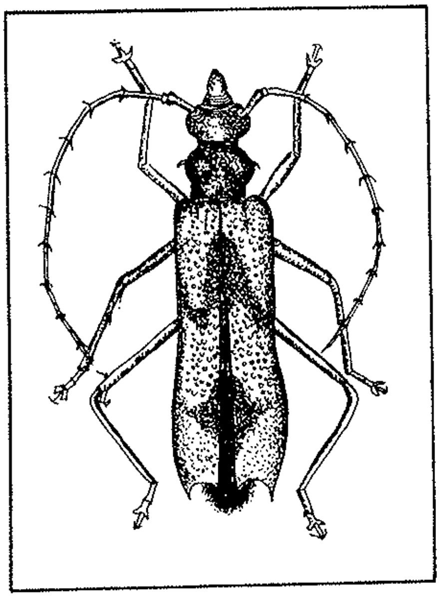
Forest Entomology Research in Western Australia

by Dr I. Abbott



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SUMMARY

Both published and unpublished information on insects harmful to trees in Western Australia is reviewed, omitting consideration of soil and litter invertebrates. A preliminary checklist of 87 such species has been compiled from insects collected by S.J. Curry from 1965 to 1983. Host tree species and the type of damage inflicted are given when available.

Over 80% of these species are beetles. However, most extensive chronic damage to trees is inflicted by caterpillars of jarrah leafminer *(Perthida glyphopa)*. The caterpillars of gumleaf skeletonizer *(Uraba lugens)* and the larvae of various longicorn (Cerambycidae) beetles have the greatest potential to inflict economic damage.

A combined experimental-observational approach is advocated for the future study of forest insects in Western Australia. Useful projects are outlined and ranked according to current research priorities. Emphasis is placed initially on studying the impact of insect populations on tree mortality, health, reproduction and growth, rather than studying the dynamics of the insect populations.

INTRODUCTION

Forest entomology is that part of forest zoology dealing with forest insects, and their effect on tree mortality, health, reproduction and growth. Given the obvious importance of the subject, very little research effort has been put into understanding insect/tree interactions (Morgan, 1961). Losses due to insects have generally not been considered as important as those caused by fire (French, 1978).

Anyone acquainted with the subject will note the emphasis on insects harmful to trees rather than those beneficial to trees. Most insect species remain uncollected, many are unnamed to species, and the biology of all but a few pests is poorly known (Campbell, 1966). This should not be taken to mean that Australian forests are more immune from insect infestation than forests elsewhere; indeed they may be more open to attack given the absence of woodpeckers (Froggatt, 1923).

The aim of this review is to summarize what is known about insects in the forests of Western Australia and how they harm trees. Invertebrates occurring on the forest floor and in the soil are arbitrarily regarded as outside the scope of this report, even though they play an important role in forest ecosystems.

HISTORY OF INVESTIGATIONS

The insect problem in Western Australian forests has been reviewed several times since the passing (in 1919) of the Forests Act - in 1921, 1953, 1966, 1971 and 1974.

Lane-Poole (1921) wrote that 'The forest insect problem in Western Australia is a very serious one from many aspects, not the least being the fact that nothing has been done in this matter from the inception of the Colony...'. The first Government Entomologist was appointed in 1894 to the Department of Agriculture (C.F.H. Jenkins, personal communication). There is little doubt that very obvious insect problems in agriculture, and lack of staff, led to little work about forest insects being done. However, incidental collections of forest insects were probably made from time to time by both resident and visiting amateurs. Such collections were never brought together. Emphasis was on describing species new to science and not on recording details about distributions and damage inflicted on trees. Earlier, the 1903 Royal Commission on Forestry alluded several times to pinholes in jarrah degrading the value of sawn timber, but the cause was unknown.

From 1919 to 1926 J. Clark conducted the first serious studies of forest insects. He was assistant to the Government Entomologist, L.J. Newman, and was based in the Department of Agriculture. He wrote a short review of the subject (Clark, 1921) and later worked out the identity and life history of the insect species causing pinholes in jarrah and, in collaboration with Newman, the cause of bud damage to tuart and leaf damage to jarrah.

When Clark left in 1926, insect problems were neglected again. Much later, Stoate (1953) observed that 'The immunity from serious attack of economic importance largely enjoyed by Australian forest has led to a fairly general disregard of forest entomology'. He was fearful of the consequences of exotic insect pests such as sirex wasp *(Sirex noctilio)* and *Ips grandicollis* on plantation forests. The 1950s was the decade when many such insects became established in Australia, or reached Western Australia.

M.M.H. Wallace of CSIRO convinced the Forests Department in 1960 to undertake a Forest Insect Questionnaire, and circulate it to all staff. So far as I can determine the results were never summarized or circulated.

There were 30 responses to the question 'List the three most important insect problems to the growing tree that you encounter in your hardwood experience in this State'.

The responses were:

Pinhole borer *(Atractocerus kreuslerae)*		19
Jarrah leafminer *(Perthida glyphopa)*		18
Tuart bud weevil *(Haplonyx tibialis)*		9
Termites *(Isoptera)*		4
Gumleaf skeletonizer *(Uraba lugens)*		3
Sawfly larvae *(Pergidae)*		3
Weevils (Curculionidae) on karri leaves		3
Insects (unidentified) attacking seeds		2
Lerps (Psyllidae)		2
(+ 15 others	each	1)

(Forests Department of Western Australia, unpublished data).

No further work was done until S.J. Curry was appointed forest entomologist in 1965, and CSIRO began a study of the population dynamics of jarrah leafminer. This was conducted by Wallace from 1962 to 1968, and Mazanec from 1969 to the present.

The approach adopted by Curry was broadly based, with emphasis on natural history. It was neither experimental nor taxonomic (Curry, 1968 and 1974).

Curry attempted to survey the distribution and to study the biology, hosts, and parasites of economically important pest species in forests, city and suburban gardens and parks, and farms. Some attention was given to the use of insecticides for controlling pests, particularly *Perthida glyphopa*, *Ips grandicollis* and *Phoracantha semipunctata*. Very little of Curry's research was published or written up.

Wallace and Mazanec used an experimental approach to investigate the ecology of jarrah leafminer. Their aim was initially to understand the ecology of the insect and ultimately to identify means of controlling populations. Mazanec quantified the impact of leafminer on diameter growth of jarrah.

A brief review of *Sirex*, *Ips* and *Perthida glyphopa* was given by Stewart (1959). Several Forests Department staff have in the course of their duties dealt with insect pests of nurseries and arboreta (A.J. Hart), gardens and farms (R.J. Edmiston) and forests products (P.N. Shedley and his predecessors). Emphasis has generally been on local insecticidal control.

The entomology branch of the Department of Agriculture believes that, in comparison to agricultural crops, the forests experience little damage from insect pests (Jenkins and Curry, 1971). Following a review of current and future requirements in forest entomology, E.R. Hopkins (personal communication) in 1964 noted that 'No single forest entomological problem appears to incur high economic loss (apart from the leafminer) at this stage of development'. This statement is essentially true 20 years later.

Nevertheless, the impact of insects on budding, seed production, seedling growth and establishment, and the growth and survival of young and old trees has rarely been quantified. The loss of timber due to degradation by insects does not appear to have been quantified. Understandably, most attention has been given to collecting, naming and working out relevant details of life histories.

The scarcity of published information about insects in Western Australian forests has led to various inconsistent perceptions outside the State about forest insect problems in Western Australia. Campbell (1966) briefly reviewed insects affecting forest trees in Australia, but made no mention of Western Australia.

Greaves (1967) reviewed the impact of insects on productivity of Australian forests, but also made no reference to Western Australia. Similarly, Browne (1968) makes no mention of Western Australia, but does list the insect pests recorded worldwide on *Pinus pinaster* and *P. radiata*. Neuman and Harris (1974) referred only to pinhole borer, but Neumann and Marks (1976) listed jarrah leafminer, pinhole borer, *Pineus*, *Phoracantha semipunctata* and *Tryphocaria*. Gilmour *et al.* (1977) referred to jarrah leafminer, pinhole borer and *Ips;* and Turnbull and Pryor (1978) listed *Tryphocaria*, pinhole borer, wood moth, and gall weevil on karri. Finally, Carne and Taylor (1978) referred to jarrah leafminer, weevils reducing karri seed production, *Phoracantha semipunctata*, and pinhole borer on karri.

PRELIMINARY CHECKLIST OF INSECT SPECIES WHICH ARE POTENTIAL OR ACTUAL PESTS OF TREES IN WESTERN AUSTRALIA.

The checklist contained in the Appendix is based primarily on pinned specimens held by S.J. Curry, Department of Agriculture*. Larval specimens were not available for examination. Localities and host species were in most cases taken from the labels, but sometimes were supplied by S.J. Curry or taken from the literature.

An elementary but useful taxonomic account of insects is given by Penfold and Willis (1961). CSIRO (1970) present more sophisticated information, with emphasis on systematics.

