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Department of Conservation and Land Management

Science and Information Division

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Sustainable Resources Group

Tree Crops Section

Entomology Report

The Autumn Gum Moth *Mnesampela privata*: A summary of observations from Western Australia and a possible method of risk assessment.

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Contents

1. Summary

The autumn gum moth *Mnesampela privata* (Guenée) is a potentially serious pest of *Eucalyptus globulus* in southwest Western Australia. Factors contributing to the risk of damage by AGM to *E. globulus* plantations are identified and discussed.

The most important elements of risk are:

1. Composition of nearby remnant vegetation or plantations, which determines the likelihood of the vegetation carrying a population of *M. privata*.

2. The area of *E. globulus* plantation in close proximity to remnant vegetation carrying a *M. privata* population. Areas less than 30 metres from remnant vegetation are most at risk.

3. An early break to the season or summer irrigation may expose plantations to larvae for a longer period.

4. The age of the plantation. Plantations are most at risk during their second autumn and winter.

A possible model of risk factors and their importance is presented, allowing prediction of risk and allocation of priorities for inspection and monitoring of hazardous populations of AGM.

2. Introduction

As the area of the *E. globulus* estate increases in Western Australia, the inherent need for adequate monitoring for pest populations (vertebrate or invertebrate) and the necessary responses required will demand a rational application of available human resources.

Potential pest species are often prevalent in forests and plantations in Western Australia and there is literature readily available to allow non-experts to identify insect pests present on trees (Howes 1990, Chalmers 1993). Responses to pest populations usually involve an assessment of the hazard posed to a plantation by the pest or pests present. Such judgements are often subjective but require knowledge of the ecology of the pest species and experience of the behaviour of pests in plantation situations.

The autumn gum moth *Mnesampela privata* (Guenée) is a potential pest of *E. globulus* in southern Australia. The following notes are a summary of observations and information from literature relevant to diminish autumn gum moth (AGM) as a pest of *E. globulus* in Western Australian plantations. They are intended, in part, to replace and augment the account in the CALM Insect Manual (Fremlin and Penfold 1990).

3. Life cycle and Biology

McQuillan (1985) has recently revised the autumn gum moth genus *Mnesampela* and formally redescribed *M. privata*. Two species are known from Western Australia, *M.*

arida and *M. privata*. Little is known about host plants and abundance of *M. arida* larvae in WA but it is probable that there is some overlap of species ranges on the eastern margins of the distribution of *M. privata*.

The life cycle of *M. privata*, like any lepidopteran, proceeds through adult, egg, larval and pupal stages:

ADULTS: In Tasmania adult moths emerge from January to June (Elliott and Bashford 1978). It is possible that soil wetting is detected by the aestivating pupae, triggering adult emergence. In WA, egg batches appearing after heavy rains in summer and autumn are usually the best sign of active moths. The moths are nocturnal fliers and are usually only encountered as recoveries from light traps.

EGGS: Eggs are found in summer only after very heavy rains but are common on suitable hosts after the break of annual drought in autumn. Characteristic egg batches (Fig. 1) tend to be deposited on the lower branches and understorey saplings of suitable host trees. According to McQuillan (1985) the eggs are ovoid, slightly flattened dorsoventrally, 0.75-0.85 x 0.55 x 0.44 mm, pale yellow when first laid, becoming mottled with reddish brown before hatching. Elliott and Bashford (1978) recorded batches up to 300 on upper or lower surfaces of leaves with a mean of 75 ± 11 per batch from a sample of 54 batches. A batch of average size would be about as large as a thumbnail. Egg batches need humid conditions to hatch, but can survive at least a month of unsuitable conditions awaiting rain (McQuillan 1985). Egg batches laid after heavy summer rain would be especially susceptible to desiccation without follow up rains.

