,6	19,0±3,1	3,3±0,9	6,2±1,6	32,3±36,4
Summer (after)	18,4±2,3	12,3±2,2	23,5±7,4	5,3±1,6	7,8±1,8	14,1±19,5

Table 5. Number of pentads of long term weather averages from weather stations near pine growing regions which fell within the minimum (8,1 ± 1,6°C) and average (13,6 ± 2,2 °C) temperatures calculated for when 80% of <u>H</u>. <u>angustatus</u> beetles were active in Lebanon State Forest.

Weather station	Number of matching pentads		Months during which the Min. Temp. pentads occur
	Min. Temp. °C (6,5 ± 9,7°C)	Ave. Temp. °C. (11,4 ± 15,8°C)	
George	28	36	May - October
Lydenburg	25	39	Apr/May + Sept/Nov
Bulwer	24	19	Apr/May + Aug/Oct
Barbarton	22	23	May - August
Howick	21	23	May/June + Jul/Sept
Kokstad	20	24	Mar/Apr + Sept/Nov
Boston (Ntl)	20	31	Apr/May + Sept/Oct
Pietermaritzburg	14	14	June - August
Ermelo	12	20	Apr/May + Sept/Oct
Greytown	12	22	Apr/May + Aug/Sept
Ohrigstad	11	23	Apr/May + Aug/Sept
Elgin	10	11	Apr/May + Sept/Oct
Constantia (CP)	10	31	July - August
Utrecht	10	13	Apr/May + Sept

The total number of beetles captured over the five year period differed greatly between sites, with site 1 recording 2803 beetles (27%) and site 2 recording 7468 beetles (73%). Although more timber was felled at Lebanon State Forest in the first two years of this study, no direct correlations between felling and beetle numbers could be found.

The optimum conditions inducive for beetle activity fell between the relatively cold winter months and the dry summer months (Table 4). The high humidity and rising temperature in spring appeared to be conducive to beetle activity whilst the low rainfall in summer appeared to depress this activity.

A comparison of the optimum climatic conditions for beetle activity prevailing at Grabouw was unable to explain fully the H. angustatus activity recorded at Jessievale by Du Toit (1975). Comparisons of long term weather averages from weather stations within the summer rainfall pine growing areas with those recorded at Grabouw showed some affinity. Of the weather parameters recorded in Table 4, only minimum and average temperatures were useful in this regard. The number of matching pentads in Table 5 does bear a resemblance to the intensity of damage experienced in the various regions, and the period in which this damage occurs.

DISCUSSION

The narrow H. angustatus activity peak recorded at Grabouw differs substantially from that recorded at Jessievale by Du Toit (1975). This difference could not be explained solely by weather conditions. Thus no accurate prediction of damage can be made for localities in other pine growing areas. Minimum temperature was the factor giving the best fit.

The difference in the number of beetles captured at the two sites is believed to be due to the endemic population levels at each site. These population levels are determined by the amount of food available to the beetles through felling operations. However, no correlation with beetle numbers could be extracted from the silvicultural records as too many imponderables were involved.

Over 80% of all beetles arrived at the trap logs when the average daily temperature fell between 11,4°C and 15,8°C (calculated from standard deviations around the mean of 13,6°C). The mean daily temperature for all beetles active at Grabouw ranged from 9,0°C to 23,0°C. This compares closely with that of the average flight period of H. angustatus at Jessievale which began at 12,2°C and ended at 16,7°C (Du Toit 1975).

Maturation feeding on the green bark of seedlings is carried out by newly emerged virgin females and dispersal flight normally occurs after, rather than before this feeding (Bevan & Jones 1964). The summer rainfall pine growing areas experience greater losses of seedlings to H. angustatus during re-establishment than do the winter rainfall areas. Du Toit (1975) calculated that the beetles are active at Jessievale (summer rain) for 277 days of each year, allowing up to five generations annually. In contrast to Lebanon State Forest (winter rain) where 95% of beetles were captured in September and October, the re-arranged data of Du Toit (1975) for these months show the corresponding percentage at Jessievale to be 34% for the obstruction traps and 35% emerging within the gauze cages. However, both localities experience the activity peak in September and October which is probably the result of both overwintering and virgin females emerging simultaneously.

The developmental period from egg to egg for H. angustatus is given by Du Toit (1969, 1975) as 48 days. Thus only one generation is likely to develop at Lebanon State Forest during the activity period which lasts only about 60 days. A second generation might develop in underground roots or stumps during summer, but the adults do not emerge until the following spring. The greater number of generations and/or sister broods in the Transvaal results in greater damage as each succeeding wave of emerging virgin females undergoes maturation feeding.

The number of generations and/or sister broods in the Transvaal is a result of the longer period over which H. angustatus is active. H. angustatus requires a high bark moisture content (Bright & Stark

1973). Such conditions persist during the summer rains in the highveld regions. However, comparison of the Cape Hylastes activity weather ranges with the times of occurrence of similar conditions at various localities within pine growing areas of the Transvaal shows little correlation with the timing of H. angustatus peaks in the two provinces. Only the spring peaks concur. The absence of summer and autumn activity at Grabouw appears to be largely due to the absence of summer rain (Table 4) after the spring flight. All peaks are determined by the availability of logs and stumps after thinning and clearfelling and the number of successive generations and/or sister broods that can emerge from such stumps. Stumps and roots, being underground, remain moist for long periods and are therefore largely independent of prevailing weather conditions. Roots and stumps present a local source of infestation from which emerging beetles attack the newly planted seedlings within clearfelled areas when temperature and soil moisture permit their emergence. In the natural forest undisturbed by logging, scolytid breeding sites are more evenly distributed than they are in plantations (Atkins 1966). The plantation system is clearly very artificial and tends to concentrate huge numbers of H. angustatus beetles in a relatively small area. In Sweden oviposition by Hylastes spp. in stumps and roots occurs until three or four growing seasons after felling, and down to 800 mm below ground (Eidman et al. 1977). This behaviour begins during and after the flight period in spring. Thus continual attacks on surrounding seedlings can be expected until the stumps are exhausted as a source of infestation.

Du Toit's (1975) data were obtained over one year only and within clearfelled areas. They would therefore represent both the initial spring flight peak followed by several subsequent peaks as successive generations and/or sister broods emerge from the stumps.

The spring activity peak which is most strongly influenced by weather conditions is crucial, since from it follows successive generations of beetles if suitable breeding material is available. The timing of the emergence of these subsequent generations, which are to be found mainly underground in stumps and roots, is determined largely by the start of the initial spring peak. They are thus less affected by climatic influences. Hence a distinction can be drawn between the spring peak (common to all regions where H. angustatus occurs) and peaks resulting from subsequent emergences (dependent on the availability of suitable substrate).

The colonisation phenology data from Grabouw and Jessievale indicate that H. angustatus emergence and flight is controlled by a combination of temperature and rainfall thresholds. Under conditions of adequate moisture, adults do not fly until the mean temperature exceeds a threshold of about 12°C. Although a mean temperature of up to 23°C did not inhibit flight, there was a marked drop in beetle numbers above a threshold of about 16°C at Grabouw (over 80% of all beetles were active below this threshold). Rainfall is necessary for beetle activity although no accurate threshold could be determined. Webb (1974) intimated that moisture was important when he stated that H. angustatus was absent from areas in South Africa which received under 508 mm of rain per year.

Unseasonal H. angustatus activity peaks do however also occur in Lebanon State Forest. Trap logs placed in a clearfelled area recorded H. angustatus peaks in January and in May 1988 (J. Winstanley unpublished). The south-western Cape Province, unlike the highveld regions, does not deal with large volumes of timber. Consequently the areas being clearfelled and replanted are much smaller. The third element needed besides temperature and rainfall for H. angustatus to become a major problem, is the availability of fresh stumps which allow the emergence of successive generations of beetles.

The pest status of H. angustatus in the summer rainfall regions is due to the presence of fresh stumps since the primary limiting factor to all bark beetles is the availability of breeding substrate (Bevan 1984). Steps could be taken to rectify this either through biological control or by insecticides applied to the stumps. However, the probable beneficial role of H. angustatus in accelerating stump decomposition (Du Toit 1975) should first be evaluated. Without such measures, prophylactic insecticide treatments of young seedlings will remain necessary.

The constant and regular H. angustatus log colonisation activity peak of 95% in September and October indicates when insecticide should be applied in the south-western Cape Province. An insecticide giving two months protection should be used in areas where re-establishment has followed the clearfelling and where there is a history of regular *H. angustatus* damage.

2. PHENOLOGY OF PINUS RADIATA LOG COLONIZATION AND REPRODUCTION BY THE EUROPEAN BARK BEETLE ORTHOTOMICUS EROSUS (WOLLASTON) (COLEOPTERA: SCOLYTIDAE) IN THE SOUTH-WESTERN CAPE PROVINCE.

ABSTRACT

The temporal distribution of Orthotomicus erosus (Woll.) beetles within a Pinus radiata plantation near Grabouw was recorded from weekly trap logs over a period of five years. O. erosus is summer active. The annual peak in which 84% of all beetles were captured, was found to vary between the months of October and February. Sex ratios varied between 1 ♂ : 1,1 ♀♀ for the trap logs, 1 ♂ : 1,2 ♀♀ for sticky traps and 1 ♂ : 2 ♀ for pheromone traps. The number of eggs and larvae produced by these beetles was monitored for two years and showed that colonisation is followed immediately by brood production.

INTRODUCTION

The European bark beetle, Orthotomicus erosus, was first discovered in South Africa in 1968 at Stellenbosch (Geertsema 1979). A general account of the species in South Africa was given by Tribe (1983). Today it is found throughout the pine growing areas of South Africa (Morrison 1988). O. erosus is native to central and southern Europe, and countries around the Mediterranean Sea where it feeds on conifers, mainly Pinus species (Chararas 1964, 1973; Chararas & M'Sadda 1973; Schwenke 1974; Mendel & Halperin 1982). Mendel (1987) regards its natural distribution as essentially Mediterranean. This accords with the name "Mediterranean pine engraver beetle" used by Klimetzek & Vité (1986). More recently (1985) O. erosus was discovered in Fiji in Pinus caribaea Morelet logging slash (G. Hosking, personal communication).

The genus Orthotomicus is of doubtful validity as it occupies an intermediate position between Pityokteines, from which it is doubtfully distinct, and Ips, with which it intergrades somewhat (Wood 1982). Since Wood (1982) was loath to group Pityokteines and Ips in the same genus with Orthotomicus, he gave all three genera equal status. Hence the genus Orthotomicus is retained here and is not relegated to subgeneric status as in Giesen et al. (1984).

In Europe, O. erosus is regarded as a secondary pest of little significance, attacking ailing, fungal infected or dead trees (Schwenke 1974). Besides attacking sick or fallen trees, in Tunisia O. erosus is reported to accelerate the death of trees suffering from only a very slight physiological disequilibrium (Chararas & M'Sadda 1973). In Israel, O. erosus is the major bark beetle species killing large numbers of pines after fires or thinning followed by winters with low rainfall (Halperin et al. 1982; Mendel & Halperin 1982). Chararas (1964) considers O. erosus a primary pest if trees stressed by adverse climatic conditions are also subjected to high beetle population levels.

In South Africa O. erosus is a secondary pest colonizing stressed trees (Tribe 1984). Significant damage has been reported from the interaction between fire, the fungus Rhizina undulata Fr. and O. erosus (Tribe et al. 1985; Baylis et al. 1986). Additional loss is caused by the beetles introducing pathogenic bluestain fungi, such as Ophiostoma ips (Rumb.) Nanf. (Wingfield & Marasas 1980; Wingfield & Knox-Davies 1980; Wingfield & Swart 1989), which depreciates the timber further. In South Africa it is not uncommon to find O. erosus in association with other pests such as Hylastes angustatus (Herbst), Hylurgus ligniperda (Fabricius) and Pissodes nemorensis Germar attacking the same tree.

In Europe, O. erosus in general has two generations per year with the first flight period in April/May and the second at the end of July (Schwenke 1974). In Tunisia there are three or rarely four generations per annum, with swarming taking place from April to December (Chararas & M'Sadda 1973). Seven annual generations occur in Israel with the first flights in March and continuing into the winter months (Mendel 1983).

Information was required to diminish attacks through optimal forest management practices. O. erosus beetles and brood have previously been found within logs throughout the year in the south-western Cape Province. The present study was undertaken to determine the flight activity peaks.

METHODS

Two permanent trapping sites were established within compartments G13a and J11 of mature Pinus radiata D. Don trees approximately five kilometres from each other in Lebanon State Forest near Grabouw (in the winter rainfall region of the south-western Cape Province). Trap logs one metre long and 150 mm in diameter were cut from P. radiata trees. Two trap logs were always present at each locality and each log remained in the plantation for a fortnight. By initially placing first one log,and then a week later the second log on the ground, it was possible to collect at weekly intervals one log from each site for analysis. Trap logs were placed in large plastic bags for removal to the laboratory. They were dissected and the number of adults, larvae and eggs, as well as the sex ratio, was recorded and plotted against the week of log retrieval. Since freshly cut logs are not immediately attractive to secondary bark beetles, the number of O. erosus was therefore plotted against the second week of each two week log exposure period. By leaving each log in the plantation for two weeks it was possible to determine the maturation state of the colonizing beetles by whether or not they laid eggs. The accumulative weekly totals of beetles, larvae and eggs over the five year trapping period were plotted using Julian weeks with an adjustment made for the leap year.

Beetles from trap logs and both sites were sexed for a two year period (from May 1981 until May 1983) by means of the presence (males) or absence (females) of large spines around the elytral declivity (Atkinson 1921; Joly 1976; Grüne 1979). This sex ratio was then compared with that obtained from Celamerck flattened cone pheromone traps baited with Linoprax at Nuweberg State Forest (near Grabouw) between January and February 1985. Further sex ratio comparisons were obtained from beetles captured on four sticky (Plantex) gauze traps each measuring 1 x 1,7 metres and hung from wire between four trees. Freshly cut pine logs were placed in the centre of the square thus formed.

The frequency of the number of females per nest was determined by dissecting infested pine logs in which young O. erosus larvae had already hatched and just begun tunneling. Nests with either males or females only were not included in the analysis.

Weather data were supplied by the Elgin Experimental Farm (courtesy of Winter Rainfall Region, Department of Agriculture and Water Supply), the weather station closest to Lebanon State Forest. These daily weather records were prepared as weekly means to coincide with the weekly trapping regime. The weather means and standard deviations were calculated for periods when the peak 80% of the beetles were active each year, beginning with the week with the highest number of captured beetles and decreasing until the required percentage was reached.

RESULTS

While _O. erosus_ was present throughout the year, it was largely a summer active species. The peak activity period varied between years and sites but always occurred between October and February (Fig. 3). During this period 84% of all beetles were captured (Fig. 4). At site 2, flight activity peaked consistently in October - November (spring, tailing off into summer) and at site 1 consistently in January - February (summer).

Marked fluctuations in beetle numbers from week to week were recorded during the peak activity period. The large differences in beetle numbers captured from year to year are shown in Table 6. Although only 5km apart, these differences also extended between sites within the same years.