* This collection has now been transferred to the Research and Planning Branch of the Department of Conservation and Land Management, Como.

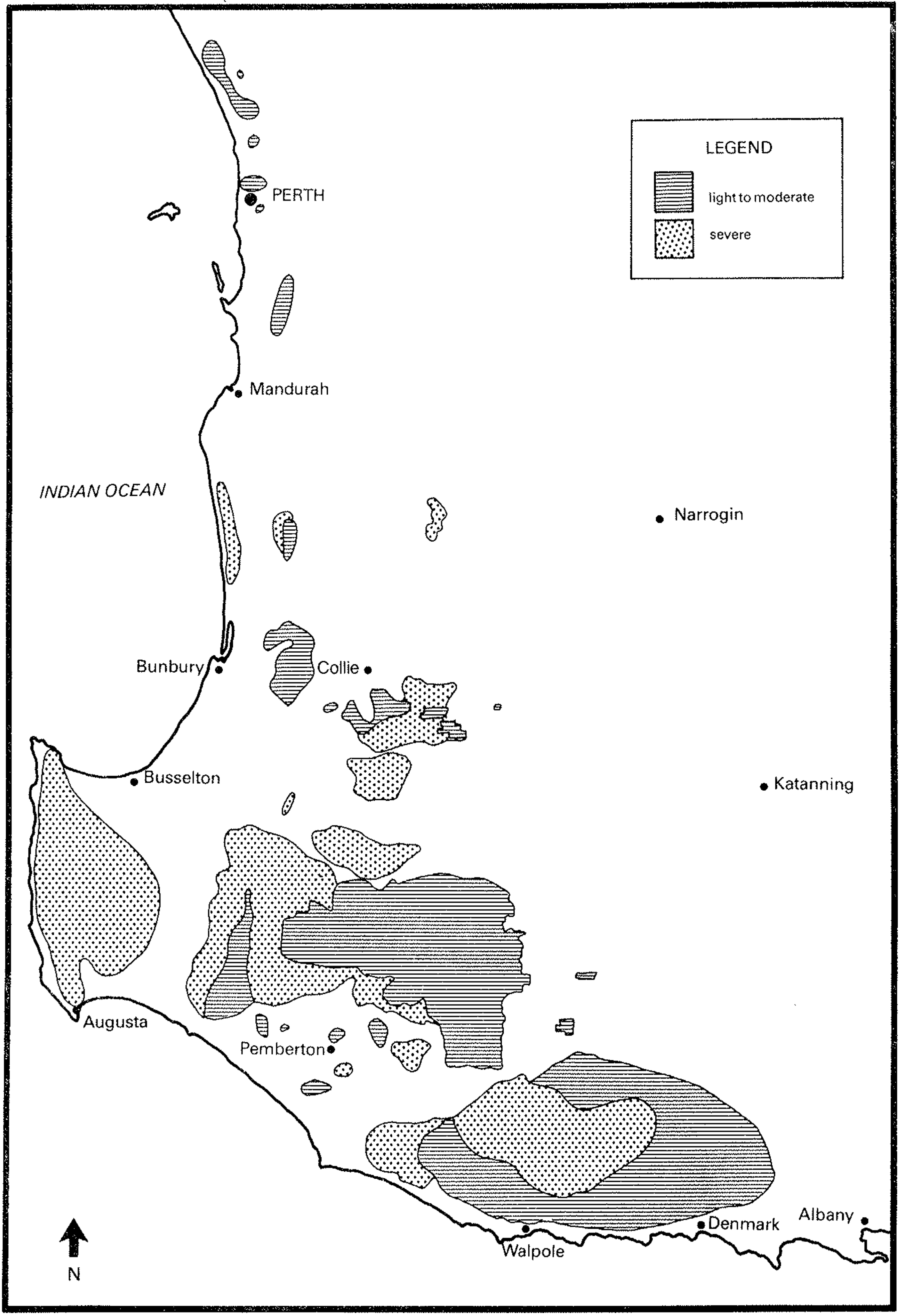
CURRENT KNOWLEDGE OF THE ECOLOGY OF INSECT SPECIES IN RELATION TO WESTERN AUSTRALIAN TREES.

The checklist contained in the appendix, although preliminary, includes many insect species causing localized or temporary damage to trees. The following section summarizes briefly the life history and ecology of the species that have been studied, and how they damage trees.

1. *Perthida glyphopa*

The informed consensus is that our most serious problem is caused by jarrah leafminer, by virtue of the large area of jarrah forest affected (S.J. Curry, J. Havel, F. McKinnell, R. Underwood, P. Christensen, F. Batini, personal communications). The range of the insect was first mapped by Wallace (1970), though it is now known that two species are involved. Mazanec (1974) mapped the extent of damage, as have the Inventory and Planning Section of the Forests Department in 1967, 1974, 1975, 1976, 1977, 1980, and 1983 (P. Collins, personal communication). The I & P maps have their limitations, nevertheless, broad trends are evident; the extent of leafminer damage to jarrah is shown in Fig. 1.

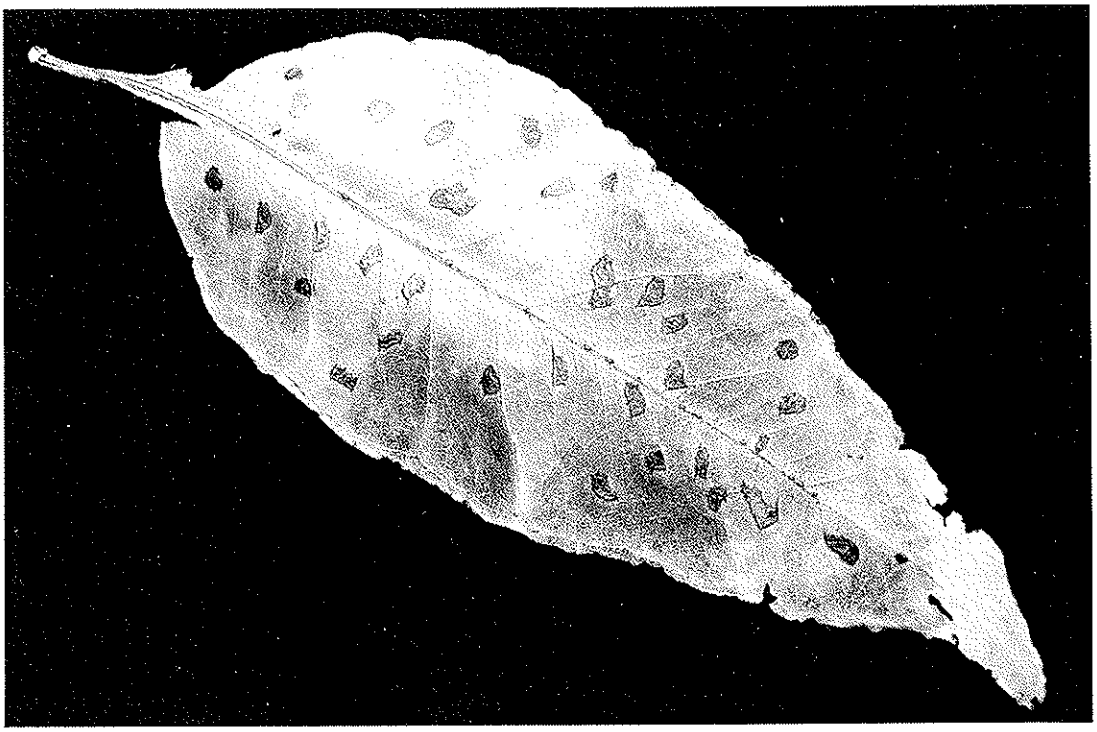
FIGURE 1 Extent of damage to *Eucalyptus marginata* by *Perthida glyphopa* in October 1983



Twelve eucalypt hosts have been recorded (Wallace, 1970). Adults emerge in April/May and the females, especially young ones 4-6 months old, lay the eggs on leaves. The larvae tunnel through the leaf tissue from June to October and then each emerges by cutting a small hole in the leaf (Fig. 2). This case falls to the ground. The larvae spend the summer below ground until pupation occurs between February and March. Larvae do not move from leaf to leaf. Thus, foliage formed after June would be unaffected by leafminer (Newman and Clark, 1925). Mined foliage of jarrah is replaced between December and January, ready for the next generation of eggs. For details, see Mazanec (1977, 1980, 1981a,b, 1983). Crown deterioration is being quantified (Forests Department of Western Australia, unpublished data).

Leafminer reduces the diameter growth of jarrah (Mazanec, 1974), even though jarrah is effectively without functional leaves for a short period only (November-January). About one quarter of all trees are resistant, but the cause is unknown. However, recent surveys by the Inventory and Planning Section of the Forests Department show marked spatial variability in the proportion of resistant trees in a stand.

Figure 2(a) Damage to leaves of *Eucalyptus marginata* by *Perthida glyphopa*.
Resistant leaf, showing aborted mines.



2(b) Susceptible leaves, showing various degrees of damage.