LARVAE: Eggs hatch within 2 to 4 weeks, time to hatching depending on adequate moisture (McQuillan 1985). Newly hatched larvae are 2-3 mm long (Fig. 2), with a light yellow body, darkening to yellowish green. The head capsule is light brown of modal width 0.3 mm. Larvae feed gregariously near the egg mass, initially removing only epidermis and mesophyll tissue, leaving only a skeleton of vascular tissue. Newly hatched larvae are susceptible to desiccation, being unable to construct leaf shelters. Indeed, hatched eggs with failed larvae were found in the Kalamunda area after heavy February rains in 1992 and on isolated marri trees exposed to strong sunlight in autumn 1993.

Third instar larvae develop the ability to completely remove all mesophyll tissue. They feed at night and retire during daylight to shelters of leaves bound together with silk (Fig. 3). These shelters are usually formed from the terminal leaves on branches. Later instars disperse through favoured foliage and are capable of removing all but the midvein of leaves. Small trees and saplings may quickly become defoliated, leaving only the terminal larval shelters, if sufficient numbers of later instars are active.

Larvae grow through 5 instars lasting about 4 months from autumn to early spring in WA. Instar development is most readily determined by head capsule widths. Frequency distributions of head capsule widths from WA (Fig. 4) are similar to those measured by Elliott and Bashford (1978) from Hobart.

Fig. 1. Hatched *M. privata* egg clutch on marri leaf. The eggs have been laid on the upper surface of the leaf as is usual and feeding by the 1st instar larvae has commenced. Approximate scale 1:1.

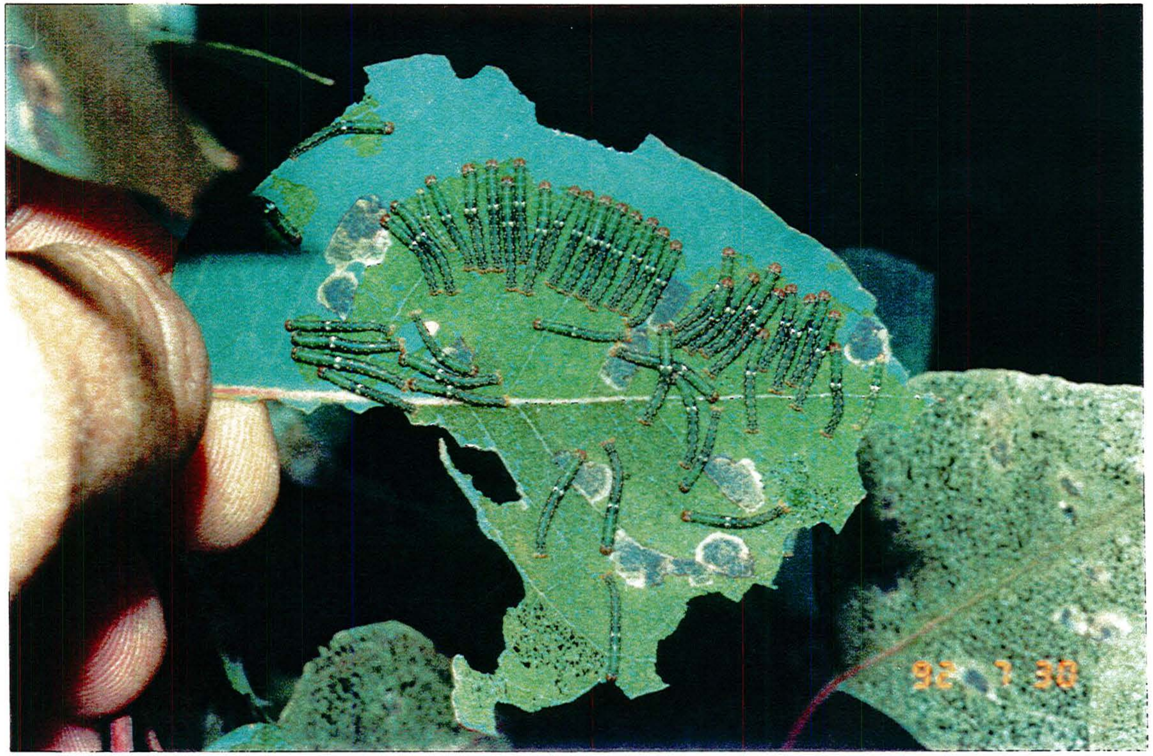

Fig. 2. *M. privata* 3rd instar larvae feeding on a flooded gum leaf. Larvae continue to be gregarious feeders and remove only the surface tissue of leaves until the end of the 3rd instar. Scale approximately 1:0.75.