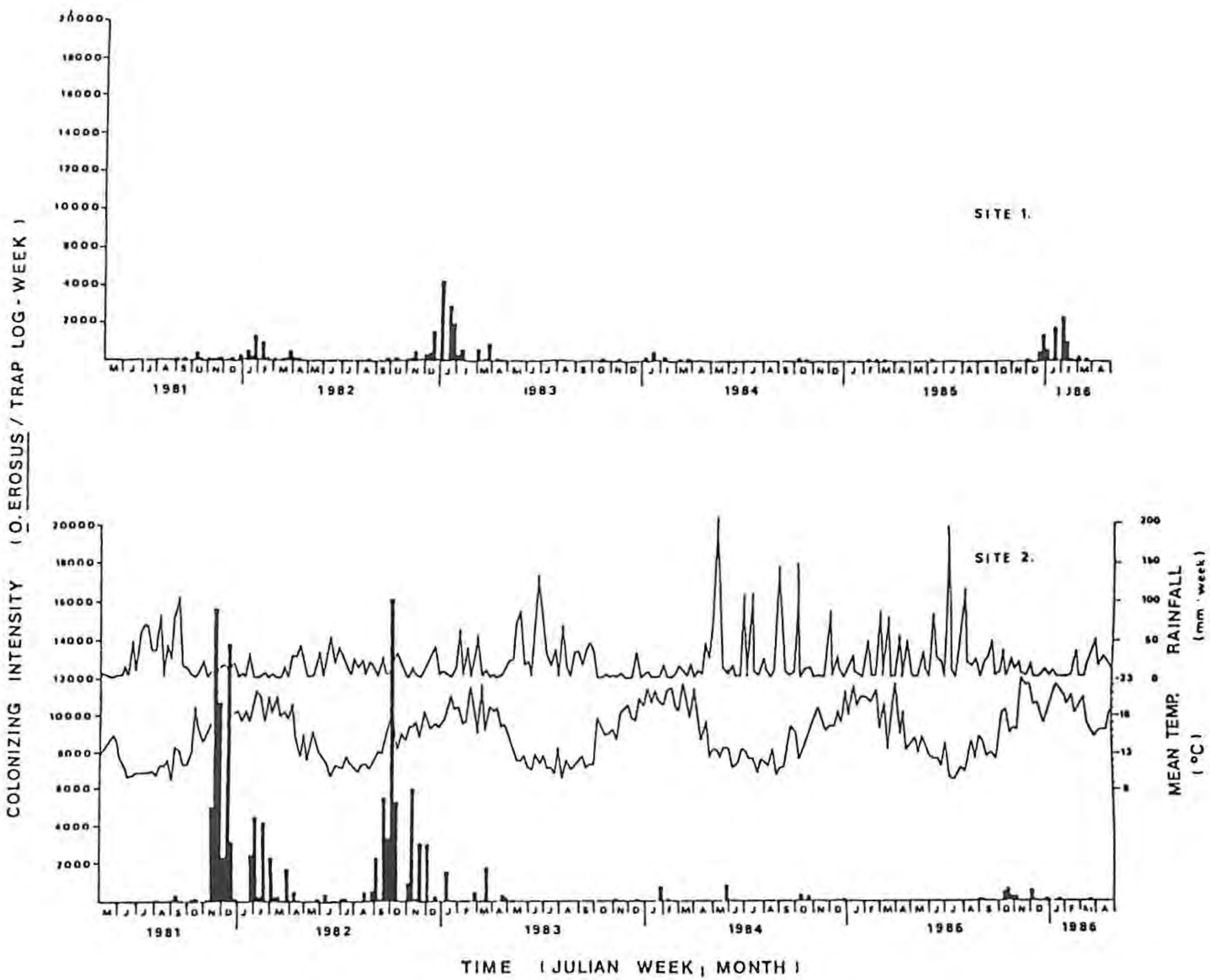

Fig. 3. Number of *Orthotomicus erosus* beetles removed from weekly trap logs at two sites (5 km apart) within Lebanon State Forest over a 5 year period and the mean weekly temperature and rainfall.

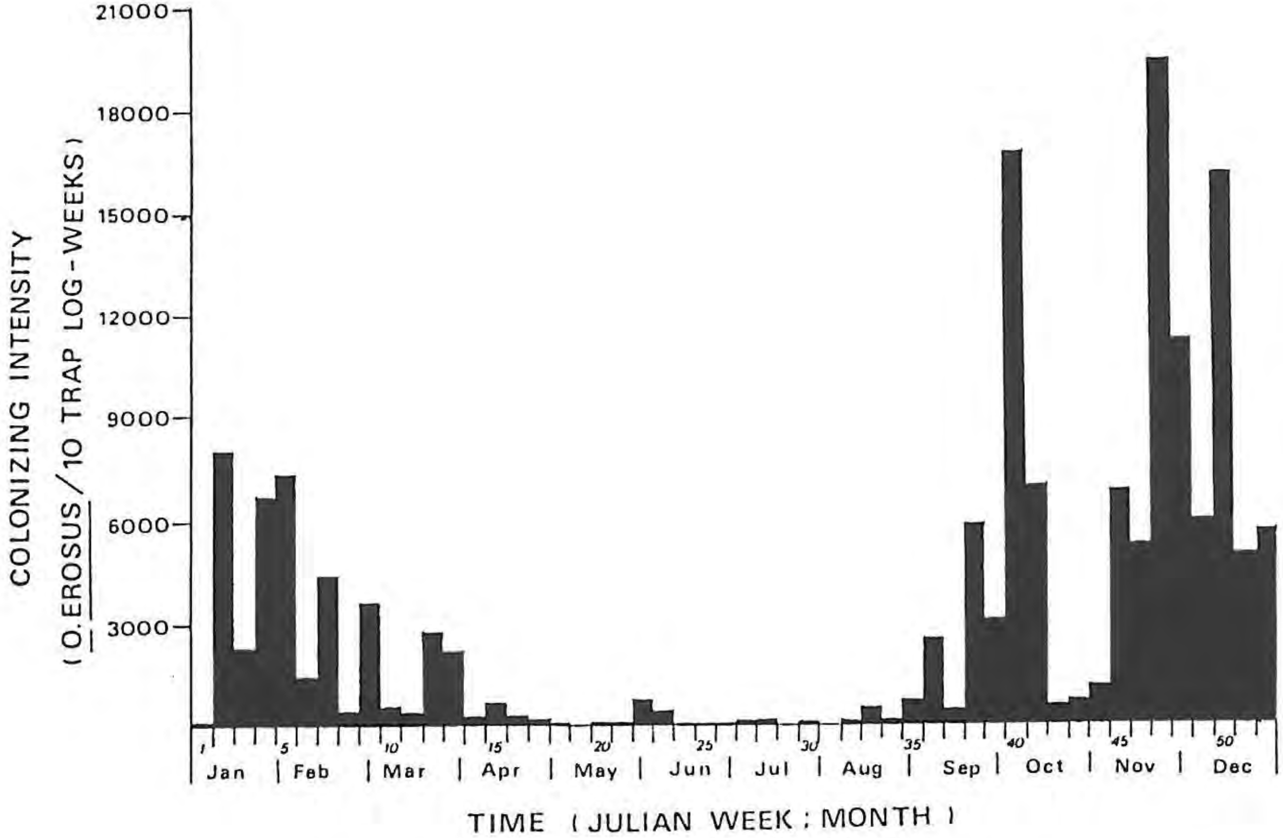

Fig. 4. The total number of *Orthotomicus erosus* beetles captured weekly over a five year period from May 1981 to April 1986 at 2 sites 5km apart in the south-western Cape Province.

Table 6. Number of *O. erosus* beetles removed from weekly *Pinus radiata* trap logs in Lebanon State Forest annually (from May to April) from two sites 5km apart.

Year	Site 1	Site 2	Sites 1 + 2
1981/82	5 843	68 908	74 751
1982/83	15 871	51 590	67 461
1983/84	1 184	968	2 152
1984/85	570	1 410	1 980
1985/86	8 597	2 655	11 252
Totals	32 065	125 531	157 596

A sex ratio of 1 male : 1,12 females was recorded over the five year period for O. erosus beetles extracted from the log traps (n = 142 213) (Table 7) and 1 male : 1,2 females from the sticky gauze traps (n = 755). The Linoprax pheromone traps gave a ratio of one male to two females (n = 18 485). The sex ratio of the beetles attracted to all three traps remained constant throughout the trapping period.

Table 7. Sex ratio of O. erosus beetles attracted to Pinus radiata trap logs in Lebanon State Forest between May 1981 and April 1983.

Site	Number beetles		Total	Sex ratio
	♂	♀		♂ : ♀
1	8 923	12 792	21 715	1 : 1,43
2	58 165	62 333	120 498	1 : 1,07
Totals	67 088	75 125	142 213	1 : 1,12

Of the nests containing both sexes, the majority (47%) of nests under the bark consisted of one male to two females (Table 8). The arrival of O. erosus beetles at a trap log was invariably followed by egg laying (Fig. 5) and the appearance of larvae (Fig. 6), confirming that this is mainly a summer active species as regards both log colonization and reproduction.

The fluctuations in the ratio of eggs or larvae to beetles from week to week depended to a large extent on the ambient temperature and whether the beetles arrived at the logs at the beginning or end of the two week exposure period.

Table 8. Frequency distribution of the number of O. erosus females per nest in Pinus radiata logs.

Sex ratio ♂ : ♀	Number of nests	% nests
1 : 1	81	37
1 : 2	105	47
1 : 3	31	14
1 : 4	4	2
	221	100

Only on one occasion (6-10-82) at site 2 were the beetles in such large numbers (16068) that no brood could be reared since the entire inner bark had been consumed. Although the pattern resembled that of aggregation galleries for overwintering beetles as described by Mendel (1983), this was due here entirely to the number of beetles present. This was

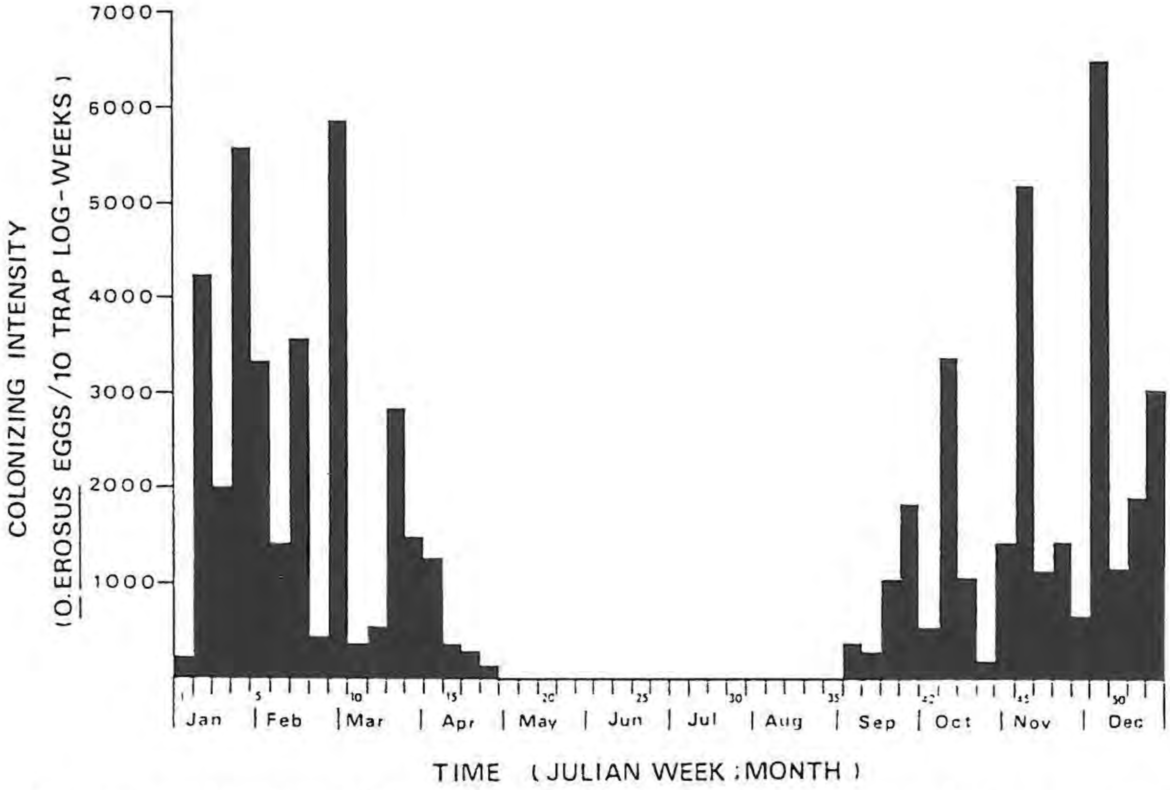

Fig. 5. The total number of *Orthotomicus erosus* eggs removed weekly from trap logs over a two year period from May 1981 to May 1983.

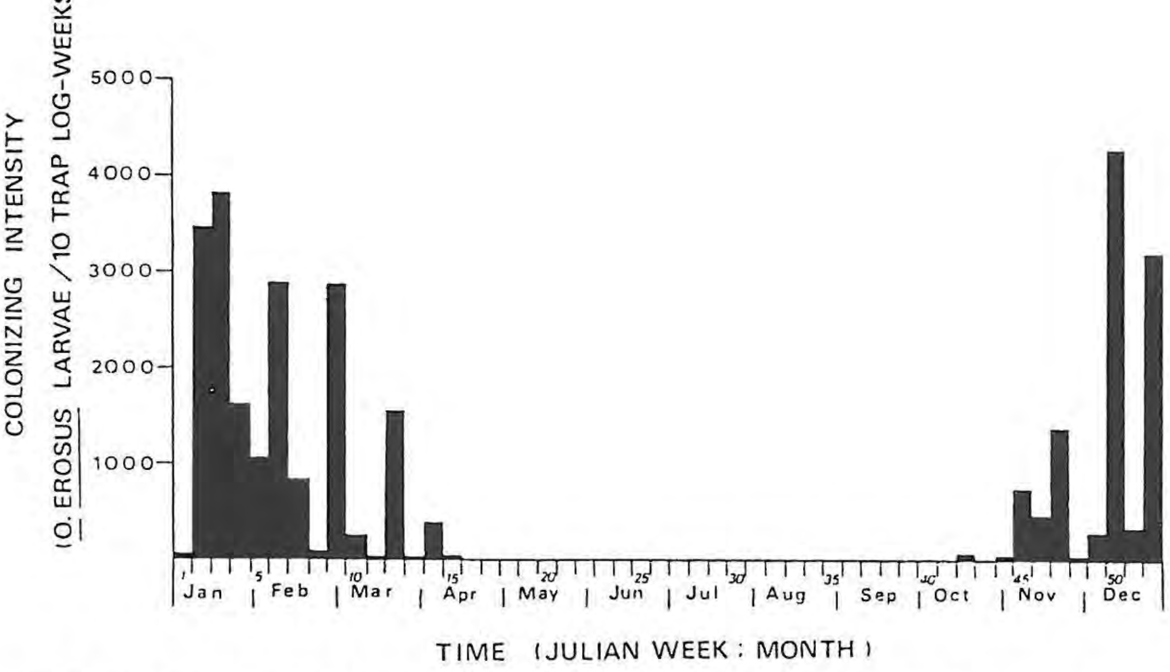

Fig. 6. The total number of *Orthotomicus erosus* larvae removed weekly from trap logs over a two year period from May 1981 to May 1983.

confirmed by removing 100 female beetles from this log and placing them on fresh logs in the laboratory. Seventy-six nests were constructed from the log ends. Each contained progeny which had been laid immediately, since teneral adults were extracted 27 days later. The females had thus been mated at the trap log but were prevented from laying eggs by sheer numbers of colonizers.