Leafminer is known to cause malformation of advance growth (Fig. 3). J. Havel's observation (personal communication) that the small-leafed short-boled form of jarrah found at the foot of the Darling Scarp appears virtually immune to leafminer, despite heavy infestation on the adjacent coastal plain, deserves further attention.

Figure 3 Effect of *Perthida glyphopa* on jarrah ground coppice.

(a) Tall, even-tapered stems of ground coppice resistant to leafminer.

(b) Forking, uneven taper and bad form of ground coppice susceptible to leafminer.

(a) (b)

Severe infestations are associated with forest edges and clearings (Wallace, 1970), or in fact any management practice causing a flush of new foliage (Forests Department of Western Australia, unpublished data). High tree density appears to restrict the population size of the insect. This may be because the female moth prefers sunny positions for egg laying. Outbreak areas of jarrah forest have basal area 8 m^2 ha^{-1} less than non-outbreak areas (Mazanec, 1980). Prescribed low intensity fire temporarily checks the population size, but unfortunately the moths can disperse widely (Mazanec, personal communication).

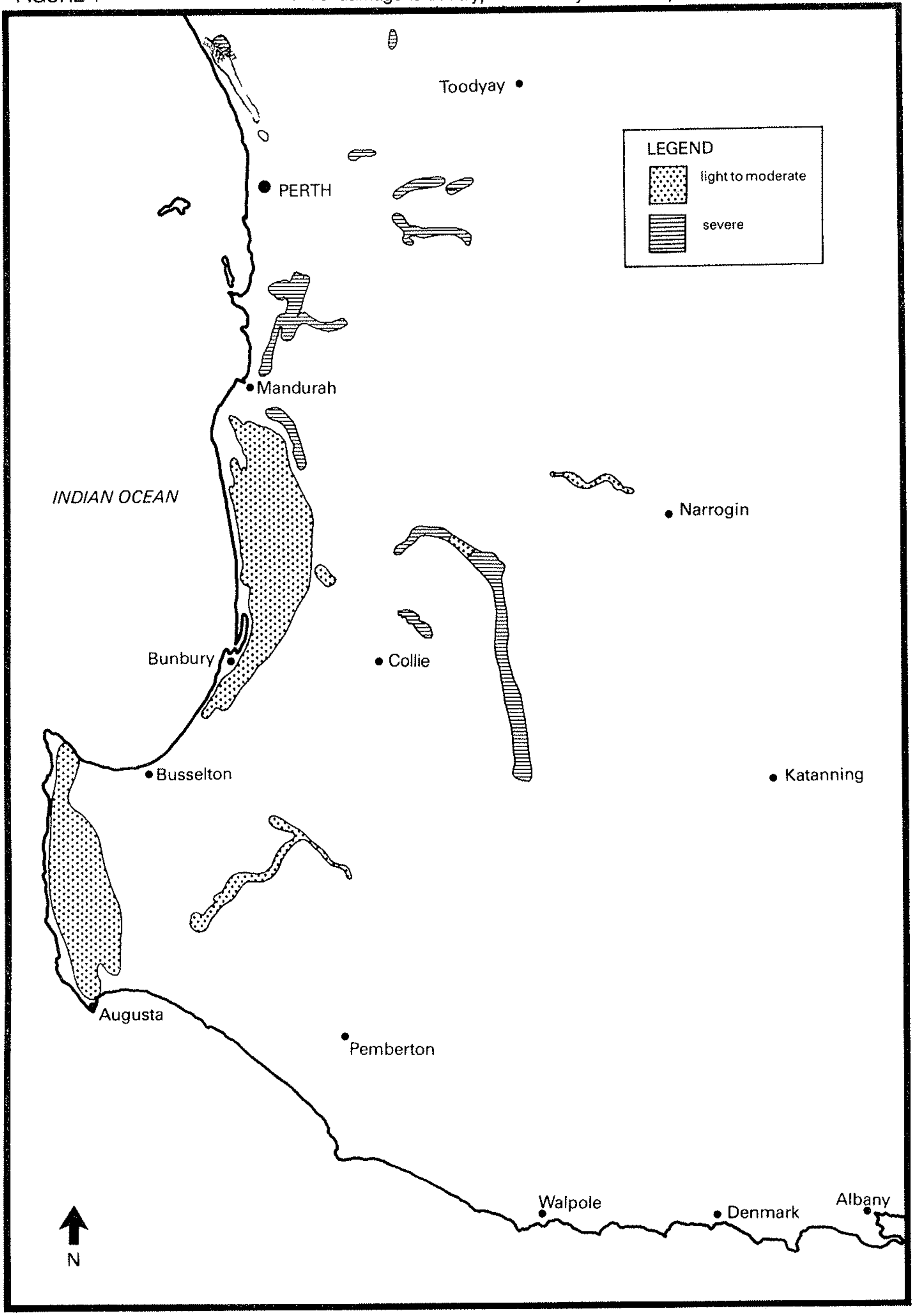
There is no consistent association, however, between outbreaks of jarrah leafminer and logging of the jarrah forest. Much of the jarrah forest near Walpole is relatively undisturbed by logging and private property, but is severely damaged by leafminer (F.J. Bradshaw, personal communication).

In any case, the northern jarrah forest has been logged since the 1870s, but has no authentic record of the presence of leafminer. The main fear (F.H. McKinnell, personal communication) is that the outbreak area could spread northwards into the prime northern jarrah forest. The feasibility of thinning affected forest by removing susceptible trees and advance growth and retaining the resistant trees and resistant advance growth requires investigation.

Leafminer can be controlled with insecticide on individual trees (Wallace, 1966). Aerial spraying proved a failure (Van Didden, 1967). Spraying of jarrah advance growth with Rogor is at present undergoing trial near Manjimup.

Leafminer damage to *E. rudis* is rampant (Fig. 4). However, it is done by an undescribed species of *Perthida*, morphologically identical to *P. glyphopa* but biochemically different (Mahon *et al.*, 1982).

FIGURE 4 Extent of damage to *Eucalyptus rudis* by *Perthida sp.* in October 1983



2. *Atractocerus kreuslerae*

Pinhole borer (*Atractocerus kreuslerae*) has long been of concern in W.A. forestry: C.L. Hastie, an Inspector in the Woods and Forests Department considered pinholes 'very objectionable' (Royal Commission, 1903). Clark (1925a) echoed these comments: 'Probably no insect does greater damage to the commercial timber growing in Western Australian forests than the pinhole borer'.

Hastie reasoned that in the virgin forest pinholes resulted from falling limbs knocking pieces of bark off the bole, allowing attack. Hewers taking chips out of trees were also thought responsible for borer attack; however, H. Earl and J.T. Rutherford who both have hewing experience asserted that pinholes seldom occurred within 3 m of the ground. Rutherford also affirmed that bark removal by fire did not lead to more pinholes.

The female beetle lays her eggs on bare injured timber. This could be, for example, an old blaze mark, where limbs have been torn off (Clark, 1925a). According to Curry (1972), the damage is confined to wood below a wound that is the partial result of fire. Larvae then bore into the tree.

About two years later the fully grown larva enlarges its tunnel and pupates near the surface. Adults emerge from December to February (Curry, monthly report, 1981) through the pinholes (Neumann and Harris, 1974). Clark (1925a) stated that host preference in order of most to the least attacked is *E. patens*, *E. gomphocephala*, *E. marginata*, *E. wandoo*, *E. rudis* and *E. calophylla*. Three other host eucalypts are recorded by Curry (1972). Being so widespread and having so many hosts, pinhole borer could not be controlled economically by artifical means (Clark, 1925a). Curry (1972) speculated that periodic low intensity burning should reduce the incidence of attack.

A survey showed that an average of 13% of jarrah logs was rejected by sawmillers (Curry, Annual Report, 1975-6) because of pinhole, in contrast to 65% rejected because of wood rot. The rejection because of pinhole varied from 2% to 26%, with the heaviest infestation in areas with severe fires in the past.

3. *Phoracantha spp.*

Little local knowledge is available, but these beetles have been introduced from Australia to Africa where they have been relatively well studied. *Phoracantha semipunctata* sometimes attacks live trees, unlike *P. recurva* (Drinkwater, 1975). Wood damage is caused mainly by the last larval stage boring deep into the heartwood to pupate there. Apart from this, the larvae confine their feeding activities between bark and sapwood.

Adults emerge from December to mid-April (Curry, Annual Report, 1979-80), so there is a relatively lengthy period of egg-laying. Eggs are laid on logs within 48 h of felling and up to 35 days after (Powell, 1982). The life cycle is completed in 7-12 months in Zambia (Ivory, 1977). Other biological notes are summarized by Duffy (1963), and some parasites of *P. semipunctata* are recorded by Moore (1963).

Phoracantha semipunctata shows preference for felled logs of eucalypts in Malawi (Powell, 1978 and 1982). How the beetles find the host is unknown; possibly water stress predisposes live trees to being attacked (Ivory, 1977).