Fig. 3. Severe defoliation of a marri branch by 4th and 5th instar larvae. Only the midveins of leaves remain and the partially chewed leaf on the left of the photograph is rolled into a shelter and bound with silk. Scale approximately 1:2.

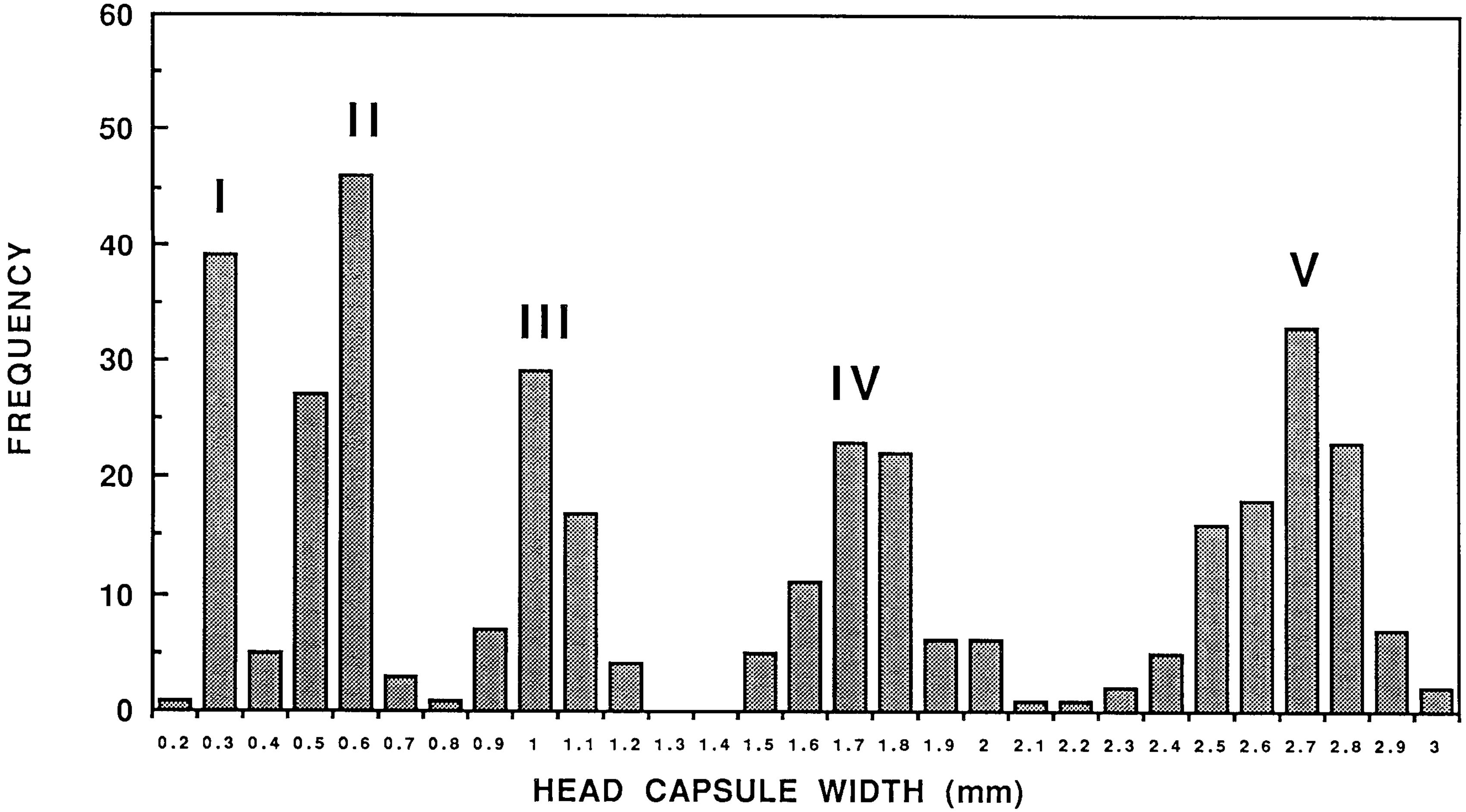

Fig. 4. Frequency distribution of M. privata larval head capsule widths sampled in Kalamunda Shire, July 1991 to May 1992. Roman script is above modal widths for each instar.

PUPAE: Larvae mature in spring and have left the host plant by late November. Larvae burrow several centimetres into the soil at the base of the host plant and pupate in a silken cocoon. The pupal stage lasts about 6-8 months in WA. Elliott and Bashford (1978) found the mean duration of the pupal stage in Tasmania to be 187.7 ± 8.9 days. Data are scarce for WA but a specimen collected from Gooseberry Hill emerged after a pupal duration of 217 days.

4. Factors affecting AGM populations

4.1. Host range and preferred hosts

M. privata has been collected in all Australian States except the Northern Territory, and from a wide range of *Eucalyptus* species and *Lophostemon sp.* (Table 1). The host range includes *E. globulus* and *E. camaldulensis*, species commonly grown in plantations in WA. *E. marginata*, *E. calophylla*, *E. wandoo* and *E. rudis*, ubiquitous components of the forested area of southwest WA (Churchill 1961, Brooker and Kleinig 1990), are noted as hosts (Table 2).