The climatic conditions prevailing when 80% of O. erosus beetles were active are recorded in Table 9. Over 80% of O. erosus beetles were active between a mean temperature of 15,2 and 20,2 °C (calculated from standard deviations about the mean of 17,7 °C). The mean temperature range over which all O. erosus beetles were active was from 9,1 to 23,0 °C.

Table 9. Weather conditions when 80% of Orthotomicus erosus beetles were active during the five years from 6 May 1981 to 5 May 1986 at two sites 5km apart in Lebanon State Forest.

Site 1 & 2	Temperature °C			Evaporation (mm/week)	Sunlight (h/d)	Rainfall (mm/week)
	mean	min	max			
Beetles active	17,7±2,5	11,8±2,4	23,6±3,1	5,6±1,4	8,1±1,9	14,1±25,8

DISCUSSION

O. erosus was found to be a summer active species in South Africa. The fluctuating Orthotomicus peaks are affected by conditions such as the availability of suitable nesting substrate, the presence and magnitude of the nearest beetle population, and weather. The strong influence of local weather conditions in initiating beetle flight is shown by the sharp weekly rise or fall in numbers even during Orthotomicus peaks.

Chararas (1964) gives the optimum temperature for O. erosus flight as 18 °C to 19 °C in France, although temperatures between 21 °C and 28 °C trigger swarming behaviour in Tunisia (Chararas & M'Sadda 1973). Females oviposit at temperatures ranging between 18 °C and 42 °C (Mendel & Halperin 1982). This compares closely with the mean daily temperature of 17,7 °C when O. erosus beetles are active in the south-western Cape Province. The mean minimum temperature of 11,8 °C recorded in the Cape corresponds to the minimum temperature of 10 to 12 °C recorded by Chararas & M'Sadda (1973) in Tunisia below which O. erosus ceases to fly.

Differences in relative abundance and seasonality of beetles is presumably due to differences in the endemic O. erosus populations at each trap site. O. erosus population levels and stages of development are largely determined by the amount and availability of food present at each site. This in turn is determined by felling operations. Any initial differences in O. erosus developmental cycles between sites are likely to be perpetuated as long as logs are present for each emerging generation. However, no correlations were able to be extracted from silvicultural records between the amount of timber felled and the relative abundance of beetles since too many imponderables were involved. The probable reason for the larger numbers of beetles captured during the first two years of this study lies in the rate of log removal from the forest. In 1981 and 1982 logs were stacked alongside roads and left for several months before removal. This resulted in colonization and the later emergence of numerous beetles from these stacks. This may be contrasted with the negligible numbers of beetles in 1984 when a similar large volume of timber was felled but removed immediately from the forest.

Based on a life cycle of approximately 35 days in Swaziland (Bevan 1984), O. erosus could be expected to have four generations per annum in southern Africa. Brood is produced within two weeks after arrival at the trap logs, corroborating observations that maturation feeding occurs mainly while the female is excavating the maternal tunnel. Larvae and pupae may be found in winter but they are the result of the autumn dispersal. They complete their development in spring.

The sex ratio of polygamous bark beetle species prior to emergence is usually one male to one female (Bakke et al. 1983; Botterweg 1982). Both the trap logs (1 ♂ : 1,12 ♀♀) and the sticky traps (1 ♂ : 1,2 ♀♀) gave a sex ratio close to the pre-emergence ratio. The pheromone trap ratio was, however, in favour of the females (1 ♂ : 2 ♀). This was presumably due to the females responding more than the males to the attractants (Bakke et al. 1983). The volatile substances released by the male O. erosus which act as an aggregation pheromone were analysed by Giesen et al. (1984) as ipsdienol, verbenone, and 2-methyl-3-buten-2-ol and their attractiveness was confirmed in field experiments by Klimetzek & Vité (1986). Giesen et al. (1984) using an ipsdienol/2-methyl-3-buten-2-ol combination were able to attract O. erosus in a balanced sex ratio (1 ♂ : 1 ♀). An increase in ipsdienol appears to increase the percentage females attracted (Klimetzek & Vité 1986). The male/female response by O. erosus beetles to the aggregation pheromone Pheroprax in Israel was 0,48 ± 0,12 during the warm season (Mendel 1988).

The bigamous behaviour of O. erosus in Israel (Mendel & Halperin 1982) and in Tunisia (Chararas & M'Sadda 1970) was also found in South Africa. However, a much greater frequency range was experienced here. Whereas Mendel & Halperin (1982) recorded 89,2% and Chararas & M'Sadda (1970) recorded 70% of family galleries containing two females, the equivalent percentage in South Africa was only 47%.

The global distribution of O. erosus suggests that there will be no barriers to its spread throughout southern Africa. Greater damage could be expected to occur in the winter rainfall area of the Cape Province since O. erosus is essentially a Mediterranean species better adapted to that climate.

Control of O. erosus is aimed at reducing and maintaining pest populations at low levels. This can be achieved in several ways. Since the primary limiting factor to all bark beetles is the availability of breeding substrate (Bevan 1984), the denial of breeding sites to O. erosus through forest hygiene is essential. This is especially important during the summer months (September to March) of peak beetle activity.

Natural enemies are effective in controlling endemic populations and thereby potential bark beetle outbreaks. Countries within the natural distribution range of O. erosus have a complement of natural enemies. South Africa with its vast exotic monoculture pine forests however,has only one parasitoid. This parasitoid, Dendrosoter sp.nr labdacus Nixon, a braconid, is restricted to the south-western Cape Province and is limited in its effectiveness by bark thickness. Outbreaks of O. erosus in South Africa have the potential, therefore, to occur more frequently and with more severity. Although suitable natural enemies are known (Mendel & Halperin 1981; Mendel 1986 a, 1986 b), attempts at biological control in South Africa in the recent past were unsuccessful (Bevan 1984; Kfir 1986).

The most susceptible period to O. erosus colonization is during the summer months. Timber cut during this period should be removed from the forest within a few days to prevent colonization. Summer is also the optimal time to release introduced natural enemies, allowing them the greatest chance for successful establishment.

3. PHENOLOGY OF PINUS RADIATA LOG COLONIZATION BY THE RED-HAIRED PINE BARK BEETLE HYLURGUS LIGNIPERDA (FABRICIUS) (COLEOPTERA: SCOLYTIDAE) IN THE SOUTH-WESTERN CAPE PROVINCE.

ABSTRACT

Hylurgus ligniperda is a minor pest of pine trees in South Africa. Weekly log trapping over five years showed that the activity peak, which accounted for 37% of the total number of beetles captured, occurred in April/May. Although beetles were present in every month, H. ligniperda is active mainly in the cooler months with lowest numbers captured in summer. Comparisons between the three exotic scolytid pine bark beetles present in South Africa, (H. ligniperda, Orthotomicus erosus & Hylastes angustatus) showed that their population peaks are temporally separated. H. ligniperda may thus be of value as a bridging host for introduced biological control agents for the other two species.

INTRODUCTION

The red-haired pine bark beetle, Hylurgus ligniperda (Fabricius), is a native of southern and central Europe, Russia, the Mediterranean area and the nearby Atlantic Ocean islands where it feeds on Pinus species (Browne 1968; Schwenke 1974). It occurs as an introduced species in Japan, Sri Lanka, south-eastern Australia, New Zealand, parts of South America, St. Helena and Swaziland (Browne 1968; Bain 1977). H. ligniperda was first recorded in South Africa in 1885 (Geertsema 1982). It is restricted mainly to the western and southern Cape Province, but has also been recorded from Natal.

H. ligniperda breeds exclusively in the bark of unhealthy Pinus, usually in thick bark near the base of the stem or in large roots (Browne 1968). In Europe it is recorded from ailing, fallen or dead pines (Schwenke 1974). Fabre & Carle (1975) record it as a secondary pest of Pinus pinaster in south-eastern France, attacking trees weakened by the scale insect Matsucoccus feytaudi Duc. In South Africa H. ligniperda is most frequently found in stumps and roots of felled trees, in trees stressed by waterlogging or by other insects, and in logs in contact with the soil.

H. ligniperda usually has one generation per annum in Europe, although up to three generations may occur in the southern regions (Schwenke 1974). Two generations per annum were recorded in the Mediterranean region by

Fabre & Carle (1975). In New Zealand the development from initiation of brood galleries to the first appearance of teneral adults takes 10 to 11 weeks (Bain 1977). At 25 °C H. ligniperda requires 45 days to develop from egg to adult (Fabre & Carle 1975).

H. ligniperda is a minor pest in South Africa. It introduces blue-stain fungi into the wood via its tunnels (Wingfield et al. 1985) and transmits the root pathogens Leptographium spp. (Wingfield et al. 1988). Although several natural enemies are known (Schedl 1959), none are present in South Africa.

Very little is known about the biology of H. ligniperda in southern Africa. A general account of H. ligniperda in South Africa was given by Tribe (1984). The aim of this study was to determine the seasonal fluctuations in activity of H. ligniperda and to compare these with those of the other two exotic scolytid pine bark beetle species present in South Africa.

METHODS

H. ligniperda beetles were monitored on a weekly basis by means of trap logs at two permanent sites five kilometres apart within mature Pinus radiata D. Don plantations in Lebanon State Forest near Grabouw (in the winter rainfall region of the south-western Cape Province). Trap logs, one metre long and 150mm in diameter, were cut from P. radiata trees. Two trap logs were always present at each locality and each log remained in the plantation for two weeks. By initially placing the first log, and then a week later the second log on the ground at the trap site, it was possible to collect a two week old log at weekly intervals from each site for analysis. Trap logs were placed in large plastic bags for removal to the laboratory. They were dissected and the number of beetles present was recorded and plotted against the week of log retrieval. Since freshly cut logs are not immediately attractive to secondary bark beetles, the number of H. ligniperda beetles was therefore plotted against the second week of each two week log exposure period. The accumulative weekly totals of beetles over the five year trapping period were plotted using Julian weeks with an adjustment made for the leap year. The identity of H. ligniperda was confirmed from samples sent to the National Collection of Insects in Pretoria.

Daily weather data were supplied by Elgin Experimental Farm (courtesy of Winter Rainfall Region, Department of Agriculture and Water Supply), the weather station closest to Lebanon State Forest. These daily weather records were prepared as weekly means to coincide with the weekly trapping regime. The weather means and standard deviations were calculated for the periods when 80% of the beetles were active.

RESULTS

H. ligniperda beetles were captured throughout each year over the five year period although the total number varied greatly between sites and years and consecutive weeks (Fig. 7). The overall activity peak was in April/May in which 37% of all beetles (n = 6483) were captured. Autumn was the optimal activity period since 58% of all beetles were captured between March and June (Fig. 8). H. ligniperda were least active in the dry summer months. This preference for cooler conditions is indicated by comparing the mean weather conditions for periods when 80% of the beetles were active with the rest of the year (Table 10).

Table 10. Weather conditions when 80% of Hylurgus ligniperda beetles were active during the five years from 6 May 1981 to 5 May 1986 at two sites 5km apart in Lebanon State Forest.

Site	Temperature °C			Evaporation	Sunlight	Rainfall
1 & 2	mean	min	max	(mm/week)	(h/d)	(mm/week)
Beetles active	14,8±3,0	9,0±2,9	20,6±3,6	3,4 ± 1,8	6,4 ± 2,6	24,4 ± 35,9

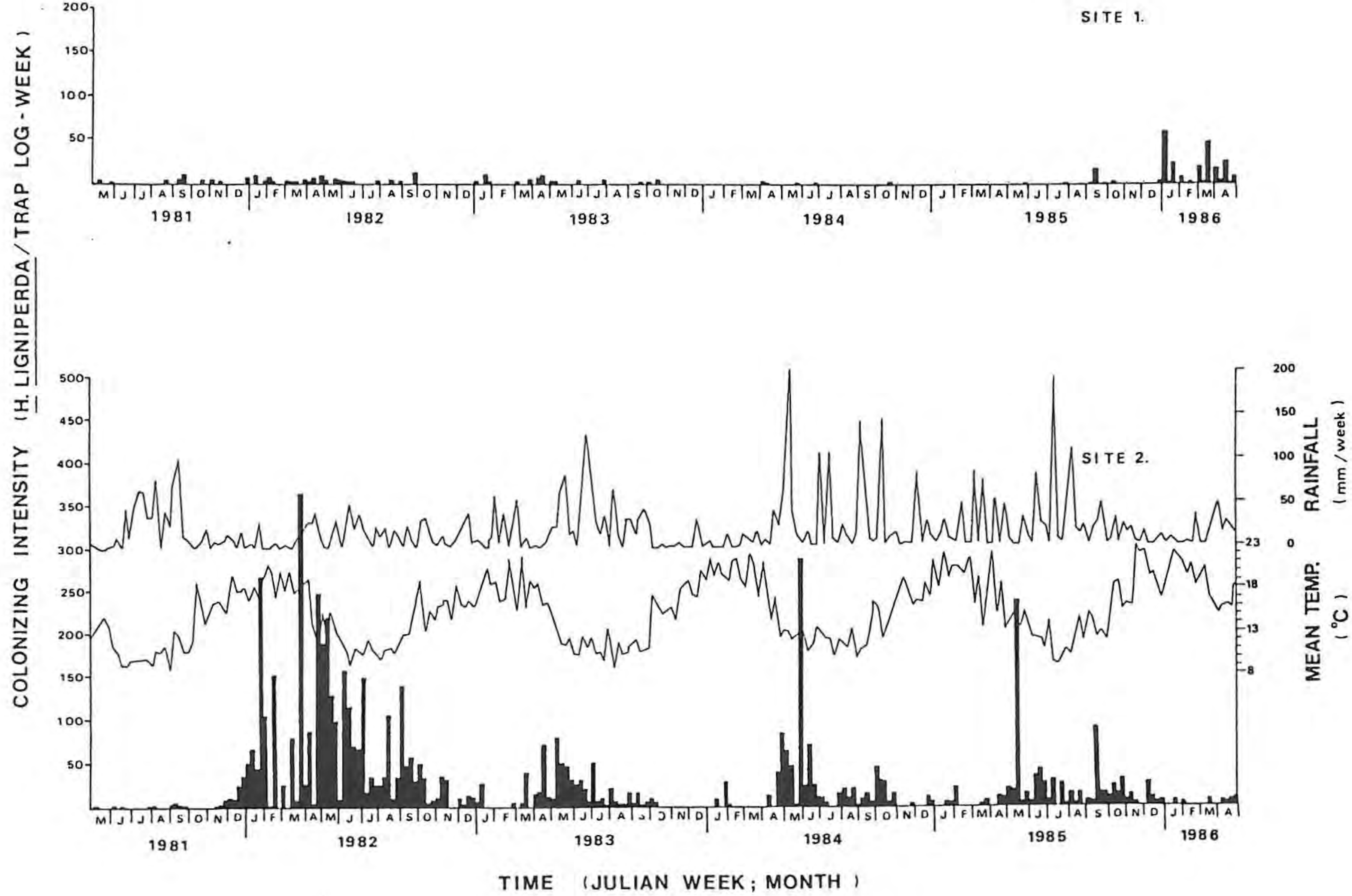

Fig. 7. Number of *Hylurgus ligniperda* beetles removed from weekly *Pinus radiata* trap logs at two sites (5 km apart) within Lebanon State Forest over a 5 year period and the mean weekly temperature and rainfall.