An increase in osmotic pressure of sap accompanied by reduction in defensive exudates of sap and gum may be involved (Chararas, 1968). Drinkwater (1975) recommends that trees should be felled in winter when adult beetles are less active, and that the bark should be removed immediately after felling.

Obviously, the first recommendation is impracticable in Western Australia given the problems with *Phytophthora cinnamomi*. Consequently, summer stockpiling of logs is practised, but this is expected to attract the beetles to a concentrated source of logs. There is some evidence that watering of jarrah logs during dry weather reduces beetle attack (Forests Department of Western Australia, unpublished data), possibly because dry bark is preferred for oviposition.

Curry (monthly report, December, 1982) noted that *P. semipunctata* sometimes emerges in newly built houses because of the greater use of unseasoned timber and the summer stockpiling of logs. This species also damages plantations of eastern states eucalypts in rehabilitated dieback and bauxite mined areas (Curry, 1972 and 1981). A large number of species round the world act as host to *P. semipunctata* (Duffy, 1963).

Phoracantha impavida is exclusively associated with tuart, with ringbarking branches and with young trees (Fox and Curry, 1980). The life cycle takes 2 years, with adults emerging from September to December.

4. Tryphocaria spp.

Until recently most knowledge about *T. acanthocera* came from Clark (1925b), who called it the marri borer. He recorded it also on *E. gomphocephala*, *E. patens*, *E. wandoo*, *E. ficifolia*, and *E. jacksonii*. Larvae of these beetles prefer living trees, feeding mainly in the heartwood. On hatching, the larva eats through the bark spiralling into the sapwood and heartwood. It has been recorded boring upwards (Clark, 1925b), downwards even into large roots (Voutier, personal communication), or erratically (Brown, 1983). When fully grown, it bores through the sapwood and excavates a broad channel between the heartwood and bark by removing sapwood. It thus constructs an ear-shaped chamber in the centre of which it tunnels again into the heartwood but downward to form a large pupal cell. The entrance is plugged with gum behind the larvae. Although this cell is prepared during April/May, pupation does not occur until October/November. Adult beetles emerge December/January. The life cycle is 2 years.

Clark (1925b) disputes that this borer causes gum veins. Brimblecombe and Moore, quoted in Duffy (1963), state otherwise. McCaw (1983) noted that a gum vein developed at each point where a gallery intersected the cambium of jarrah. The older, narrower channels of *T. acanthocera* in *E. resinifera* become clogged with kino (Brown, 1983). Bark borers were regarded by Jacobs (1955) as an important cause of gum veins.

One karri with a stem diameter (measured over the bark at 1.3 m above ground level) of 30 cm had 7 or 8 different galleries running along much of the length of the bole (R. Voutier, personal communication). These tunnels degrade the value of such trees for sawmilling (see also Fig.5.). Gallery lengths of *T. acanthocera* up to 10 m have been recorded in *E. resinifera*, whereas those of *T. solida* never exceeded 2 m (Brown, 1983).

Figure 5 Damage to *Eucalyptus diversicolor* by *Tryphocaria* spp.

Nothing conclusive is known about the stand or site factors promoting infestation. McCaw (1983) notes that fire is apparently unimportant, and that damage to jarrah is not confined to suppressed or injured trees. Certain areas, including Inglehope and Amphion, seem more heavily attacked.

It appears that discoloration of the bark of karri around the bullseye (R.J. Voutier and K.C. Low, personal communication) and peculiar spiral cankers on jarrah (McCaw, personal communication) represent external evidence of this borer. If so, these signs could allow rapid assessment of its incidence in the forest, without the need for felling trees. Before this method is used, however, it requires rigorous evaluation.

Recent quantitive surveys have been conducted on rehabilitated bauxite sites (Brown, 1983; Benjamin, 1984). Higher levels of infestation occur at Del Park than at Jarrahdale. *Tryphocaria acanthocera* attacks *E. resinifera* but not *E. microcorys*, *E. maculata* or *E. wandoo*; and *T. solida* attacks *E. saligna*. *Eucalyptus resinifera* was attacked most (22% of trees at Del Park, 41% at Jarrahdale). Nearly one quarter of *E. saligna* trees were attacked at Del Park. There is little conclusive evidence relating degree of infestation of *E. resinifera* plantations to age or spacing (Benjamin, 1984).

The larva is never exposed to attack by cockatoos because it lives mainly in the heartwood (Forests Department of Western Australia, unpublished data).

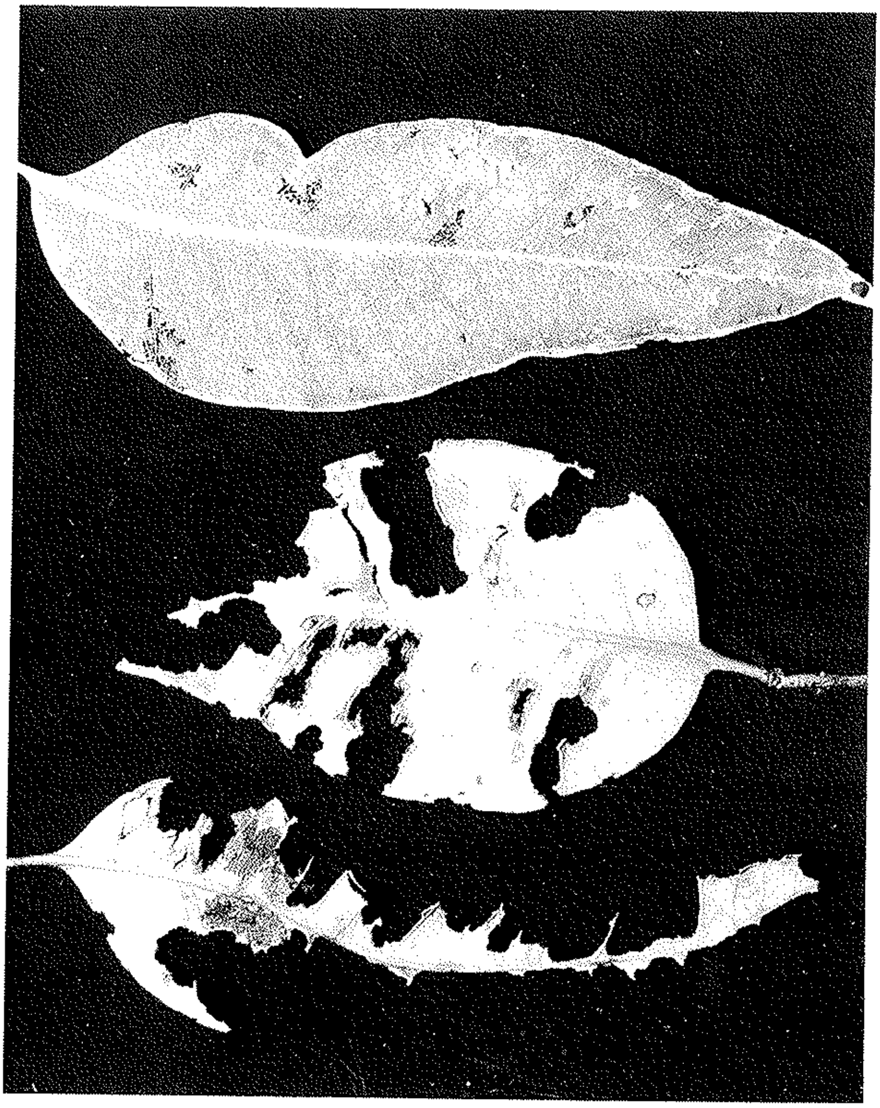
5. *Uraba lugens*

Although this species was mentioned thrice in the 1960 Questionnaire, and also by Jenkins and Curry (1971), it was not until January 1983 that it caused concern in Western Australia. It was then recorded in plague proportions, defoliating jarrah stands in 20 blocks between Manjimup and Walpole (K. Haylock, personal communication). The larvae of this moth remove the green leaf matter exposing the mid-rib and veins (Fig. 6.).

Most knowledge about this species' biology comes from several eastern states studies concerning periodic defoliation of *E. camaldulensis* (Campbell, 1962; Brimblecombe, 1962; Harris, 1974 and 1975). The moth exists in three geographical forms, two of which have two generations each year. In the summer generation, eggs hatch in January, larvae pupate in March and adults emerge in April/May. In the winter generation, the respective times are June/August, December and December/January. In 1983, larvae of the winter generation began to hatch in April (G.J. Strelein, personal communication).

Figure 6 Damage to leaves of *Eucalyptus marginata* by *Urabe lugens*.

Top: Removal of leaf tissue (early stage).
Middle: Later stage of (top).
Bottom: Final stage of (top), leaving mostly mid-rib.



Eggs are laid mostly within 3 metres of the ground, on coppice or advance growth, preferably in humid sites. Larvae are gregarious when young but solitary later. They use silken threads to cross to other trees. Pupation takes place in the litter or under the bark close to the base of the tree. The adults do not feed and are poor fliers.