To some extent the host list reflects the tendency of AGM to attack nearby less favoured hosts when AGM is very abundant (Farrow et al. 1994). Conversely, favoured hosts in plantations are extremely attractive to egg laying females compared to nearby native vegetation where their populations originate. The high frequency of AGM collections from *E. globulus* (Table 2) in WA and our observations of high frequencies of infested plants compared to adjacent native forest is consistent with an

Table 1. Host species on which *M. privata* larvae have been noted.

Host Species		Reference or location
Eucalyptus	*amygdalina*	Elliott and Bashford (1978)
	bicostata	McQuillan (1984)
	calophylla	Location: Kalamunda, Waroona.
	camaldulensis	McQuillan (1984)
	cinerea	McQuillan (1984)
	cladocalyx	Location: Harvey.
	cordata	Elliott and Bashford (1978)
	crenulata	Elliott and Bashford (1978)
	globulus	Elliott and Bashford (1978)
	grandis	Moore (1972)
	gunnii	McQuillan (1984)
	leucoxylon	McFarland (1979)
	loxophleba	Location: West Dale.
	maculosa	McQuillan (1984)
	maideni	Elliott and Bashford (1978)
	marginata	Location: Kalamunda, Collie.
	nitens	Elliott and Bashford (1978)
	nitida	McQuillan (1984)
	obliqua	Elliott and Bashford (1978)
	odorata	McFarland (1979)
	patens	Location: Kalamunda
	perriniana	McQuillan (1984)
	pilularis	Moore (1972)
	risdoni	Elliott and Bashford (1978)
	rudis	Location: Kalamunda, Waterford.
	saligna	Moore (1961). Location: Jarrahdale.
	stellulata	McQuillan (1984)
	tenuiramis	Elliott and Bashford (1978)
	urnigera	McQuillan (1984)
	viminalis	Elliott and Bashford (1978)
	wandoo	Location: Kalamunda.
Lophostemon	*sp.*	Location: Midland, Perth.

Table 2. Locations and hosts of *M. privata* collected in Western Australia.