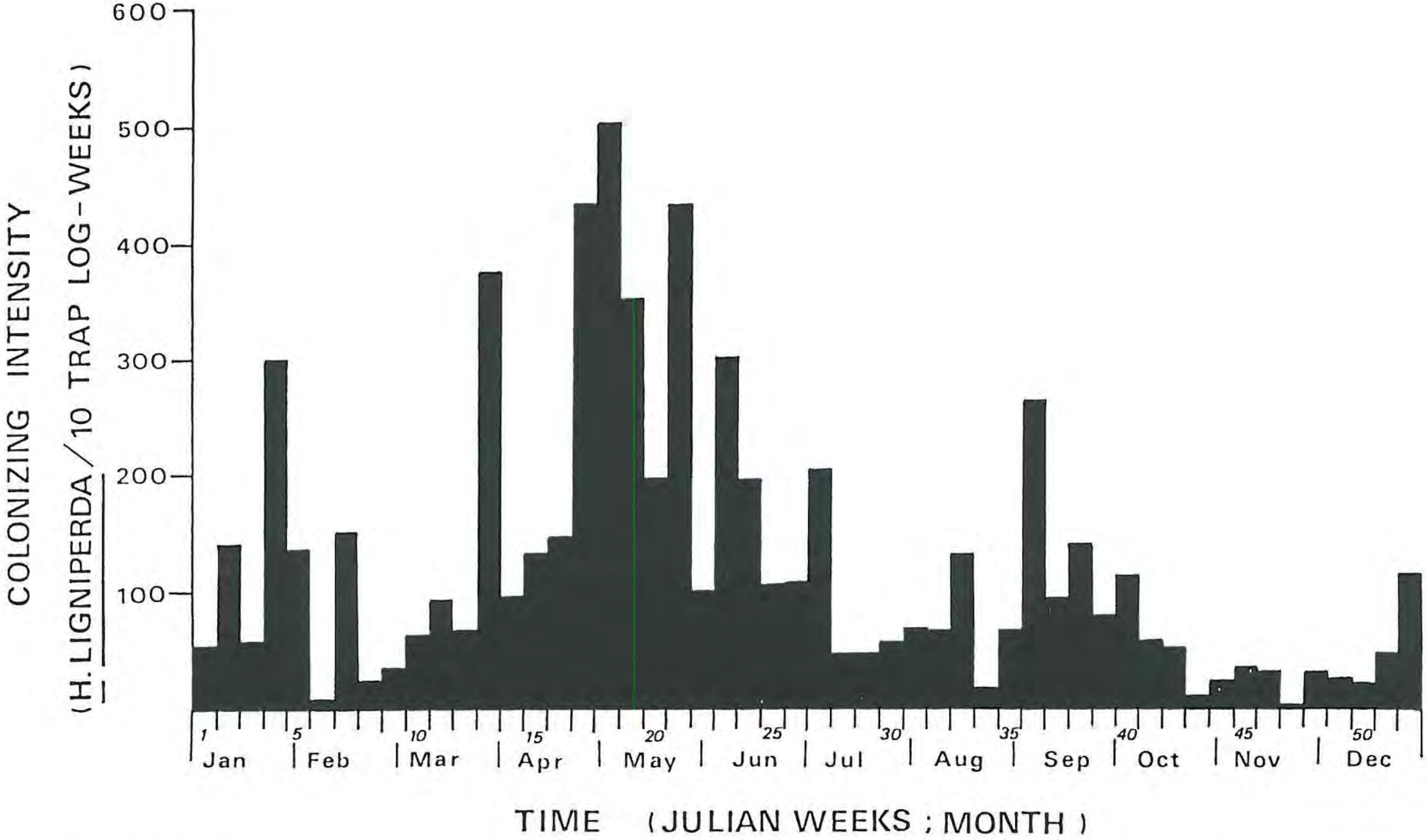

Fig.8. The combined total number of <u>Hylurgus ligniperda</u> beetles captured weekly over a five year period from May 1981 to April 1986 in the south-western Cape Province.

DISCUSSION

The autumn activity peak of H. ligniperda in the south-western Cape Province is similar to that of Hylurgus micklitzi Wachtl in Israel. H. micklitzi were trapped in resin in large numbers in autumn (Oct. - Nov.) (Mendel et al. 1985). Unlike the South African situation they were, however, not present in other seasons.

The major activity peak of H. ligniperda in south-eastern France coincided with that of the first generation and is shown in the life history diagram of Fabre & Carle (1975) to occur in spring. This is followed by a shorter peak in autumn coinciding with the second generation, after which the adult beetles enter a winter hibernation. This is reversed in the south-western Cape where the major activity peak occurs in autumn (May) and minor peaks in spring (September) and summer (January). The table of approximate swarming periods given by Fabre & Carle (1975) shows that similar to the south-western Cape, H. ligniperda beetles are also active in every month of the year in south-eastern France. They also show that there is variation in the occurrence of activity periods from year to year in south-eastern France although H. ligniperda is essentially active in spring and autumn, with least activity occurring in summer.

Based on the 10- to 11 week developmental period given by Bain (1977), H. ligniperda could have four or five generations per annum in the south-western Cape. H. micklitzi in Israel only establishes one annual generation, which includes two or three sister broods (Mendel et al. 1985). Perhaps the milder weather and the commercial nature of the plantations provides ideal conditions for year round activity in the south-western Cape.

Three exotic scolytid pine bark beetle species, Hylurgus ligniperda, Hylastes angustatus (Herbst), and Orthotomicus erosus (Woll.) occur in South Africa. These have activity peaks at different times of the year. H. angustatus has the most consistent peak where 95% of beetles are captured in September and October in the south-western Cape Province (Tribe 1990 a). The O. erosus peak varies from year to year but always occurs between October and February when 84% of the total activity occurs (Tribe, 1990 b). Although H. ligniperda has a peak in April/May, it also has the greatest temporal distribution, with beetles present throughout the year.

The differing activity peaks of H. ligniperda, H. angustatus and O. erosus reflect the optimal weather conditions for each species that favour their ecological requirements. H. ligniperda and H. angustatus as root and stump inhabitants, require a high moisture level and low temperatures. O. erosus occurs within stem bark, is active under much drier and hotter conditions and has a shorter life cycle. Hence it possesses a strong aggregation pheromone, allowing maximum utilization of a transient nutritional resource such as a felled tree (Tribe 1985).

H. ligniperda beetles emerged for flight in south-eastern France when the ambient temperature was between 15 and 16 °C (Fabre & Carle 1975).

Activity occurred at lower mean temperatures in the south-western Cape where 80% of H. ligniperda beetles were active between 11,8 and 17,8 °C (calculated from standard deviations around the mean of 14,8 °C). H. ligniperda has a greater tolerance of climatic conditions as shown in both their distribution throughout the year and the larger standard deviations recorded for each weather parameter.

Spring and autumn weather conditions are similar at sites within the pine growing regions of South Africa. A bimodal activity peak would, therefore, be expected for both H. ligniperda and H. angustatus. Yet each species has its activity peak in one or the other season. The H. ligniperda activity peak occurs in autumn and that of H. angustatus in spring. There are thus important cues to which each species is responding. H. ligniperda and H. angustatus are active under very similar weather conditions and both species inhabit mainly the underground stumps and roots of pines. O. erosus, which occurs in the above ground parts of pines, differs from them in being active under more extreme weather conditions where rainfall requirements are less essential. H. ligniperda is generally found deeper along the roots than H. angustatus and is possibly more sensitive to waterlogging. Such waterlogging is more prevalent in spring after the winter rains in the Western Cape when H.

angustatus is more active than H. ligniperda. The mean weekly rainfall when H. angustatus is active is 32,3 mm compared with 24,4 mm for H. ligniperda.

The seasonal distribution of H. ligniperda has potential value in future biological control programmes against O. erosus and H. angustatus. H. ligniperda could act as a reservoir for natural enemies during months when there is reduced or no activity on the part of the target species. The activity peaks of all three species are so spaced that natural enemies, especially predators, which are common to all three species could be continually active throughout the year. This would enhance their effectiveness against the two most injurious bark beetle species.

4. PHENOLOGY OF THREE EXOTIC PINE BARK BEETLE SPECIES (COLEOPTERA: SCOLYTIDAE) COLONIZING PINUS RADIATA LOGS IN THE SOUTH-WESTERN CAPE PROVINCE.

ABSTRACT

Orthotomicus erosus (Woll.), Hylastes angustatus (Herbst) and Hylurgus ligniperda (F.) are exotic bark beetle pests of pine plantations in South Africa. Results from weekly trapping of adult beetles over a period of five years in the south-western Cape Province showed that the different species have activity peaks at different times of the year. H. angustatus is the most consistent with 95% of the beetles trapped in September and October. The O. erosus activity peak was more variable but always occurred in the summer months (October to February) when 84% of the beetles were captured. H. ligniperda was the most variable, being found in every month of the year, although an autumn peak representing 37% of the beetles occurred in April/May. The period of lowest beetle activity was in midwinter. The use of this information in the formulation of control measures is discussed.

INTRODUCTION

The three exotic pine bark beetle species present in South Africa originate from Europe. O. erosus, although occurring in central and southern Europe, is essentially a Mediterranean species (Mendel, 1987). H. ligniperda is native to southern and central Europe, Russia and the Mediterranean area (Schwenke, 1974). H. angustatus is of European and southern Russian origin (Schedl, 1959). All three species feed on the cambium and inner bark of conifers, mainly Pinus species. All commercially grown pine species in South Africa are colonized by the three bark beetle species.

In their countries of origin, these three bark beetle species are regarded as secondary pests attacking ailing or dead trees. Chararas (1964) considered O. erosus a primary pest if trees stressed by adverse climatic conditions were also subjected to high beetle population levels. Stressed trees which would normally recover with time are killed once they are colonized by O. erosus (Tribe, 1984). In contrast, H. angustatus becomes a serious pest in South Africa during its maturation feeding phase. Virgin females then feed on the green bark of seedlings before dispersing and constructing nests in stumps or logs (Forestry Commission, 1946). Over 50% of pine seedlings in a newly planted stand may be killed by this under-bark girdling of the roots and root collars by the beetles (Browne, 1968; Du Toit, 1975). H. ligniperda is a minor pest in South Africa, and damage is largely due to the bluestain fungi associated with their brood galleries (Wingfield et al., 1985).

All three bark beetle species may be found simultaneously in the same pine tree. The bark beetle species, however, inhabit different parts of the tree. H. angustatus are encountered at or below soil level in the root-collars and roots (Du Toit, 1975). Similarly, H. ligniperda occurs along the roots of stumps and dead trees (Browne, 1968). Both species may be found in bark where the logs are in contact with the ground. Unlike the former two species, O. erosus occurs in bark above soil level only.

The three pine bark beetle species present in South Africa are known vectors of both bluestain and pathogenic fungi (Wingfield & Knox-Davies, 1980; Wingfield & Marasas, 1980, 1983; Wingfield & Swart, 1989). These fungal associations serve to enhance the potential destructiveness of the beetles.

Bark beetles occupy temporary habitats and are therefore adapted to a rapid increase in numbers once a suitable nesting site is found. This ability for rapid increase in numbers is compounded in South Africa by the contiguous stands of exotic pine hosts and the absence of the bark beetles' normal complement of natural enemies. Both long and short term control measures are necessary which are aimed at keeping bark beetle numbers continually at low levels.

This study was to determine when the adults of each bark beetle species are active and how each species relates to the others in terms of numbers and seasonal activity fluctuations. It also serves to bring together previously published information on each individual species and to present the overall picture of bark beetle activity in south- western Cape plantations. This basic information enables foresters to make the correct management decisions when confronted with regular damage to certain plantations or local upsurges in bark beetle numbers which require immediate control strategies.

METHODS

Two permanent trapping sites were established within compartments G13a and J11 of mature Pinus radiata D. Don trees, approximately five kilometers from each other in Lebanon State Forest near Grabouw (in the winter rainfall region of the south-western Cape Province). Trap logs, one meter long and 150 mm in diameter were cut from P. radiata trees. Two trap logs were always present at each locality and each log remained in the plantation for a fortnight. By initially placing first one log, and then a week later the second log on the ground, it was possible to collect at weekly intervals, one log from each site. Trap logs were placed in large plastic bags for removal to the laboratory. They were dissected and the number of beetles present was recorded and plotted against the week of log retrieval. Since freshly cut logs are not immediately attractive to secondary bark beetles, the number of beetles extracted was therefore plotted against the second week of each two week log exposure period. The accumulated weekly totals of beetles over the five year trapping period were plotted using Julian weeks with an adjustment made for the leap year. The identities of the bark beetle species were confirmed by the National Collection of Insects in Pretoria.

Weather data were supplied by Elgin Experimental Farm (courtesy of Winter Rainfall Region, Department of Agriculture and Water Supply), the weather station closest to Lebanon State Forest. These daily weather records were prepared as weekly means to coincide with the weekly trapping regime. The weather means and standard deviations were calculated for the periods when 80% of the beetles were active, beginning with the week with the highest number of captured beetles and decreasing until the required percentage was reached.

RESULTS AND DISCUSSION

The three bark beetle species have activity peaks at different times of the year in the south-western Cape (Fig. 9). H. angustatus has both the most consistent and the narrowest peak in which 95% of all beetles were captured in the months of September/October (Tribe, 1990 a). O. erosus is a summer active species with the population peak occurring any time between October and February in any year, wherein 84% of all beetles were