Curiously, Morgan and Cobbinah (1977) obtained no records of egg-laying on planted jarrah growing in South Australia, but recorded oviposition on planted trees of karri, tuart and yellow tingle. Larvae hatched but did not usually survive for long.

The main factor limiting population density is the winter flooding of the river red gum forest (Campbell, 1962). High density of trees and abundant low foliage also favour the species. Experimental studies showed the value of thinning: movement of larvae between crowns was restricted, and the number of suitable sites for egg-laying was reduced (Harris, 1975). In south-western Australia, gumleaf skeletonizer has the potential to be a very serious forest pest. Two generations a year mean the jarrah forest could be defoliated and given no chance to refoliate. In contrast, leafminer permits annual refoliation.

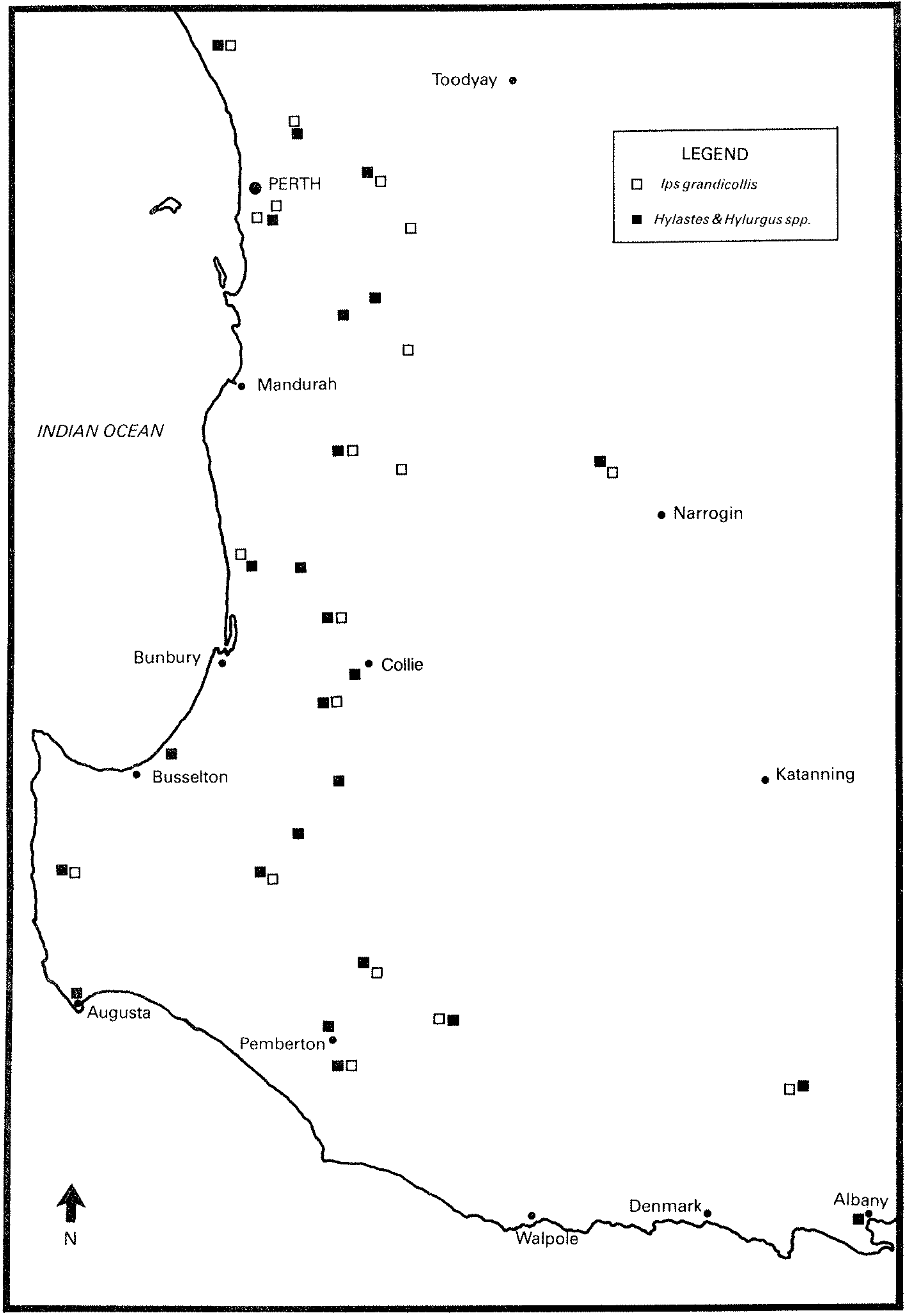
6. Bark beetles

Only three species of bark beetle (Family Scolytidae) have been found in south-western Australia (Fig. 7.). All are introduced species attacking coniferous trees. *Ips grandicollis* is the most serious in Western Australia (Curry, n.d.), and has been recorded attacking 8 pine species, usually after felling (Curry, 1974). Its biology is reviewed in detail by Morgan (1967). *Ips* mines between bark and wood of branches and stems, engraving both layers with galleries.

The male beetle bores through the bark, and attracts the female which lays eggs in the walls of the galleries. The young beetles emerge through holes in the bark. The life cycle is about 6 weeks in summer. Between September and May there may be 5-6 generations.

The mechanical damage caused by tunnelling is not serious, but the fungus introduced stains the wood (Rimes, 1959). Preliminary work on insecticidal control was done by Harding, Van Noort and Pirrett, and was reviewed by Stoate (1953). Later research was summarized by Rimes (1959).

FIGURE 7 Ranges of *Ips grandicollis, Hylastes ater* and *Hylurgus ligniperda*



Curry (1983) suggested that removal of bark from logs or the burning of logs and slash to char the bark would also help control overwintering populations, thereby reducing attacks on live trees. In Portugal, *Ips* is not important economically because all slash is removed by the local people for fuel (Perry and Hopkins, 1967).

Drought is believed to predispose *P. pinaster* plantations to attack by *Ips* (Butcher and Havel, 1976). Reduction in resin pressure may be involved, as vigorous trees probably produce enough resin to flood galleries and asphyxiate larvae (Foster, 1968). The part that thinning of plantations plays in alleviating droughting is well established (Butcher and Havel, 1976). There has been no experimental study of the effect of thinning on *Ips* populations, but the insect is only a problem on unthinned plots (Havel, personal comunication). Curry (personal communication) suggests that a dry winter followed by a hot summer is the critical factor.

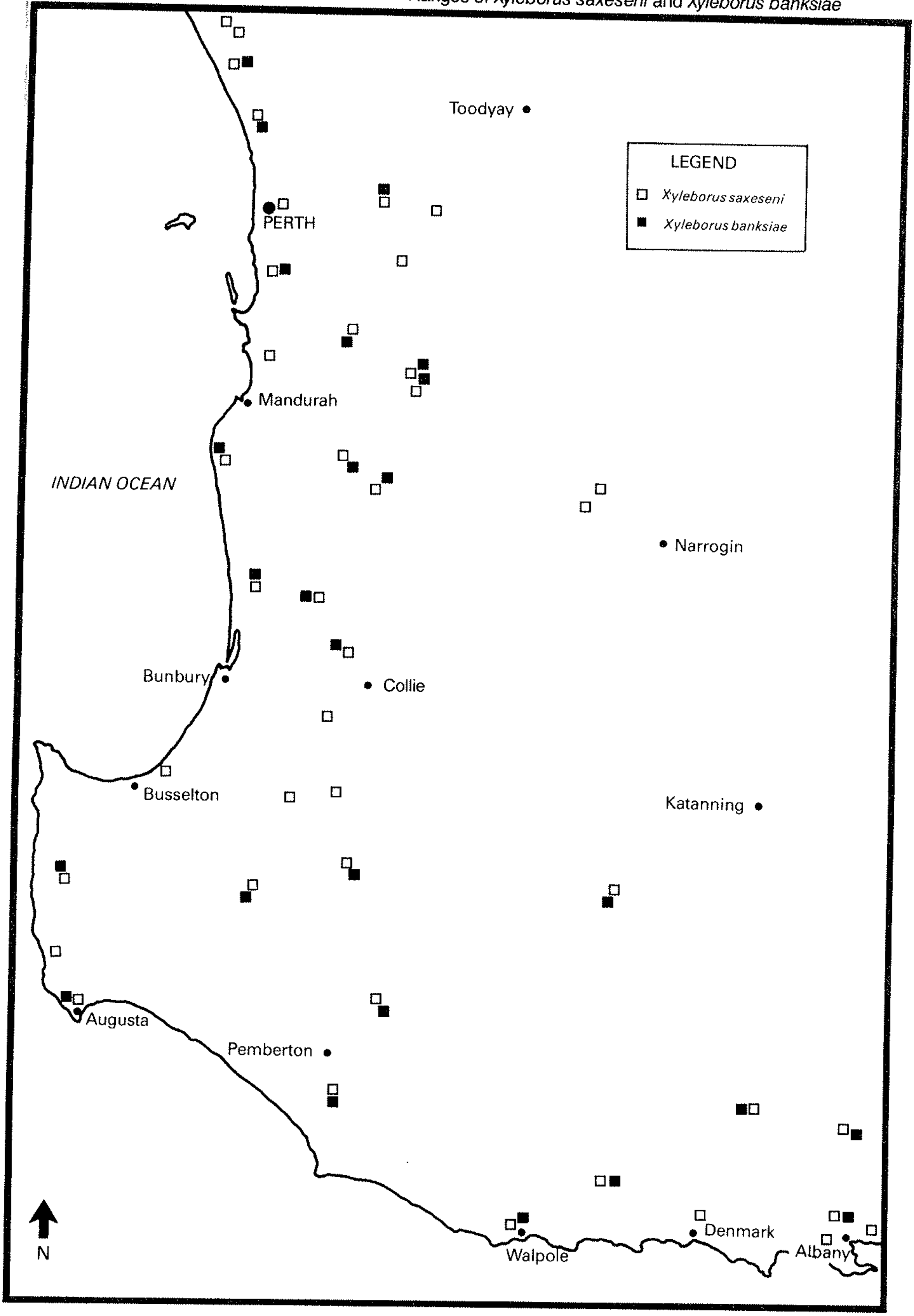
The other two species of bark beetle recorded in W.A. are *Hylastes ater* and *Hylurgus ligniperda* (Fig. 7.). Outside Australia both species can ringbark trees, but this has not been recorded here (Curry, personal communication). Instead they attack only logs and stumps in winter (Curry, 1974). Note that Neumann (1979) did not list either of these species as present in W.A..