Abbreviations: DAWA: Department of Agriculture Western Australian, collection.
CALM: Department of Conservation and Land Management, field notes and collection.
WAM: Western Australian Museum, collection.
McQ: Specimens examined by McQuillan (1985).

	Location	Host	Collection
Larvae	Busselton	*E. globulus*	DAWA
	Northam		DAWA
	Harvey	*E. cladocalyx*	DAWA
	Albany		DAWA
	Gosnells		DAWA
	Eneabba		DAWA
	Darlington		DAWA
	Katanning		DAWA
	Yeticup	*E. marginata*	CALM: IA, TEB, PVH
	Mooralup	*E. marginata*	CALM: IA, TEB, PVH
	Cardac	*E. marginata*	CALM: IA, TB, PVH
	Dingup	*E. marginata*	CALM: IA, TB, PVH
	7 km N. of Waroona	*E. calophylla*	CALM: PVH
	Logue Rd 500m E. of SW HWY.	*E. calophylla*	CALM: PVH
	Keysbrook	*E. globulus*	CALM: PVH, TEB
	Kalamunda NP	*E. rudis, E. calophylla, E. patens*	CALM: PVH, TEB
	Mt Barker	*E. globulus*	CALM
	Kalamunda	*E. rudis, E. calophylla, E. patens, E. marginata*	CALM: PVH, TEB, AJW
	Mt Barker	*E. globulus*	CALM: Farrow
	Collie	*E. marginata*	CALM: AJW, TEB
	West Dale	*E. loxophleba*	CALM: AJW, TEB
	Mt Barker	*E. globulus*	CALM: AJW, TEB
Moths collected as larvae	Midland	*Lophostemon sp.*	DAWA: Koch
	Gooseberry Hill		WAM: Car
	Brookton Highway	*E. bicostata*	CALM: SJC
	Jarrahdale	*E. saligna*	CALM: SJC
	Jarrahdale	*E. globulus*	CALM: SJC
	Cunderdin	*E. globulus*	DAWA: Henty
Moths	Northam		WAM
	Toodyay		DAWA: Shedley
	Dumbleyung		WAM: Udell
	Deepdene		DAWA: O'Halloran
	Dumbleyung		WAM: Udell
	Dumbleyung		WAM: Udell
	Beverley		McQ
	Bridgetown		McQ
	Hamel		McQ
	Kojonup		McQ
	Nannup		McQ
	Ravenswood		McQ
	19 mls W. of Watheroo		McQ

hypothesis that juvenile foliage of this species is favoured over local species by egg laying female moths.

4.2. Climate

Climate appears to be an important determinant of the geographic range of AGM, with most adult specimens having been collected from areas with average annual rainfall greater than 500 mm (McQuillan 1985, Fig. 60.). Climate is likely to affect AGM performance in two ways: Climatic events control the life cycle of AGM, rainfall triggering adult emergence or drought preventing egg hatch, for example. Climate also determines the distribution range and abundance of the most suitable hosts, either remnant native vegetation or planted *E. globulus*.

The BIOCLIM (CSIRO 1986) computer program was used to derive a predictive match between climate parameters of AGM collection points and modelled climates of locations in southwest Western Australia. Location data from AGM adults collected in southern Australia(ie excluding northern NSW and southern Queensland) were derived from McQuillan's (1985) specimen list of adults, and Western Australian collection locations of adults and larvae (Abbott ,Van Heurck, Burbidge and Wills unpublished data). Altitudes of collection locations were estimated from maps in the 1:100,000 NATMAP series and 1:50,000 CALMAP series.

AGM has been collected from a wide mean annual rainfall range and the modelled lower limit is about 400 mm while the upper limit is in excess of 1400 mm (Fig. 5).