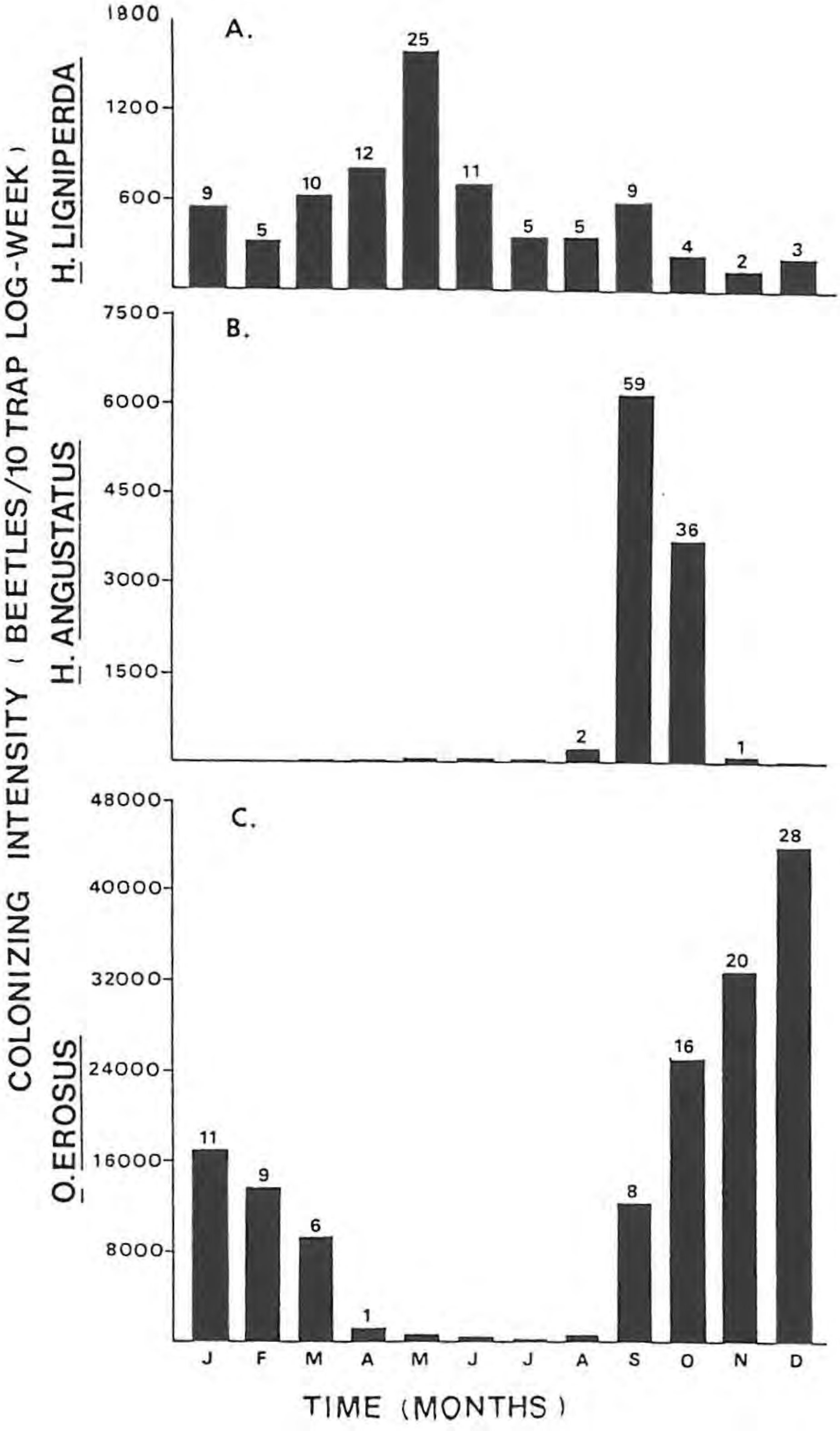

Fig. 9. The total number of Hylurgus ligniperda (A), Hylastes angustatus (B) and Orthotomicus erosus (C) beetles captured in log traps over a five-year period in the Lebanon State Forest. The numbers above each histogram denote the % of the total population for that month of each species.

captured (Tribe, 1990 b). The actual timing of this activity peak is determined by the availability of fresh logs, weather, the nearest source of beetles, and their stage of development. The most variable of the species is H. ligniperda which was found in proportionally larger numbers throughout the year. They, however, also had a distinct activity peak in April/May in which 37% of the total number of beetles were captured (Tribe, 1991).

As could be expected, the weather requirements for 80% of each bark beetle species to be active also varied (Table 11). H. angustatus and H. ligniperda required cool temperatures and high humidity during their activity peaks, whereas O. erosus was active under much hotter and drier conditions. The former two species are essentially root and stump dwellers, in contrast to O. erosus which colonizes the aerial parts of the tree. H. ligniperda which had the most variable temporal distribution, being active in every month of the year, also had the largest standard deviations for all weather factors (Table 11).

Table 11. Corresponding climatic means when 80% of each bark beetle species was active in each of the five years from 6 May 1981 to 5 May 1986 in the winter rainfall region of the south-western Cape Province.

Species	Temperature °C			Eva-poration	Sunlight (h/d)	Rainfall (mm/week)
	mean	min	max			
H. angus-tatus	13,6±2,2	8,1±1,6	19,0±3,1	3,3±0,9	6,2±1,6	32,3±36,4
H. ligni-perda	14,8±3,0	9,0±2,9	20,6±3,6	3,4±1,8	6,4±2,6	24,4±35,9
O. erosus	17,7±2,5	11,8±2,4	23,6±3,1	5,6±1,4	8,1±1,9	14,1±25,8

Temperature plays an important role in the developmental rate of bark beetles (Chararas, 1964; Mendel and Halperin, 1982) and flight intensity is positively correlated with temperature (Botterweg, 1982). O. erosus has a 30 day developmental period in summer (Mendel, 1983) which would allow a possible four generations per annum in southern Africa.

H. angustatus with an average developmental period from egg to adult of 38 days at a temperature of 24 - 28 °C, allows four or possibly five generations per year at Jessievale in the summer rainfall area of the eastern Transvaal (Du Toit, 1975). The shorter H. angustatus activity period in the south-western Cape would make only one generation per annum likely. H. ligniperda which has a 10- to 11 week developmental period (Bain, 1977) could have four or five generations per annum in the south-western Cape.

Both long and short term control measures are necessary to reduce detrimental effects of bark beetles. Long term measures involve forest hygiene accompanied by the introduction of natural enemies where the aim is to keep beetle numbers at tolerable levels. Short term measures involve the application of specific procedures according to the biology of the species concerned where local beetle numbers rise to pest proportions. These may include prophylactic insecticide sprays to protect seedlings from H. angustatus damage where the correct timing of such sprays is crucial, to management decisions such as the removal of fire damaged trees before O. erosus infects them with bluestain fungi.

The primary limiting factor to all bark beetles is the availability of breeding substrate (Bevan, 1984). Through forest hygiene the denial of such sites to bark beetles will result in lower population levels. The introduction of biological control agents will further reduce beetle numbers, natural enemies being most effective at low population levels. One natural enemy is present in South Africa and it is restricted to O. erosus pupae, and found only in the south-western Cape Province. It is a braconid parasite of unknown origin, identified as Dendrosoter sp. nr labdacus Nixon, which is limited in its effectiveness by bark thickness. Many natural enemies of the three bark beetle species have been recorded from Europe and the Mediterranean Basin (Mills, 1983; Mendel, 1986 a, b; Mendel & Halperin, 1981). Priority in any biological control programme should be given to introducing those species which attack all three bark beetle species and are able to move within the hosts' galleries.

Where a plantation experiences a bark beetle outbreak or has a history of such damage, local control measures must be initiated. These measures will depend on the biology of the bark beetle species concerned.

In the case of H. angustatus the acceptable rate of loss above which replacement becomes necessary is 15% (Bevan, 1987). Chemical protection of seedlings through prophylactic insecticide sprays is regarded as the only effective control measure (Bevan & Jones, 1965; Du Toit, 1975). Because H. angustatus feeds beneath the bark and mainly below ground, the beetles have already departed by the time the damage is first noticed (Du Toit, 1975). Thus the timing of the insecticide spray is crucial. It is important to distinguish between the spring activity peak (as shown in the south-western Cape data) and subsequent peaks which result from successive emergences of beetles from stumps and roots within clearfelled areas. The spring peak is crucial since from it follows successive generations of beetles if suitable substrate is available. In Sweden, stumps of trees felled after the flight period in spring may not be attacked until the next year (Eidmann et al., 1977). Although the spring peak will occur within all areas infested with H. angustatus in southern Africa, subsequent activity peaks will be influenced directly by felling operations. This is because beetles feeding in stumps and roots will produce several generations until the stumps are exhausted as a food source. Thus pine seedlings planted between these stumps will suffer successive attacks from virgin females undergoing their maturation feeding.

H. angustatus damage to seedlings in the south-western Cape Province is a rare event and it is not economically viable to institute an annual spraying programme. In plantations with a high incidence of H. angustatus damage, the crucial spray is at the beginning of September prior to the spring flight. The application of further sprays will depend on the presence or absence of stumps and their potential for generating successive emergences of beetles. This does not mean that seedlings planted where stumps are absent are immune from attack. Beetles at high population levels will radiate out from the source of infestation into areas previously devoid of beetles.

O. erosus on the other hand is a pest of felled or ailing trees. Forest hygiene, therefore, could virtually eliminate O. erosus as a problem in healthy plantations. Financial loss can be expected only when this equilibrium is upset as in the case of drought or fire (Tribe et al., 1985; Baylis et al., 1986). Since bluestain fungi may further depreciate sawn timber, extra care must be taken to prevent access to O. erosus beetles. O. erosus beetles will move from their centre of infestation to the nearest food source. Hence their presence and numbers in a forest will determine the speed at which trees on a stressed site are colonized, and the severity of this attack. Debris resulting from pruning operations dries out rapidly and is rarely colonized by O. erosus.

An effective means of monitoring O. erosus populations has been made possible through the use of pheromone traps. The aggregation pheromone released by male O. erosus beetles has been identified as a combination of ipsdienol, verbenone and 2-methyl-3-buten-2-ol (Giesen et al., 1984). The attractiveness of this pheromone was field tested by Klimetzek & Vité (1986) in Europe. In South Africa it was tested at Nuweberg State Forest (near Grabouw) using the commercial formulation Linoprax as the attractant in Celamerck flattened cone pheromone traps. Beetles were attracted in a sex ratio of one male to two females (Tribe, 1990 b). The highest number of beetles captured in a single pheromone trap after seven days of exposure was 16 851 (Anonymous, 1985). No trials have been conducted in South Africa to determine whether these pheromone traps can be used to protect ailing trees during population outbreaks.

H. ligniperda beetles are secondary pests attacking dead or ailing trees, and are mostly found in roots or stumps. No control methods are necessary. However, due to their activity peak in May and their presence throughout most of the year, they may play an important role as a bridging host for natural enemies introduced to control the other two bark beetle species (Tribe, 1991).

5. COLONIZATION SITES ON PINUS RADIATA LOGS OF THE BARK BEETLES, ORTHOTOMICUS EROSUS, HYLASTES ANGUSTATUS and HYLURGUS LIGNIPERDA (COLEOPTERA: SCOLYTIDAE)

ABSTRACT

The colonisation sites of three exotic bark beetle species were determined using buried and partially-buried pine logs placed vertically in the soil. Four trials of increasing complexity were conducted over four seasons within a mature plantation of *Pinus radiata* D. Don. Almost all (98%) *Orthotomicus erosus* (Wollaston) were found in the protruding parts of the logs, while most (86%) *Hylurgus ligniperda* (Fabricius) occurred below soil level. The distribution of *Hylastes angustatus* (Herbst) was intermediate with 64% of the beetles occurring in the buried parts of the logs. Both *H. angustatus* and *H. ligniperda* were able to detect and colonise logs buried horizontally at depths down to 400 mm, but *O. erosus* beetles were unable to do so. To ensure adequate protection of seedlings from all three bark beetle species, insecticide should be applied to both stems and roots of young pine trees.

INTRODUCTION

Three exotic bark beetle species, Orthotomicus erosus (Wollaston), Hylastes angustatus (Herbst), and Hylurgus ligniperda (Fabricius), which are native to Europe and the Mediterranean Basin (Schwenke 1974), occur in South African pine plantations. While generally secondary pests colonising ailing or dead trees in their native lands, they are sometimes more virulent under favourable conditions in South African monocultural pine plantations and damage healthy trees (Tribe 1990 a).

The red-haired pine bark beetle, H. ligniperda, is the least damaging of the three pest species, but is an indirect problem because it transmits pathogenic bluestain fungi (Tribe 1991). The pine bark beetle, H. angustatus, is usually the most troublesome of the three species, being responsible for the underbark girdling and death of over 50% of newly planted seedlings in some instances (Browne 1968; Du Toit 1975), thus greatly exceeding the 15% level of seedling loss that is generally acceptable and above which replacement is necessary (Bevan 1987).

Current control measures against the beetles are primarily geared to the prevention of damage to seedlings (Anonymous 1946). Where newly established pine trees are at risk, chemical protection is regarded as the only effective control measure (Bevan & Jones 1964; Du Toit 1975). The correct timing of such sprays has been determined for the south-western

Cape Province (Tribe 1990b). The present investigation was undertaken to determine where the beetles enter the seedlings in order to formulate the best method of insecticide application.

METHODS

Four trials, successively increasing in complexity, were conducted in Lebanon State Forest (34° 10' 50" S, 19° 07' 30" E) near Grabouw in 1983, 1984, 1986 and 1990, during September and October, when there is a peak of activity of H. angustatus. Each of the trials is described in detail below, but in essence they measured the sites at which the beetles colonised logs cut from freshly felled P. radiata trees. Beetles were denied access to particular sections of the logs by soaking the bark with insecticide (Cypermethrin in a 0,4% a.i. m/v solution).

Trial 1. Twenty-four logs, approximately 160 mm in diameter and 500 mm long, were buried vertically to half their length in the soil (Fig. 10a). Eight of the logs were untreated (= control), while the rest had either the protruding half (8 logs) or the buried half (8 logs) coated with the insecticide. The logs were left in place for four weeks, until the untreated logs were thoroughly infested with beetles. The logs were then placed in separate plastic bags and frozen until they could be inspected and the beetles in each section of the log counted. Tunnels which clearly

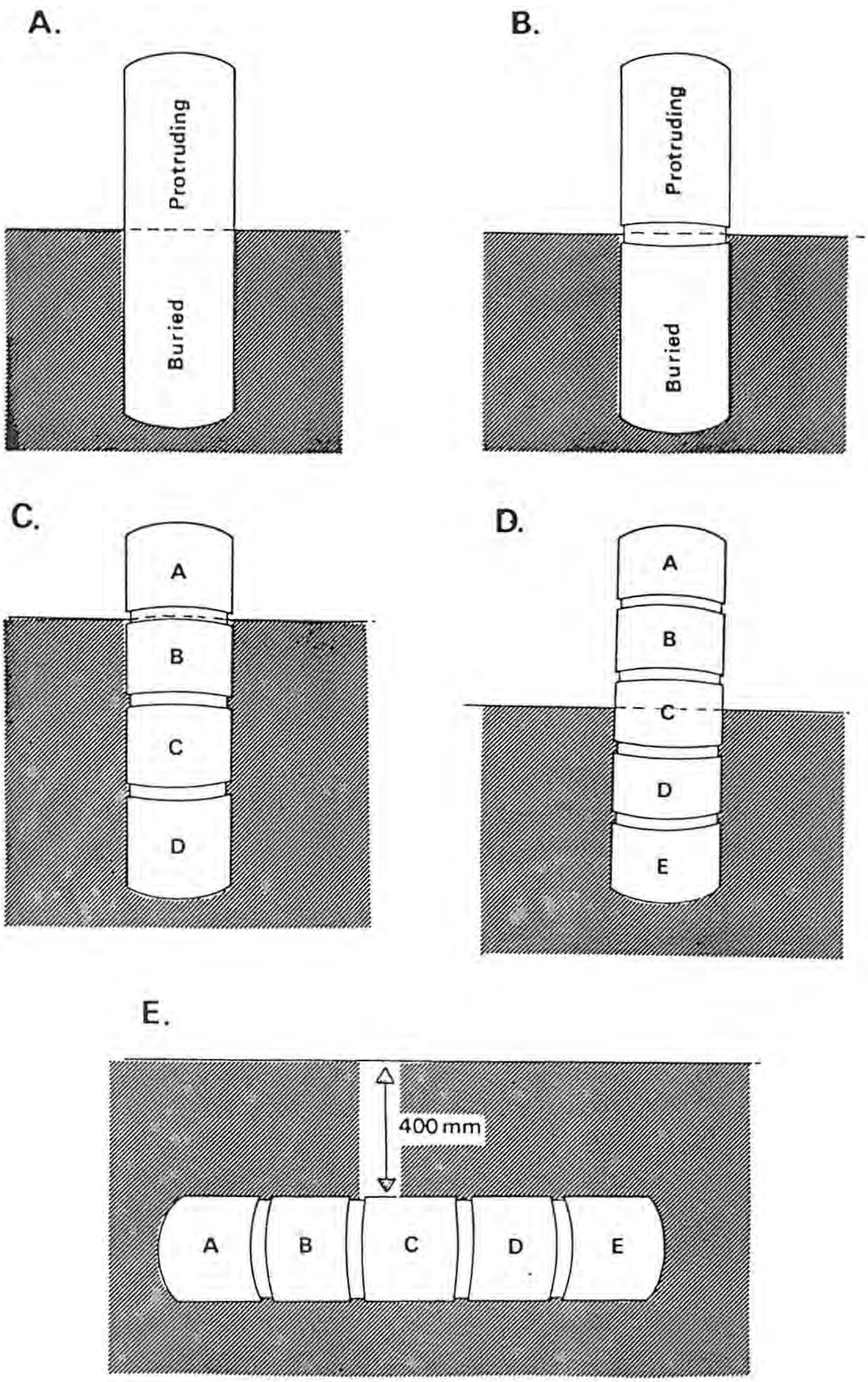

Fig. 10. Diagrammatic representation of the placing of the experimental logs in the field trials. A = trial 1; B = trial 2; C = trial 3; D and E = trial 4.

indicated that a beetle had migrated from one section of a log to another were enumerated in the half in which they originated.