7. Ambrosia beetles

Of the few species of scolytid ambrosia beetles found in south-western Australia, *Xyleborus saxeseni* and *X. banksiae* are abundant in forest areas (Fig. 8.). Their biology has been studied by Curry (1976, 1981, Annual Report, 1978-9; and in Harris and Minko, 1980). Both species were first recorded in 1972 on apple and stone-fruit trees. They are believed to be indigenous (Curry, personal communication), though according to Harris and Minko (1980) they are introduced. Although boring deeply into the heartwood of felled logs and fire-damaged, unhealthy and dead trees of 12 eucalypt species (*Banksia spp., Casuarina spp., Pinus radiata* and *P. pinaster*), they have little economic significance. However, *X. saxeseni* has been recorded as damaging *radiata* boards at Harvey (Forests Department of Western Australia, unpublished data). The adults are recorded between September and May, but are most active in October and November. A moisture content in wood exceeding 40% is essential to support the ambrosia fungus, introduced into the galleries as food for larvae and adults (Curry, 1981).

FIGURE 8

Ranges of *Xyleborus saxeseni* and *Xyleborus banksiae*



8. *Coptotermes acinaciformes*

This termite is described as 'the most abundant and destructive species in the southern part' of Western Australia (Calaby and Gay, 1955). Many eucalypt species are attacked, though jarrah, tuart, marri, river red gum and flooded gum were recorded as having high resistance. However, trees cannot be attacked unless wood is first affected by fungus (D. Perry, personal communication). Hence, attack is concentrated on trees damaged by fire.

9. **Xyleutes sp.**

Nothing conclusive is known about the habits of the local species of cossid wood moth recorded attacking karri (see Fig. 9). However, an excellent ecological study of an eastern states species is available (McInnes and Carne, 1978).

Figure 9 Damage to *Eucalyptus diversicolor* by cossid moth.

10. Haplonyx tibialis

The larvae attack the flower buds of tuart between November and April (Newman and Clark, 1924). The life cycle takes about 5 months. A reduction in honey and seed yield follows (Jenkins, 1963).

11. Strongylorhinus ochraceus

This species attacks karri and tuart, but mainly flooded gum (Jenkins, 1963; Jenkins and Curry, 1971). Adults are active in spring. The life cycle takes 'several months' (Jenkins, 1963). Larvae tunnel into the sapwood, causing swelling of tissue (Fig. 10). The galls formed cause breakage of branches.

Figure 10 Damage to *Eucalyptus diversicolor* by *Strongylorhinus ochraceus*.

12. *Pineus pini*

A detailed ecological study of this insect on *P. radiata* was reported by Tanton and Alder (1977). They found significant negative correlations between tree height and diameter of bark (DOB) and an infestation index. Infestation may cause trees to become suppressed.

In Western Australia, this aphid possibly causes 'branch twisting' in *P. pinaster* (Hopkins, 1960). Clones of *P. pinaster* vary in their ability to resist infestation, but according to G.W. Chester (personal communication) it is unknown if this has a genetic basis. This aphid was widespread in Western Australian pine plantations in the 1950s, and was first recorded near Esperance in 1983. It is considered a serious pest of *P. pinaster* in South Africa (Forests Department of Western Australia, unpublished data).

13. *Sirex noctilio*

Neumann and Minko (1981) and Taylor (1981) provide excellent recent reviews of the biology and impact of sirex wasp on *P. radiata*. Infestation of a radiata plantation in Victoria had a ruinous effect on volume production within seven years (McKim and Walls, 1980).

Sirex wasps were intercepted frequently by the quarantine authorities at Fremantle in the 1950s and 1960s, and once in Subiaco (Forests Department of Western Australia, unpublished data). A survey of pine plantations during 1962-3 by F. Gorringe failed to find it. Sirex wasps were first located in SE South Australia in 1980, presumably having colonized overland from Victoria.

The life cycle of the sirex wasp is one year. From November to April the female wasp lays eggs and introduces spores of a wood rotting fungus in sapwood of *P. radiata*. Trees chosen for oviposition are physiologically stressed. This is evidenced by lowered osmotic pressure and temporary cessation of growth. The fungal infection spreads through the cambial layer and ringbarks the tree. Timber is degraded by the larval tunnels and exit holes of the adults.

14. *Orgyia athlophora* and *Ochrogaster contraria*

Caterpillars of these moths are not serious forest pests (Jenkins, 1962b). They cause localized defoliation only.

15. Pests of forest products

The life cycle and methods of control of *Lyctus brunneus* (the powderpost beetle) are described in detail in the circular entitled *Wood Borers in Australia*, 1935. Females can oviposit within 24 hours of emergence. The eggs are laid within the vessels of the wood to a depth of approximately 5 mm (Gay, 1953). Heartwood is rarely attacked. Development is inhibited by extremely low or high humidity, and less so by temperature extremes. Any timber treatment not penetrating at least 5 mm will not prevent attack. No evidence of attack is visible on the surface until the flight holes are made at the end of the life cycle (Howick, 1968). Karri and wandoo are immune from attack, and jarrah is highly resistant *(Forest Entomology*, 1966). It is not known whether the *Lyctus* beetles collected in the forest are a different species (Curry, personal communication).

Bostrychid beetles differ from *Lyctus* in their mode of attack. The adult female bores into the timber and oviposits in the tunnel (Howick, 1968). The larvae then create a network of tunnels. Attack is confined to sapwood having moisture content of 20-35%. Jenkins (1962a) mentions the jesuit beetle as a pest of fruit trees.

The introduced furniture beetle (*Anobium punctatum*) does not attack eucalypts (Boas, 1947). The European house borer (*Hylotrupes bajulus*) was introduced to Australia in prefabricated houses after World War II. It attacks seasoned softwoods.

16. Pests of wheatbelt and garden trees

A wide variety of insects has been recorded. For details see Curry (monthly reports, 1981), Curry and Moulden (1981) and Hart (1980,1982, undated).

17. Beneficial insects and other animals

Beneficial insect species are just as important as damaging ones. The former species prey on the latter. Beneficial species were omitted from the preliminary checklist. They include parasitic wasps (Braconidae, Ichneumonidae) and predatory beetles (Cleridae).

Other invertebrate animals, especially spiders, are also abundant predators in Western Australian forests. There is little specific information about which bird species are the most important predators of pest insects, except for leafminer (Mazanec, 1980).

COMPARISON WITH INSECT PROBLEMS ELSEWHERE IN AUSTRALIA

Economically important damage to trees by insects in other parts of Australia is considerable. It has been reviewed by Campbell in 1966, Greaves in 1967, Neumann and Harris in 1974, Neumann and Marks in 1976, Gilmor *et al.* in 1977, Turnbull and Pryor in 1978, Carne and Taylor in 1978, and Newmann in 1979.

In comparison, Western Australia has no problems with platypodid beetles (another family of ambrosia beetles), sirex wasp and termites. There are essentially no problems with phasmatids (stick insects) and chrysomelid beetles. To date there has been only one serious outbreak of gumleaf skeletonizer in Western Australian forests.

FUTURE RESEARCH

Sources of future concern need appraisal. The jarrah forest is unusual among Australian forests in that a relatively large area is dominated by a single tree species. Increasing areas of monocultures of even-aged stands of exotic pine and regenerated karri could alter the balance between insects and trees. Insect species that previously were economically unimportant could infest these stands.