Trial 2. Logs were buried vertically in the soil and divided into controls and treated halves as in trial 1. However, a ring of bark 15 mm wide was removed from the middle of each log to prevent beetles from migrating from the one half to the other. Each log was buried so that the soil was flush with the excised strip (Fig. 10b). In addition, a set of logs was completely buried horizontally at a depth of 400 mm. There were five replicate logs in each category viz. controls, treated-protruding, treated-buried (vertical); and untreated-buried (horizontal).

Trial 3. Fifteen P. radiata logs, 460 mm long and 110 mm in diameter, were divided into four segments by removing a ring of bark 20 mm wide at 100 mm intervals. All the logs which were buried with only one segment (A) protruding from the soil and three segments (B, C & D) buried (Fig. 10c). Five untreated logs served as controls. Ten treated logs were divided into two sets of five, each with one segment treated with insecticide. The first set had the protruding segment (A) treated, and the second set the second segment (B) treated.

In addition, five untreated control logs (250mm x 110mm) were placed horizontally on the soil surface. These were compared with other logs that were buried horizontally with no part protruding at depths of 200, 300 and 400mm. There were five logs at each depth.

Trial 4. Freshly felled P. radiata tree trunks 100 mm in diameter were cut into 830 mm lengths. Each log was divided into five segments by removing a ring of bark 20 mm wide at intervals of 150 mm along their lengths. Sets of eight logs were either placed horizontally on bricks 100 mm above the soil surface, or were partially buried vertically, so that two and a half sections protruded from the soil (Fig. 10d), or were buried completely, at a depth of 400 mm (Fig. 10e).

RESULTS

Each of the three bark beetle species orientated to different portions of the exposed, buried and partially-buried logs. Table 12 shows that the preference was most pronounced in O. erosus where 100% of the beetles were found in logs placed on or above the soil surface as opposed to those buried at a depth of 400mm. Neither were O. erosus beetles found in logs buried horizontally at the shallower depths of 200 and 300mm.

Table 12. Comparisons of the numbers of three species of bark beetles found in logs placed on or above the soil surface and those buried horizontally at a depth of 400mm. Trial numbers refer to methods in text.

		Trial number (year)			
Beetle species	Position of log	2(1984) n (%)	3(1986) n (%)	4(1990) n (%)	Totals n (%)
O. erosus	surface	2008(100)	2306(100)	46(100)	4360(100)
	buried	0 (0)	7 (0)	0 (0)	7 (0)
H. angustatus	surface	15 (14)	10 (6)	10 (4)	35 (7)
	buried	91 (86)	151 (94)	243 (96)	485 (93)
H. ligniperda	surface	0 (0)	13 (42)	0 (0)	13 (18)
	buried	38(100)	18 (58)	4(100)	60 (82)

H. ligniperda preferred the buried logs and although they were also found in logs where they were in contact with the soil surface, they did not colonise the logs placed on bricks (Trial 4). Hylastes angustatus also showed a distinct preference for logs buried at 400mm but a small percentage colonised logs placed both on the ground and on bricks. Hylastes angustatus beetles were able to locate and colonise logs buried horizontally at depths of 200 (31%), 300 (38%), and 400mm (31%) equally well.

Where the beetles were given a simple choice of colonising either the protruding or buried halves of vertical, partially buried logs, there was a similar distribution pattern (Table 13). Orthotomicus erosus mainly colonised the protruding portions, H. ligniperda the buried portions and H. angustatus, while found in both portions, was predominantly located in the buried portion. Those O. erosus beetles which were found in the buried portions in Trial 2 had entered the logs below the debarked ring at ground level and could therefore only migrate downwards.

Table 13. Comparison between the numbers of three bark beetles colonising either the protruding or buried sections of untreated logs partially-buried, vertically, in the soil. Trial numbers refer to methods in text.

	Position on log	O. erosus n	(%)	H. angustatus n	(%)	H. ligniperda n	(%)
Trial 1.	Protruding	18151	(99)	317	(34)	59	(20)
	Buried	237	(1)	610	(66)	244	(80)
Trial 2.	Protruding	1244	(72)	8	(11)	0	(0)
	Buried	492	(28)	64	(89)	63	(100)

Table 14 shows that when the beetles were denied access to either the protruding or buried portions of the vertically buried logs, no major disruption in the basic distribution pattern was recorded. Only in Trial 1 were substantially more H. angustatus beetles found in the protruding portion but this was not repeated in the following year.

Table 14. Numbers of three species of bark beetles which colonised the untreated sections of logs partially-buried, vertically, in the soil. In each case, the corresponding protruding or buried sections of the logs had been treated with insecticide and were not occupied by any beetles. Trial numbers refer to methods in text.

	Untreated section	*O. erosus*	*H. angustatus*	*H. ligniperda*
Trial 1.	Protruding	7893	783	66
(1983)	Buried	11	129	210
Trial 2.	Protruding	764	3	0
(1984)	Buried	1	73	40

The characteristic distribution pattern of the three bark beetle species is also evident in Table 15. Furthermore, *H. angustatus* and *H. ligniperda* were distributed more or less evenly over the buried portions. Where insecticide was applied to section B of the vertically placed logs (i.e. the section just below soil level), *H. ligniperda* beetles (75%) colonised mostly the deepest buried section (D) with fewer beetles found in the section (C) just above it (25%). When the protruding section of the logs (A) was treated with insecticide, more H. angustatus beetles (45%) were found in the section just below the soil surface (B), than in the two deeper sections C (21%) and D (34%).

Table 16 most clearly defines the distribution pattern of the three bark beetle species. There was a diminution in numbers of O. erosus from the top section A (67%) to sections B (21%) and C (12%). The numbers of H. angustatus also declined in both directions from section C where 43% of the beetles occurred. Aerial sections B (3%) and A (1%) had negligible numbers of H. angustatus when compared with the buried sections D (30%) and E (23%). Similarly there was a decrease in numbers of H. ligniperda from section C (43%), through section D (34%) and E (23%). The importance of section C as the convergence point containing the largest proportion of beetles and where the three bark beetle species overlap is readily apparent.

Table 15. Numbers of three species of bark beetles occurring in segments (A,B,C,D) of logs divided into four sections and buried vertically in the soil so that only section A protrudes (i.e. trial 3; see methods text).

Treatment	Section of log	*O. erosus* n	(%)	*H. angustatus* n	(%)	*H. ligniperda* n	(%)
All sections untreated	A	48	(91)	37	(16)	0	(0)
	B	5	(9)	63	(28)	14	(41)
	C	0	(0)	71	(31)	7	(21)
	D	0	(0)	58	(25)	13	(38)
Section B treated	A	70	(100)	45	(35)	0	(0)
	C	0	(0)	29	(23)	12	(25)
	D	0	(0)	53	(42)	36	(75)
Section A treated	B	0	(0)	56	(45)	8	(24)
	C	0	(0)	26	(21)	10	(29)
	D	0	(0)	42	(34)	16	(47)

Table 16. Numbers of bark beetles of each species colonising logs divided into five sections and buried vertically so that sections A, B and half-C protrude above the soil.

	O. erosus		*H. angustatus*		*H. ligniperda*	
Section	n	(%)	n	(%)	n	(%)
A	33	(67)	3	(1)	0	(0)
B	10	(21)	6	(3)	0	(0)
C	6	(12)	84	(43)	67	(43)
D	0	(0)	58	(30)	52	(34)
E	0	(0)	44	(23)	36	(23)

A comparison in the numbers of beetles of all three species in the aerial and buried sections of logs for all four trials combined is shown in Table 17 (excluding section C of Trial 4). *Hylastes angustatus* is positioned in between *O. erosus* which colonised the aerial parts of logs, and *H. ligniperda* which was found largely in buried logs. *Orthotomicus erosus* was very numerous representing 88% of all bark beetles, followed by *H. angustatus* (9%) and *H. ligniperda* (3%).

Table 17. Combined results of all four trials comparing the differential colonisation by the three bark beetle species of exposed and buried logs at Lebanon State Forest (excluding section C of trial 4).

	O. erosus		*H. angustatus*		*H. ligniperda*	
	n	(%)	n	(%)	n	(%)
Above ground	30565	(98)	1222	(36)	138	(14)
Below ground	758	(2)	2191	(64)	850	(86)
Total	31323	(88)	3413	(9)	988	(3)

DISCUSSION

The results show that the three scolytid species orientate to and colonise different parts of the logs, largely dependent on whether the logs are above or below soil level. This confirms field observations that these species may be divided into largely aerial dwelling or root dwelling species.

Orthotomicus erosus occurred almost exclusively in the aerial parts of the logs and apparently does not colonise buried logs because the adults cannot dig through compacted soil. Orthotomicus erosus is able to access logs buried under loose stones or soil clods (unpublished data).

H. ligniperda is predominantly a root dwelling species which tunnels directly through the soil to its food source. Where logs are in contact with the soil, H. ligniperda may colonise the immediate aerial parts, but only infrequently and in small numbers. There is no evidence that they first orientate to the protruding stump as they were found evenly distributed in all buried sections of vertically and horizontally buried logs. H. ligniperda has a relatively longer life cycle and is active throughout the year (Tribe 1991). The beetles require high moisture levels and are therefore largely confined to subterranean habitats where there is adequate moisture and environmental conditions are more stable.

Hylastes angustatus is essentially a root-dwelling species, but is adaptable and colonises the aerial parts of logs, particularly in regions adjacent to the soil. Although H. angustatus largely orientates to parts of logs which are in contact with the soil, the beetles are also able to locate and colonise logs buried 400mm below the surface. Eidmann et al. (1977) found that after uprooting stumps, roots left in the ground remained suitable to *Hylastes brunneus* Er. and *H. cunicularis* Er. development, while roots on the surface dessicated rapidly and became unsuitable. Thus temperature and moisture regimes seem to restrict the utilisation of aerial parts of the logs by *H. angustatus*, and prevailing climatic conditions could account for the large differences in numbers of *H. angustatus* beetles recorded in the protruding portions of the logs in the different trials.

Hylastes spp. are attracted to pine trees by the resinous secretions alone (Vité & Gara 1962; Rudinsky & Zethner-Mϕller 1967) and require no additional cues (Miller et al. 1986; Witcosky et al. 1987; Löyttyniemi et al. 1988). Roots of freshly cut trees are known to be especially attractive to *Hylastes* spp., and *Hylastes nigrinus* (Mannerheim) is able to invade root sections not attached to stumps or other roots by digging directly through the soil (Zethner-Mϕller & Rudinsky 1967). Pine seedlings are most vulnerable to *H. angustatus* in the first year after planting, after which they become relatively immune (Du Toit 1975).

These trials have shown that *H. angustatus* orientates to the interface of the seedling with the soil and enters at, or just below, soil level. When the aerial parts of the seedling alone are protected with insecticides, *H. angustatus* is still able to penetrate the soil, away from the aerial parts of the seedling, and colonise the roots. This explains results obtained by Heritage et al. (1989) who found that spraying container-grown seedlings with Lindane before planting was less effective against Hylastes spp. and Hylobius abietis L. than immersing the plants in the same solution. They also found that spraying aerial parts of the plants after planting did not provide adequate protection.

Protection of seedlings from the three bark beetle species requires that both roots and stems be treated with insecticide. The most cost efficient method of achieving this is to immerse the potted seedlings (i.e. planter-flats) in insecticide immediately prior to planting. Since most planting is undertaken during spring, at least in the summer rainfall regions of South Africa, the plants would be protected from the beetles during the period (i.e. spring) when they are most active.

Additional sprays, to protect the seedlings from beetles that emerge later in the summer, should be directed at the stem and bole of the plants, with some run-off penetrating the soil around the root crown. This will not exclude beetles which dig directly through the soil to the roots, but will protect the stems close to the soil surface where many of the beetles initially colonise the plants.

INDIGENOUS BEETLE DEFOLIATORS OF PINUS:-

6. PHENOLOGY OF OOSOMUS VARIUS (CURCULIONIDAE) AND PRASOIDEA SERICEA (CHRYSOMELIDAE) ON PINUS RADIATA IN THE SOUTH-WESTERN CAPE PROVINCE.

ABSTRACT

Oosomus varius and Prasoidea sericea adults feed on the needles of Pinus radiata planted within or adjacent to fynbos vegetation in the south-western Cape Province. Activity peaks were determined by counting, at weekly intervals, the number of beetles present on 10 young pine trees. The O. varius activity peak occurred in August when 42% of all beetles were active, with 87% of the beetles active in July, August and September. P.sericea also had their activity peak in August when 60% of all beetles were active, but with August and September alone accounting for 87% of all beetles. P.sericea adults were also active under colder conditions than O. varius. The occurrence of the activity peaks was consistent each year over the five-year study period. This information facilitates the correct timing of prophylactic insecticide sprays.

INTRODUCTION

Two indigenous beetle species, Oosomus varius Boheman and Prasoidea sericea (Gyllenhal), cause damage to Pinus radiata D. Don foliage in the south-western Cape Province. High population levels of either species can lead to severe damage, resulting in deaths of trees.

Little is known of the biology of the diamond-back snout beetle (O. varius) whose adults are flightless and have only been recorded feeding on P. radiata needles (Swain and Prinsloo, 1986; Annecke and Moran, 1982). The indigenous hosts are unknown. O. varius and Oosomus hariolus Boheman are believed to be synonymous (Tribe, 1984).

The fruit-nibbler (P. sericea) is best known as an important pest of pome and stone fruit. P. sericea has a wide host range, having been recorded from several indigenous plants as well as exotic ornamentals (Barnes, 1978; Myburgh, 1978; Annecke and Moran, 1982; Swain and Prinsloo, 1986). Most damage to orchards by P. sericea occurs between early September and late October (Barnes, 1978). Beetles enter orchards either from adjoining fynbos (Annecke and Moran, 1982) or from pine trees grown as windbreaks (Barnes, 1978).

The P. sericea life cycle in orchards has been described by Barnes (1978). Eggs are laid on the host plants in September soon after the female emerges from the soil. They hatch in October. The larvae enter the soil and feed on the host plants' roots, with pupation occurring during July/August after a period of nine to ten months after the eggs were laid. Therefore, only one generation per year occurs (Myburgh, 1978). Although most of the attacked trees recover, severe infestations can kill trees (Annecke & Moran, 1982).