There seem to be two dangers. In the first place, a relatively harmless indigenous species of insect could cause widespread degradation or death of trees because the composition or structure of the native forest has been altered severely, perhaps by fire, or logging. Secondly, exotic insect species could be introduced to Western Australia. This is a quarantine problem outside the control of the C.A.L.M. Department. However, regular surveillance of plantations would result in earlier detection of these introductions, and therefore a better prospect of their elimination.

Apart from leafminer, there have been no effective studies of the ecology of insects found on trees in Western Australia. The role of silviculture in reducing pest populations has not been studied experimentally. Emphasis (e.g. by Rimes, Jenkins) has been on insecticidal methods of control, an approach that lacks detailed understanding of insect/tree interactions. Simple experiments involving silvicultural factors such as thinning, fertilizer, site quality or fire would yield useful information on the management of populations of insects. Fire would probably allow direct manipulation of the habitat of the insect species, but thinning and fertilization, by improving water availability and nutrition, should enhance tree vigour and hence resistance.

In the literature, changes within the tree in osmotic pressure, decreases in carbohydrate levels, and increases in levels of essential oils are emphasized (Foster, 1968; Weetman and Hill, 1973), but primacy of any one factor is disputed. Application of nitrogen fertilizer reduces insect attack (Baule and Fricker, 1970; Baule, 1973) except in the case of aphids and other sap-suckers. The approach that should initially be emphasized is the impact of insects on the tree and the tree's response, subjects that have been greatly neglected.

The ultimate goals in forest entomology research in Western Australia should be as follows (adapted from Waters, 1970):

to measure and predict forest insect population numbers and the impact of insects on forest productivity and values;

to determine the factors causing insect numbers and their impact on forests to vary;

to develop effective silvicultural and other methods of regulating insect numbers to tolerable levels.

Useful research projects, ranked according to current priority, are as follows:

Very High Priority

1. Jarrah leafminer

Does jarrah leafminer kill trees? If so, there could be serious increases in soil and stream salinity. How permanent is the damage to jarrah crowns? Exactly how is leaf production and longevity affected?

Can Mazanec's classification of trees as either resistant or susceptible be expanded? G.J. Strelein and C.G. Ward (personal communication) have suggested four categories: antagonistic (no egg laying), resistant (mines are aborted), tolerant (low degree of damage) and susceptible (high degree of damage).

Growth rates of trees in these categories need to be established using the I & P growth plots around Manjimup. Mazanec's studies of growth have been done over bark with dendrometer bands; this obviously includes bark growth and changes in bark hydration. The I & P approach measures increase in diameter under bark. In addition, the study of growth rings from selected felled trees may enable the chronology of infestation to be elucidated. This could then be related to recent management of stands. The close study of leaf dynamics entails marking leaves in the canopy and following their life. In the past, Curry (1969) and Mazanec (1980) have sampled leaves destructively, by shot-gun. Artificial defoliation of the new foliage of advance growth would also provide baseline information to compare with the effect of leafminer.

2. Insect grazing on jarrah leaves

What are usual levels of insect grazing on jarrah leaves? Do insects cause premature death of leaves? Which insects have most impact, and at which time of year? Does leaf age affect grazing? Do any leaf characteristics inhibit grazing? How much crown dieback and deterioration can be ascribed to insects?

These questions would be studied in high and low quality jarrah forest near Jarrahdale. The low quality stand would provide a comparison with the low quality forest affected by leafminer near Manjimup. Emphasis would be placed on collecting and studying leaves and insects in the canopy.

There is supportive evidence that phytophagous insects regulate forest primary production (Mattson and Addy, 1975). "Normal" (usual) insect grazing may impair or accelerate growth, but "outbreak" (unusual increase in numbers) species by defoliating trees add nutrients to the soil-litter system. An average of 20% of the photosynthetic area of one-year-old jarrah leaves is consumed by insects (Springett, 1978).

Much recent attention has been given to insect grazing of tree crowns in the eastern states. A survey of 44 eucalypt species showed that an average of 15% of the expanded leaf area was grazed by insects (Fox and Morrow, 1983). However, another study found that consumption of the annual leaf production by insects did not exceed 3% (Ohmart *et al.*, 1983). In rain forest, maximum insect abundance coincides with leaf flushing in the canopy (Lowman, 1982a). Experimental studies indicate that 25% removal of whole leaves or of leaf tissue stimulates seedling growth rates, whereas 50% removal suppresses growth. Recovery is thus more likely from partial removal of leaves than from their complete removal (Lowman, 1982b).

The levels of leaf N are important for the survival, the feeding and the growth of insects. Morrow and Fox (1980) suggested that small differences in the N content of leaves may have great effect on herbivore performance. Production of N-rich epicormic foliage enhances build-up of insect populations (Landsberg and Wylie, 1983). Repeated defoliation exhausts the carbohydrate reserves of the tree, resulting in further crown deterioration and eventually death.

Studies by Pryor (1952) indicate that resistance to leaf-eating beetles has a genetic basis.

3. Borer damage to regenerating karri stands.

The arrangement and extent of cerambycid galleries should be quantified. Does external evidence of borers relate consistently to their internal workings? If so, such external signs could be the basis of rapid surveys of the incidence of borers in relation to DOB, position of the tree in relation to forest canopy, logging history, fire history, and site.

High Priority

4. Checklist and distribution maps of insect species in W.A. forests.

This should be an ongoing project related to maintaining a reference collection of both preserved and pinned specimens. Every specimen should have the locality and the identity of the host tree recorded. Duplicates of specimens are to be lodged with the Australian National Insect Collection, so that ultimately they will be formally described by taxonomic experts.

At first, preference will be given to compiling a check list of insects present in monocultures (pines, even-aged karri regeneration) and noting qualitatively the extent of insect damage. In New Zealand, a checklist of insects recorded damaging eucalypt plantations has been published (Zondag, 1979). Various simple methods would be used to collect insects. However, Malaise traps, extensively used by Curry (1974, 1976), would not be used, as the source of the insects trapped is never precisely known.

In Britain the number of insects species associated with a tree species reflects the range of distribution of that tree species (Strong, 1974). In Western Australia, expanding plantations of introduced pines should therefore accumulate insect species. Sixty-five indigenous insect species have been recorded feeding on pines in New South Wales (Campbell *et al.*, 1962). Such insects will inevitably reduce forest productivity.

Low Priority

These are areas not being researched currently.

5. Ecology of pinhole borer

Is pinhole borer a serious problem? What is its incidence in northern jarrah forests stands? Does the number of pinholes on the bark give an accurate indication of the extent of damage to the wood?

6. Ecology of Ips grandicollis

Which stand conditions predispose pines in Western Australia to attack by *Ips?*

7. Effect of insects on forest regeneration

Does insect grazing of leaves seriously reduce the establishment of seedlings? Ants remove many jarrah seeds from the jarrah forest floor; and insects, particularly grasshoppers, diminish the survival of seedlings of many plant species in banksia woodland adjacent to forest (Whelan and Main, 1979).

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APPENDIX

PRELIMINARY CHECKLIST OF INSECT SPECIES WHICH ARE POTENTIAL OR ACTUAL PESTS OF TREES IN WESTERN AUSTRALIA.

Abbreviations:

HOST SPECIES

J. *Eucalyptus marginata*
K. *E. diversicolor*
M. *E. calophylla*
R. *E. rudis*
Y. *E. patens*
W. *E. wandoo*
T. *E. gomphocephala*
B. *E. astringens*
A. *E. jacksonii*
F. *E. ficifolia*
C. *E. cladocalyx*
Q. *E. resinifera*
S. *E. microcorys*
U. *E. globulus*
V. *E. saligna*
Pr. *Pinus radiata*
Pp. *P. pinaster*
#. other species
?. no data or caught in light trap

PARTS OF HOST EATEN

l. leaf
s. shoot
r. root
c. cambium
w. wood
d. rotting wood, dead trees, logs.

The injurious stage of the life cycle is also given.

* introduced insect species
\+ introduced insect species but not established in W.A.