Both beetle species nibble the edges of the needles along their length, the dead needles turning brown yet remaining attached to the tree. The damage caused by the two species can be distinguished. The brown P. sericea damaged needles especially give an untidy appearance since they point in any direction. Because O. varius feeds mainly from the tip of the needle downwards, the undamaged bases of the growing needles may remain green whereas the rest of the needles are brown. Almost all seedlings in a P. radiata stand at Tokai State Forest were killed by O. varius in 1983. Trees damaged by P. sericea are most frequently self-sown pines growing beneath mature trees. P. sericea generally feed only on trees which are not exposed to direct sunlight. Yet large trees have also been killed. At Kransbos State Forest (Knysna) in 1982, 10 thirteen-year-old P. radiata trees were killed by P. sericea beetles and several others were severely damaged. Adjacent wild pomegranate trees (Burchellia bubalina (L.f.) T.R. Sim) were also defoliated.

Several pine plantations in the winter rainfall region of both the western and southern Cape Province are regularly damaged by either O. varius or P. sericea. Protecting pine seedlings from attack by using chemical sprays is the most effective means of combating these beetles. The present study was to determine the activity peaks of the adult beetles in plantations to facilitate correct timing of prophylactic insecticide sprays.

METHODS

Two permanent sites were chosen, one for O. varius at Tokai State Forest (Cape Town) and the other for P. sericea at Lebanon State Forest (Grabouw). The O. varius site contained P. radiata seedlings planted within fynbos vegetation in a previously clearfelled area. The P. sericea site consisted of mature P. radiata trees beneath which young self-sown pines were present. Ten young P. radiata trees were tagged at each site and the number of beetles were counted in situ on the trees at weekly intervals for five years.

O. varius monitoring began in December 1983 and ended in December 1988. In July 1987 the site was changed to a nearby location due to the clearing of the fynbos and the pruning of the trees in the original site. P. sericea monitoring began in August 1983 and ended in December 1988. Thinning operations in 1985 resulted in the destruction of the marked trees and a second set of trees was selected to replace them.

Weather data were supplied by the staff of the Elgin Experimental Farm (Department of Agricultural Development) and from Groot Constantia (courtesy of Elsenburg Agricultural College), the weather stations closest to Lebanon and Tokai State Forests. Weather means and standard deviations conducive to beetle activity were calculated for periods when the peak 80% of beetles were active each year, beginning with the week with the highest number of beetles present and decreasing until the required 80% was reached. Cumulative weekly totals of beetles over the five-year trapping period were plotted using Julian weeks.

Surveys were conducted within the south-western Cape to determine the ranges of the two species and to record any additional host plants.

RESULTS

O. varius had a single annual activity period from June to October which was constant for each year of the five-year study period (Fig. 11A). The peak activity within this period varied slightly from year to year (Table 18) but usually occurred in August (Fig. 12). Only the 1987 data, the year in which the experimental site was relocated, did not conform with this trend. July (24%), August (42%) and September (21%) accounted for 87% of the total population active from 1984 to 1988.

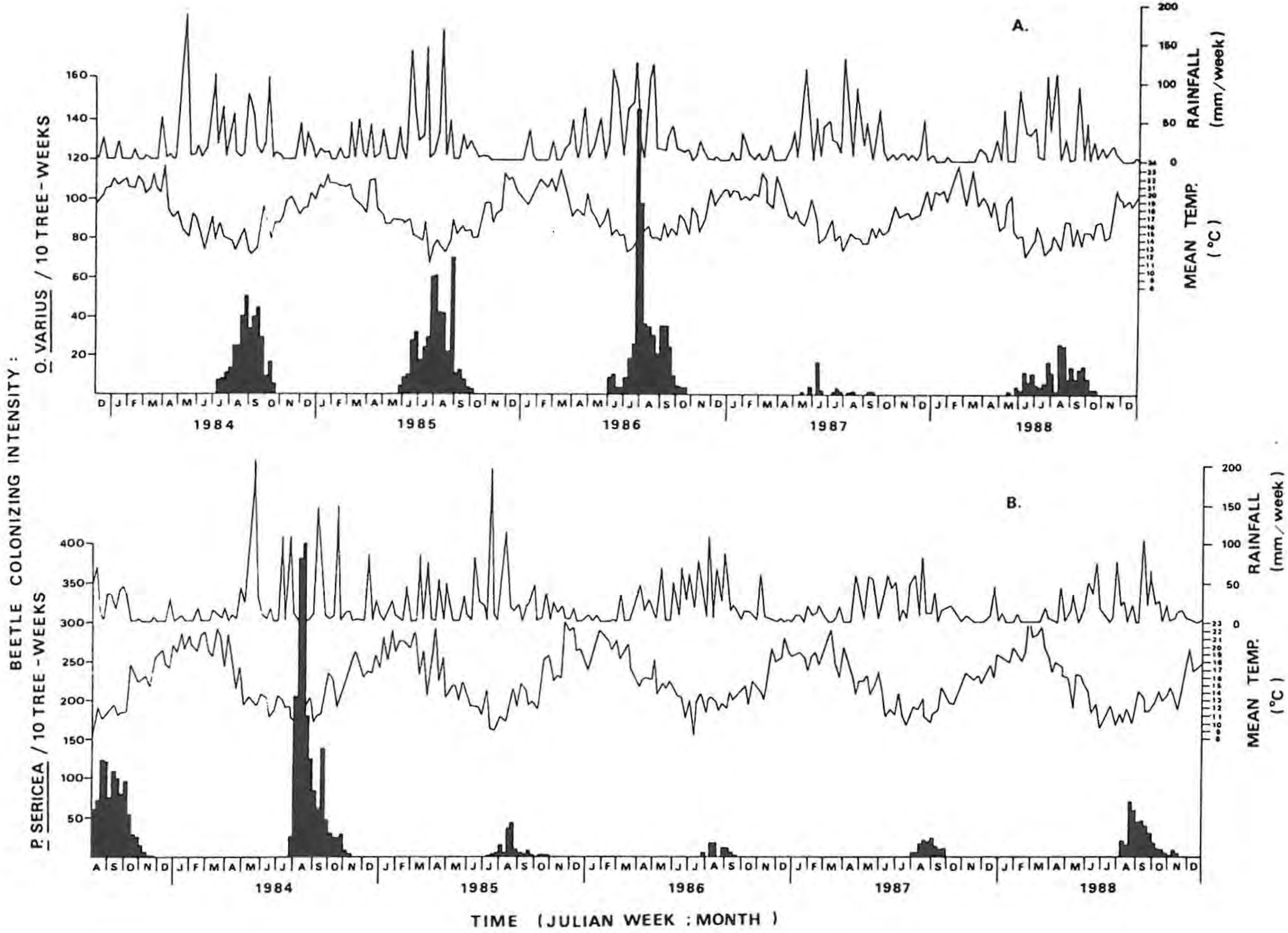

FIGURE 11. *Number of* Oosomus varius *beetles at Tokai (A), and* Prasoidea sericea *beetles at Grabouw (B) on ten marked pine trees over a five-year period and the mean weekly temperature and rainfall.*

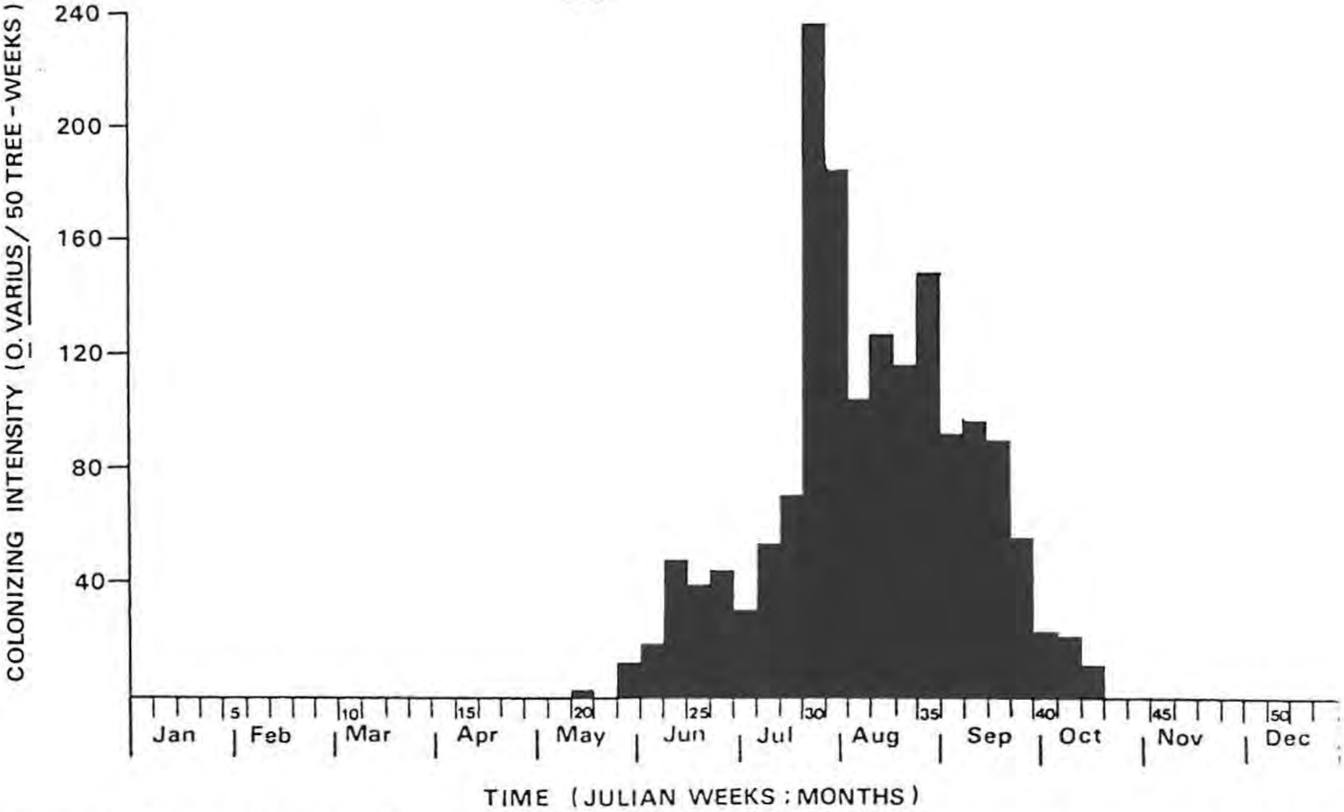

FIGURE **12.** *The total number of* Oosomus varius *beetles counted each month on ten marked pine trees over a five year period in Tokai State Forest (Cape Town).*

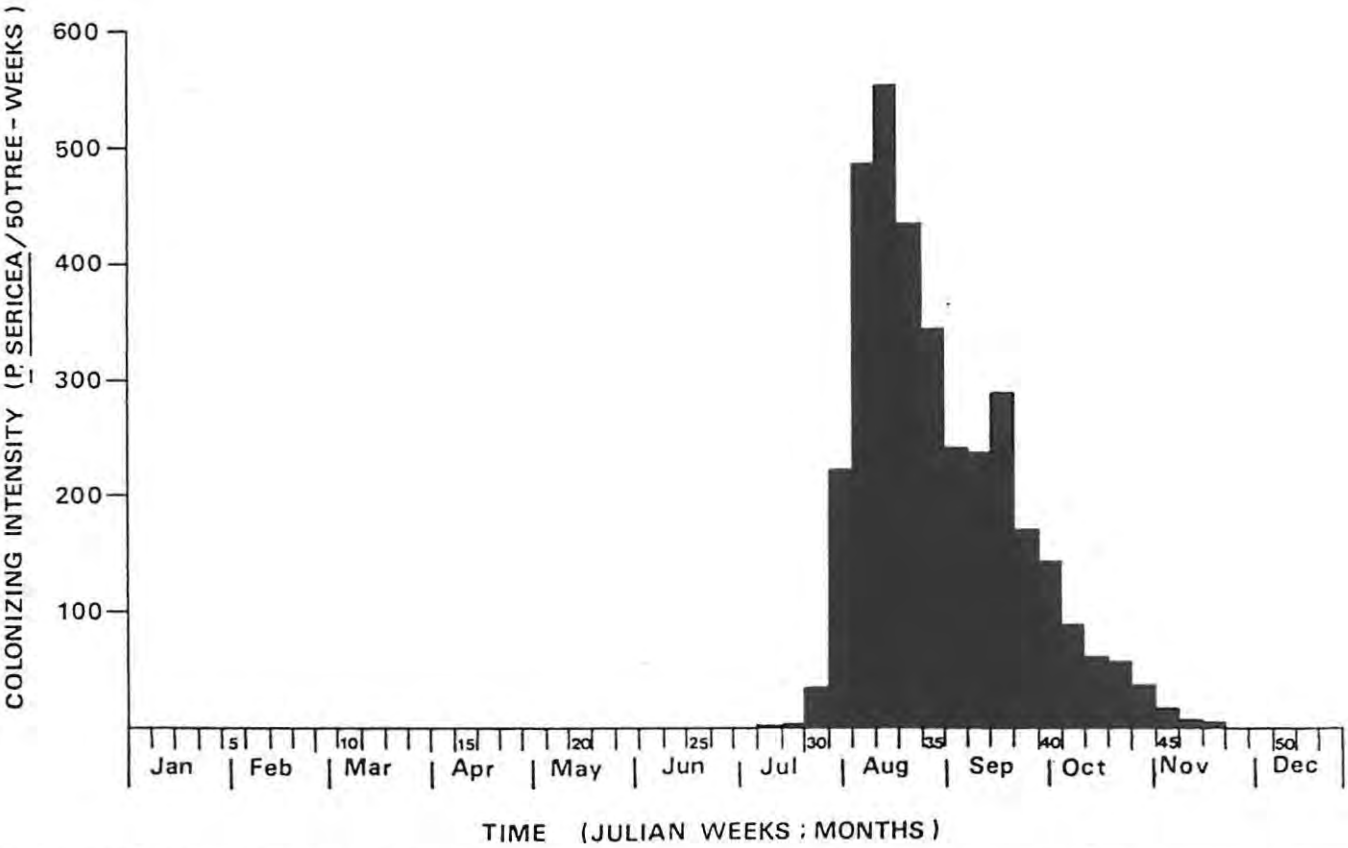

FIGURE **13.** *The total number of* Prasoidea sericea *beetles counted each month on ten marked pine trees over a five-year period in Lebanon State Forest (Grabouw).*

Table 18. Number of Oosomus varius beetles counted weekly at Tokai on ten young P. radiata trees and expressed as monthly percentages of each year from 1984 to 1988.

	PERCENTAGE OF POPULATION				
MONTH	1984	1985	1986	1987	1988
May	0	1	0	14	2
June	0	16	4	51	15
July	7	27	36	16	15
August	43	49	39	8	36
September	41	7	19	11	25
October	9	0	2	0	7

P. sericea had a single annual activity period from August to October which was constant for each year of the five-year study period (Fig. 11B). The peak activity within this period always occurred in August (Table 19). August (60%) and September (27%) accounted for 87% of the total population over the five years (Fig. 13).

Table 19. Number of Prasoidea sericea beetles counted weekly at Grabouw on ten young P. radiata trees and expressed as monthly percentages of each year from 1984 to 1988.

PERCENTAGE POPULATION

MONTH	1984	1985	1986	1987	1988
July	-	1	6	0	0
August	39	73	81	53	44
September	37	19	11	46	43
October	21	6	2	0	10
November	3	1	0	1	3

Weather conditions prevailing during the period when 80% of the beetles were active in each year are tabulated for both O. varius and P. sericea (Table 20). O. varius was active under consistently higher temperature and rainfall conditions than P. sericea, with minimum temperature showing the greatest effect.