APPENDIX

Order & Family	Genus & Species (if known) & Location	Common name (if any)	Host species	Part(s) of host affected.
ISOPTERA				
	Coptotermes acinaciformis (localities given by Calaby and Gay, 1955)			w
	C. michaelseni (localities given by Calaby and Gay, 1955)			w
ORTHOPTERA				
Acrididae				
	Phaulacridium sp. coastal areas from about Dandaragan to Esperance (J. Moulden, pers. comm.)	Wingless grasshopper	#	l,s
HEMIPTERA				
Psyllidae				
	Creiis periculosa	Lerp	R	l
Adelgidae				
	* *Pineus pini*	Pine Woolly-aphid	Pp,Pr	l,s
COLEOPTERA				
Lymexylidae				
	Atractocerus kreuslerae Mundaring, Jarrahdale, Dwellingup, Harvey, Dryandra, Collie, Ludlow, Manjimup, Perup, Pemberton, Yornup, Wheatley, Nannup, Magaret River	Pinhole borer	JKYWBT	c & w (larva)
	A. crassicornis Pemberton, Nannup, Walpole, Kalamunda, Helena Valley		JKY	c & w (larva)
Cerambycidae				
	Phoracantha recurva North Yanchep, Kojonup, Tammin	Bardi (larva)	TC	c & w (larva)
	P. semipunctata N. Yanchep, Rockingham, Jandakot, City Beach, Mosman Park, Julimar, Mundaring, Nollamara, Beraking, Ludlow, Dwellingup, Dryandra, Pemberton, Karridale	Bardi (larva)	JMTUQSV	c & w (larva)

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	P. impavida	Tuart borer	T	c & w (larva)
	Coptocercus sp. Yanchep, Glen Forrest, Mundaring, Dwellingup, Harvey, Ludlow, Manjimup, Pemberton.		JTK	w (larva)
	Bethelium spp. N. Yanchep, S. Perth, Claremont, Rockingham, Ludlow, Mundaring, Dwelingup, Wheatley, Dryandra		JKT#B	w
	Coleocoptus senio Mundaring, Rockingham, Ludlow		T	w (larva)
	Bardistus cibarius Yanchep, Mundaring		#	w (larva)
	Aphanasium sp. Yanchep		?	w (larva)
	Piesarthrius sp. Yanchep		?	w (larva)
	Uracanthus ? bivittata Yanchep, Applecross, S.Perth, Maylands		#	w (larva)
	U. triangularis Yanchep		#	w (larva)
	Toxeutes sp. Pemberton, Manjimup, Karridale, Walpole		KPr	w (larva)
	Sceleocantha pilosicollis Yanchep, Dwellingup, Ludlow, Pemberton		?	w (larva)
	Pachydissus boops Yanchep, Kings Park		#	w (larva)
	Cnemoplites sp. Yanchep, Ludlow, Lake Grace, Pingrup		?	w (larva)
	Tryphocaria acanthocera (syn. *hamata*)	Bullseye borer	KJMTYWAFQV	c,w (larva)

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	T. punctipennis Yanchep, Bullsbrook, Kalgoorlie, Ludlow		W	c,w (larva)
	T. solida bauxite pits (Jarrahdale, Del Park)		SQV	c,w (larva)
	Dioclides prionoides Yanchep, Ludlow		T	w (larva)
	Scolecobrotus westwoodi Ludlow		?	w (larva)
	S. sp. Yanchep		?	w (larva)
	Ancita sp. South Perth, Greenmount, Dryandra Narrogin, Dwellingup, Manjimup		*Acacia* spp., *Albizia*	w (larva)
	Syllitus grammicus Yanchep, Beraking, Manjimup		*Acacia* spp.,	w (larva)
	Stenoderus suturalis Rockingham, Ludlow, Margaret River, Boranup		T Pr #	w (larva)
	Adrium artifex North Yanchep, Yanchep, Mundaring, Dwellingup, Kirup		JMTW	w (larva)
	Mycerinopsis sp. Yanchep		?	w (larva)
	Platyomopsis sp. Dryandra		*Acacia*	w (larva)
	Velora sp. Yanchep		?	w (larva)
	Pitheus latebrosus Kings Park		#	w (larva)
	Eroschema ceresioides Perth Airport		?	w (larva)
	Obarina ceresioides Kings Park, South Perth		?	w (larva)

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	+Hylotrupes bajulus Swanbourne	European House Borer		w
Buprestidae				
	Anilaria sp. North Yanchep, Nedlands, Rockingham, Pinjarra, Harvey, Ludlow, Mundaring, Julimar, Bindoon, Beraking, Jarrahdale, Dwellingup, Wurnaming, Yornup		JMT#S	w (larva)
	Melobasis andersoni Rockingham		T	w (larva)
	Buprestis novemmaculata Collier, Como		Pr	w (larva)
	Stigmodera conspiculata High Wycombe		?	w (larva)
	S. cancellata Busselton, Denmark		#	w (larva)
	Diadoxus erythrurus North Yanchep, Claremont, Perth, Lesmurdie, Dryandra, Corrigin, Manjimup		#	w (larva)
Scarabaeidae				
	Liparetrus similis N. Yanchep, Pinjarra	Spring Beetle	Pp,Pr	l (adults)
	L. sp. Albany, Gnangara, Brookton		Pr,#	l (adults)
	Heteronyx sp. Yanchep, Ludlow, Narrogin, Brookton, Pemberton, Boranup		TPp W#	l (adults)
	Heteronychus atrator Bunbury, Walpole		K	l (adults)
Scolytidae				
	**Ips grandicollis* Carnarvon, and widespread from Yanchep to Albany (Fig. 7)	American Bark Beetle	Pr,Pp#	c

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	**Hylastes ater* (Range mapped in Fig. 7)		Pr	c
	Hylurgus ligniperda (Range mapped in Fig. 7)		Pr, Pp	c
	Xyleborus saxeseni Widespread from Yanchep to Albany (Fig. 8)	Ambrosia Beetle	#Pr, Pp	w
	X. banksiae Widespread from Yanchep to Albany (Fig. 8)	Ambrosia Beetle		w
Curculionidae	*Otiorrhynchus cribricollis* Dwellingup, Bridgetown		Pr	l (adults)
	Laemosaccus sp. North Yanchep, Kings Park, Rockingham		T	l (adults)
	Strongylorhinus ochraceus Perth, Bentley, Welshpool, Kewdale, Ludlow	Gregarious gall-weevil	KTR#	s,w (larvae)
	Catasarcus sp. Yanchep, Kings Park, Bassendean, Welshpool, Mundaring, Kirup, Manjimup, Northcliffe, Shannon River, Walpole, Denmark		JMK Pr Q#	l (adults)
	Haplonyx tibialis Yanchep, Wanneroo, Kings-Park, Ludlow	Tuart bud weevil	T	shoot (adults)
	Polyphrades sp. Ludlow, Margaret River, Shannon River, Boranup, Manjimup, Pemberton, Denmark		TK	l (adults)
	Chaetectorus bifasciatus Yanchep, North Yanchep, Rockingham, Ludlow		T	l (adults)
	Oxyops sp. North Yanchep, Manjimup		JT	l (adults)

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	Rhadinosomus lacordairei Boranup, Pemberton		K	l (adults)
	Tranes sp. Dwellingup		J	l (adults)
Lagriidae				
	Lagria aneoviolacea Jarradale, Northcliffe		W	w
Trogositidae				
	Leperina lacera N. Yanchep, Collier, Rockingham, Ludlow, Julimar, Mundaring.		JT Pr M	w
Lyctidae				
	**Lyctus brunneus* Perth, Denmark	Powder post beetle	#	w
	L. sp Kings Park, Yanchep, Harvey, Bunbury.		MWT	w
Bostrychidae				
	Bostrychopsis jesuita Yanchep, Como, Morley, Maylands, Mundaring, Helena Valley, Boddington, Williams, Bunbury, Ludlow.	Jesuit beetle	Pp, # JM	w
	Xylopsocus rubidus Harvey, Bunbury, Margaret River, Mt. Barker.		MW	w
Chrysomelidae				
	Chrysophtharta amoena Bull Creek, Wanneroo, Rockingham, Ludlow, Gibson, Jarrahdale, East Brookton, Collie, Broome Hill, Donnybrook, Manjimup, Pemberton, Boranup, Walpole, Denmark.		TK	l (larva)
	C.minerva East Brookton		?	l (larva)

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	C. ?lacsa Shannon		?	1 (larva)
	Trachymela infuscata East Brookton		?	1 (larva)
	Paropsis advena East Brookton, Pemberton, Boranup		K	1 (larva)
	P. regularis North Yanchep, Ludlow.		T	1 (larva)
	P. elytrura Pemberton, Walpole, Denmark		K	1 (larva)
	P. elliptica Pemberton, Walpole, Boranup		?	1
LEPIDOPTERA				
Nolidae	*Uraba lugens*	Gumleaf skeletonizer	JMRYK	1 (larva)
Incurvariidae	*Perthida glyphopa* (Range mapped in Fig. 1)	Jarrah leafminer	J	1 (larva)
	P. sp. (Range mapped in Fig. 4)		R	1 (larva)
Cossidae	*Xyleutes* sp.	Wood moth	K	w (larva)
Noctuidae	*Heliothis punctigera*	Native bud worm	Pr	1 (larva)
Lymantriidae	*Orgyia athlophora*	Tussock Moth	#	1 (larva)
Notodontidae	*Ochrogaster contraria*	Processionary (or bag-shelter) caterpillar	#	1 (larva)

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HYMENOPTERA				
Pergidae				
	**Phylacteophaga froggatti* Introduced in nursery stock 1978, now found throughout the Southwest, including Esperance, Narrogin, Katanning, Albany, Augusta and Yanchep. Also found in Kalgoorlie. A pest of trees in gardens and parks but not trees in the forest (Curry, pers. comm.)	Leaf blister sawfly	R#	l
Siricidae				
	+* *Sirex noctilio*	Sirex wood wasp	Pr	w (larva, adults)