O. varius appears to be restricted to the south-western Cape, mainly on the sand flats from Tokai to Franschhoek. P. sericea has a much wider distribution, occurring in both the western and southern Cape. In the south-western Cape it occurs most frequently in the higher mountainous

Table 20. Mean weather conditions and standard deviations when 80% of *Oosomus varius* and *Prasoidea sericea* beetles were active over the five-year period.

Species	Temperature °C			Evaporation (mm/week)	Sunlight (h/d)	Rainfall (mm/week)
	mean	min.	max.			
O. varius	14,38 $\pm$ 1,56	10,55 $\pm$ 1,25	18,15 $\pm$ 2,10	2,47 $\pm$ 0,95	5,90 $\pm$ 1,61	34,96 $\pm$ 42,35
P. sericea	12,07 $\pm$ 1,29	6,60 $\pm$ 1,73	17,51 $\pm$ 1,75	2,45 $\pm$ 0,67	5,65 $\pm$ 1,26	26,52 $\pm$ 23,83

areas around Grabouw, Steenbras Dam and Franschhoek. It was uncommon to find both beetle species simultaneously on the same host tree.

Additional host records for O. varius were recorded from the south-western Cape Province. This beetle was found feeding on the leaves of the indigenous hosts Restio spp., Rhus spp. and also on the flower heads of Thesium aggregatum A.W. Hill. Strawberry (Euonymus americana) plants were also severely damaged in a Cape Town suburb.

DISCUSSION

Only P. radiata trees within or adjacent to fynbos vegetation have been known to be attacked by O. varius and P. sericea beetles. Pinus pinaster Aiton trees are left unscathed. Usually P. radiata seedlings planted in the open within fynbos are destroyed by O. varius.

Mating beetle pairs of both species were observed throughout the activity period and presumably eggs were also laid regularly during this time. It is unlikely that O. varius has more than one annual generation. Nothing is known about the juvenile stages of O. varius whose larvae are presumed to feed on the roots of various fynbos hosts. As the pine trees grow taller than the surrounding fynbos the attacks by O. varius diminish in severity.

The restriction of *P. sericea* mainly to the colder mountainous areas of the south-western Cape Province is supported by the lower climatic conditions under which they are active (Table 20). Although at first glance it may appear from Figures 12 & 13 that *O. varius* is more cold tolerant than *P. sericea*, Table 20 shows that the opposite is true. The sea has a modifying influence on the climate of the Cape Peninsula and this is expressed in the milder weather experienced at Tokai. The climatic conditions at Grabouw and Tokai are thus not directly comparable. Yet the data presented here may be regarded as relevant for each species in the areas in which they are likely to become pests.

Climatic conditions strongly influenced the activity periods of *O. varius* and *P. sericea*. The relatively small standard deviations for all weather factors, except rainfall, indicate narrow weather parameters conducive to activity. The presence of rain during the activity periods appears to be important in causing the host plants to flush and allowing the larvae to penetrate the soil, although the actual amount is unlikely to be crucial. Together with the distribution of their natural host plants, this may explain why these beetle species are restricted to the winter rainfall areas of the western and southern Cape.

It is unlikely that the presence of *P. radiata* windbreaks around orchards are responsible for *P. sericea* attacks on fruit trees. It is apparent that pine plantations (Fig. 13) and orchards are simultaneously invaded by the beetles in spring. It is unknown whether pine windbreaks increase P. sericea populations within orchards by providing an additional food source.

Young trees planted within or adjacent to fynbos vegetation are most susceptible to these beetles. Because the activity peaks of both beetle species are constant each year, the prophylactic insecticide sprays can be accurately timed. Local monitoring of the increase in beetle numbers on recently planted seedlings in vulnerable plantations would precisely define the timing of the insecticide sprays. For P. sericea such sprays would commence in about the first week of August and for O. varius in the second week of July. Due to rainfall during beetle activity, further sprays may be necessary at intervals.

CONCLUSION

The arrival of the European bark beetle (O. erosus) in South Africa in 1968 was viewed with apprehension by the forestry industry because of its close relationship to the Ips group. In fact, O. erosus was originally described as Ips erosus and is still recognised as such by several researchers (eg. Giesen et al. 1984). Ips species are serious pests in Europe and North America where they are able to overcome the trees' defences by mass attack which is coordinated by pheromonal means. The ensuing investigations in South Africa have placed the pest status of O. erosus in perspective and confirmed them as largely secondary pests. Only in combination with other disturbances such as fire, pruning at the wrong time of year, fungal diseases or other insect pests do they cause significant financial loss. The solution to the O. erosus problem is the growing of healthy trees and forest hygiene, supported by several biological control agents which still need to be introduced, which can prevent or delay an upsurge in beetle numbers when optimal conditions arise.

The present studies on H. angustatus in the south-western Cape have resulted in a clearer understanding of the factors influencing the activity peaks of the beetles throughout South Africa. Du Toit's (1975) pioneering work had shown that H. angustatus was active for 277 days of the year and caused severe damage to seedlings planted in the summer rainfall areas. The south-western Cape studies have shown that there is a spring activity peak which is not extended into the summer months if climatic conditions are unsuitable or if breeding sites are absent. The same intrinsic spring activity peak is present in the Transvaal but continues for much longer because the summer rain is favourable to the beetles and the stumps left behind after clearfelling remain suitable for several further generations of beetles to be produced. Each succeeding generation of beetles emerging from the stumps represents another attack on the newly planted seedlings, where they undergo maturation feeding before colonising suitably fresh stumps or logs in which to breed. The spring activity peak is crucial to what follows and successful control at this stage would result in an immediate reduction in beetle numbers and, consequently, in damage.

A denial of breeding substrate to H. angustatus would substantially reduce the pest status of the beetles. The emphasis of the research should now be directed to the stumps from which the successive waves of newly emerged beetles emanate. By neutralising these stumps as a breeding substrate for H. angustatus it is conceivable that the mortality of seedlings could be lowered to below the economic threshold of 15% above which replacement ("blanking in") becomes necessary. Critical data needed includes the influence of the date of clearfelling, the diameter of the stump, and the period over which the stump remains suitable for breeding, on the numbers of beetles and generations of beetles produced. Neutralising of the stumps could be achieved possibly through insecticide treatment of the xylem tissue immediately after felling and/or the introduction of biocontrol agents. H. angustatus beetles have been shown to be able to locate and colonise roots by digging directly through the soil to a depth of at least 400mm and the effectiveness of insecticide treatment will depend on how far it is translocated from the cut perimeter to the roots. Insecticide treatment also raises the question of cost effectiveness and the possible prolonging of the degradation of the stumps, a process in which bark beetles play an important role.

Under the plantation system the success of biological control of H. angustatus is not exceptionally promising and this is why it has not been recommended in the past wherever Hylastes spp. are pests. Yet the possible success of specially chosen natural enemies in South African plantations should not be dismissed out of hand. The conditions which allow a proliferation of H. angustatus beetles could lead to a complementary proliferation of their natural enemies. Because the stumps in freshly clearfelled areas represent the centre of infestation, predators (and parasites) which are able to enter the beetles' tunnels and follow them below soil level are essential if biological control is to be successful. Such natural enemies do exist and will feed on all three scolytid species present in South Africa. The temporal distribution of the three species should ensure that prey is available throughout the year, each bark beetle species serving as a reservoir of the natural enemies for the other two bark beetle species. Thus the less damaging H.

ligniperda could become a valuable bridging host for natural enemies which are common to all three bark beetle species but had been introduced largely for the more problematic H. angustatus and O. erosus.

For the present though, the treatment of seedlings with prophylactic insecticide sprays remains the only effective control measure against H. angustatus. The orientation of H. angustatus mainly to the lower stem and roots of seedlings necessitates that these areas are fully protected. The most cost effective method would be to dip planter-flats into insecticide before planting out the seedlings. This would have to be followed up by sprays on the lower-stem in areas where this proves necessary. This applies only to the first year after planting for once the seedlings have passed their first year in the soil, only a small percentage is attacked the following year (Du Toit 1975).

These pine bark beetles are intimately associated with their host tree (Mattson et al. 1988) and have not been found in any of the indigenous tree species. It is very unlikely that any introduced natural enemies of these beetles will orientate to any host other than the exotic conifers. This attraction would be reinforced by the kairomones produced by the colonising beetles to which they orientate.

Almost none of the biology of the diamond-back snout beetle, Oosomus varius, and little of that of the fruit-nibbler, Prasoidea sericea, is known. However, for the purposes of control it was only necessary to study their phenology on pine seedlings and to ascertain when and how regular their activity peaks were. This approach was taken because both insect species are indigenous and associated with fynbos vegetation and that the pine tree is the alien in this environment. The seasonal regularity of the activity peaks of both species accurately defined the time of spraying. Only where pine seedlings are planted in or adjacent to fynbos vegetation can damage be expected. Unpublished data have shown that one 0,4% a.i m/v solution of cypermethrin spray administered at the correct time is all that is necessary to protect seedlings for the year. As the trees grow above the level of the fynbos, the attacks by the beetles usually diminish.

At this stage it is necessary to consider the future direction of forest entomology in South Africa. For this purpose Table 21 has been compiled and is based on a similar table submitted by Van Rensburg (1988) to the Forest Industry Technical Advice Committee on Plant Protection. This subjective view of forest entomology has a future research emphasis on biological control. For many of the problem insect species candidates for biological control are known and it depends on the research priority, as determined by the forestry industry, whether a biocontrol programme will proceed or not. Several projects could immediately benefit from biological control approaches. The re-introduction of the pupal parasitoid Aprostocetus sp. (Tetrastichinae) for the control of Drosophila

Table 21. Expected direction of forest entomological research in South Africa based on past achievements and possible solutions to unresolved insect problems.

PEST SPECIES	Biology known?	Relative Abundance known?	Present Pest Status (1992)	PRESENT CONTROL MEASURES: None	Forest Hygiene	Insecticides	Pheromones	Biological Control	Resistant Hosts	FUTURE RESEARCH DIRECTIONS: None	Insecticides	Biology	Pheromones	Biological Control	Resistant Breeding
IMBRASIA CYTHEREA	***	***	**	-	-	*	*	-	-	-	-	-	*	-	-
EUPROCTIS TERMINALIS	**	*	***	-	-	*	-	-	-	-	-	*	-	-	-
PACHYPASA CAPENSIS	**	*	*	-	-	*	-	-	-	*	-	-	-	-	-
PRASOIDEA SERICEA	*	***	*	-	-	*	-	-	-	-	*	-	-	-	-
OOSOMUS VARIUS	*	***	*	-	-	*	-	-	-	-	*	-	-	-	-
HYLURGUS LIGNIPERDA	**	**	*	-	*	-	-	-	-	-	-	-	-	*	-
HYLASTES ANGUSTATUS	**	**	***	-	*	*	-	-	-	-	*	*	-	*	-
ORTHOTOMICUS EROSUS	**	**	*	-	*	-	*	*	-	-	-	-	-	*	-
XYLEBORUS SAXESENI	*	*	*	*	-	-	-	-	-	-	-	*	-	*	-
PISSODES NEMORENSIS	*	*	***	*	-	-	-	-	-	-	-	*	*	*	-
CINARA CRONARTII	**	**	*	-	-	-	-	*	-	*	-	-	-	-	-
PINEUS PINI	*	*	***	*	-	-	-	-	-	-	-	*	-	*	*
EULACHNUS RILEYI	*	*	*	*	-	-	-	-	-	-	-	*	-	*	-
PHORACANTHA SEMIPUNCTATA	***	**	**	*	-	-	-	-	-	-	-	-	-	*	-
PHORACANTHA RECURVA	***	**	**	*	-	-	-	-	-	-	-	-	-	*	-
GONIPTERUS SCUTELLATUS	***	***	**	-	-	-	-	*	*	-	-	-	-	*	*
TRACHYMELA TINCTICOLLIS	**	***	*	-	-	-	-	*	-	*	-	-	-	-	-
DROSOPHILA FLAVOHIRTA	*	*	***	*	-	-	-	-	-	-	-	-	-	*	-

flavohirta in early spring will enable it to become established. The initial introduction in 1987 was in autumn due to the late location of the parasitoid in northern New South Wales followed by the lengthy quarantine period. Subsequent releases were made during unfavourable climatic conditions which were probably responsible for its non-establishment. The Aprostocetus sp. occurs around Cairns (northern Queensland) where it is active much earlier than in New South Wales and this is where future collections should be made. Aprostocetus sp. (Eulophidae) accounted for 97% of the parasitised pupae and an eucoilid for the remainder. This eucoilid is probably a larval parasitoid and as such may also be worth importing if satisfactory control cannot be established with Aprostocetus sp. alone. Similarly, the two newly discovered egg parasitoid species, Anaphes tasmaniae Huber & Prinsloo and Anaphes inexpectatus Huber & Prinsloo, and several larval parasites of Gonipterus scutellatus from Tasmania could be introduced into highveld areas. Two projects presently under investigation at Rosebank, the deodar weevil Pissodes nemorensis and the eucalypt borers Phoracantha spp., also show promise as biological control solutions.

The worldwide movement away from the indiscriminate use of pesticides has vindicated the biological control approach which has been favoured by South African forest entomologists. This approach has never been solely altruistic but is most effective for a crop which remains in the ground for an extended period and where costs therefore become accumulated.

One of the failures of forest entomology in South Africa has been the inability of accurately determining the loss of timber to the industry by insect pests. It is only through such assessments of timber loss that the priority of each insect pest should be made.

Although different tree species and clones have been tested against various insect pests, no tree breeding programme in South Africa has involved selection against insect pests as a priority. In the case of eucalypts, which supply 80% of South Africa's honey, there is a danger that new clones may result in a diminished nectar secretion (because this aspect is not included in the tree breeding programme). The resultant loss of honey and pollination units, while not directly affecting the forestry industry, could have long term implications for agriculture. Co-operation between apiculturalists and the tree-breeders could prevent such problems from arising.

Pheromone traps as monitoring devices for several of the pests should be more widely utilized. The Pheroprax commercial aggregation pheromone is highly effective in attracting both Ips typographus and O. erosus and is available in South Africa. The commercial formulation of the sex-pheromone of the pine emperor moth I. cytherea (Henderson et al. 1973) is embedded in wax chips for slow release and successfully attracts moths. However, it appears that an arrestant compound is absent for the moths do not settle in the numbers in which they are attracted. The analysis of the pheromone revealed two peaks of which only one has been identified and included in the wax chips (B.V. Burger pers. comm.). This pheromone is no longer commercially available and any future formulation which includes the second peak could be more effective. The aggregation pheromone produced by Pissodes nemorensis males is a combination of grandisol and grandisal (Fontaine & Foltz 1982; Phillips et al. 1984) but no commercially available source exists.

It is inevitable that new forestry pests will find their way to South Africa and they could be minor secondary pests or more virulent species. The list of possible pests of both eucalypts and pine trees is exceedingly long. A further danger lies in the accidental introduction of virulent pathogens associated with certain insects, especially bark beetles, which could turn a secondary pest into a major problem. Most of the pests which could arrive in South Africa would be amenable to a greater or lesser degree to biological control. But it is those insect species which are pests in their lands of origin which are to be feared the most should they arrive in South Africa.

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