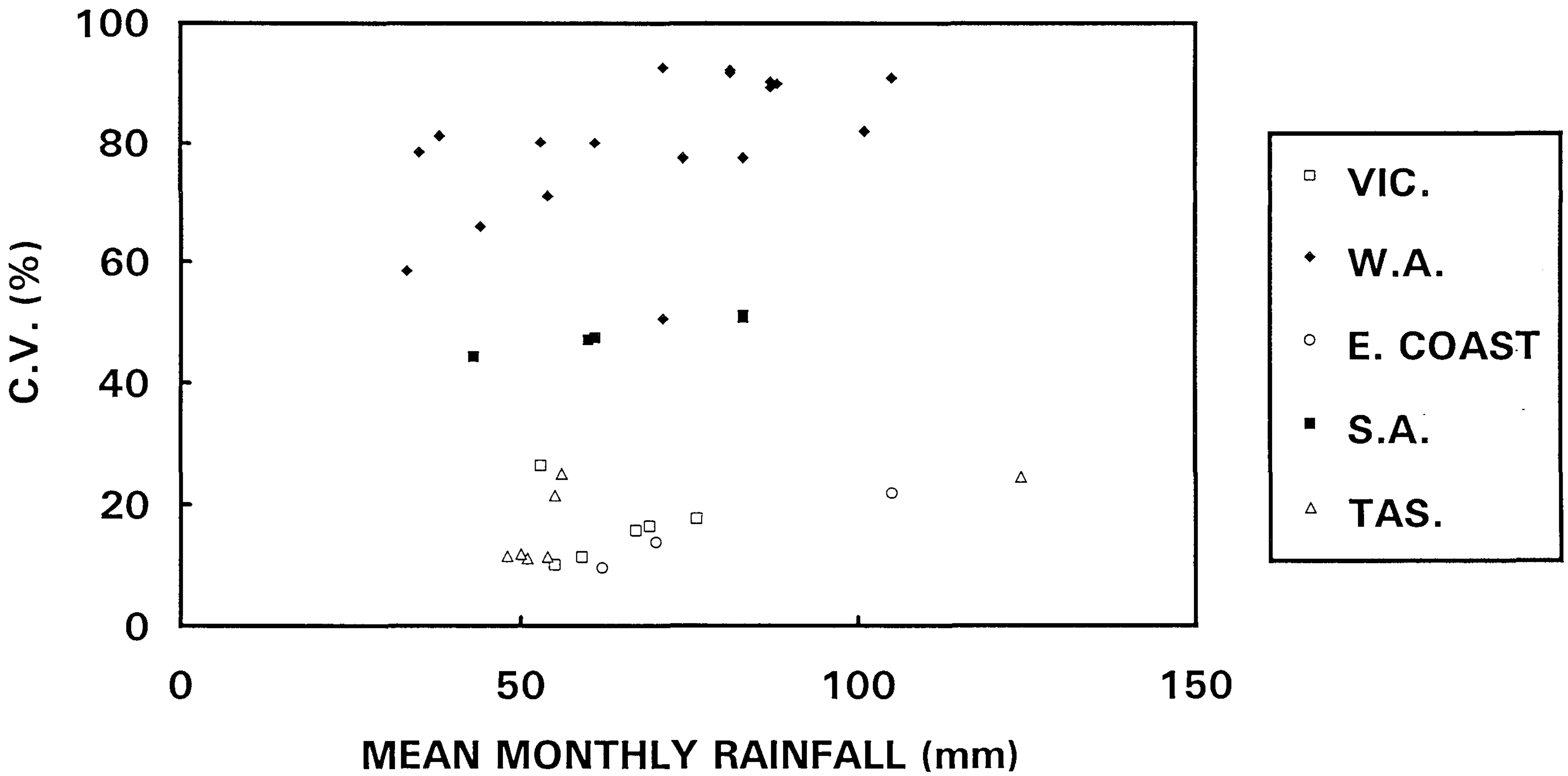

Fig. 5. BIOCLIM estimates of coefficient of variation versus mean monthly rainfall for M. privata collection sites (excluding Queensland and northern New South Wales).

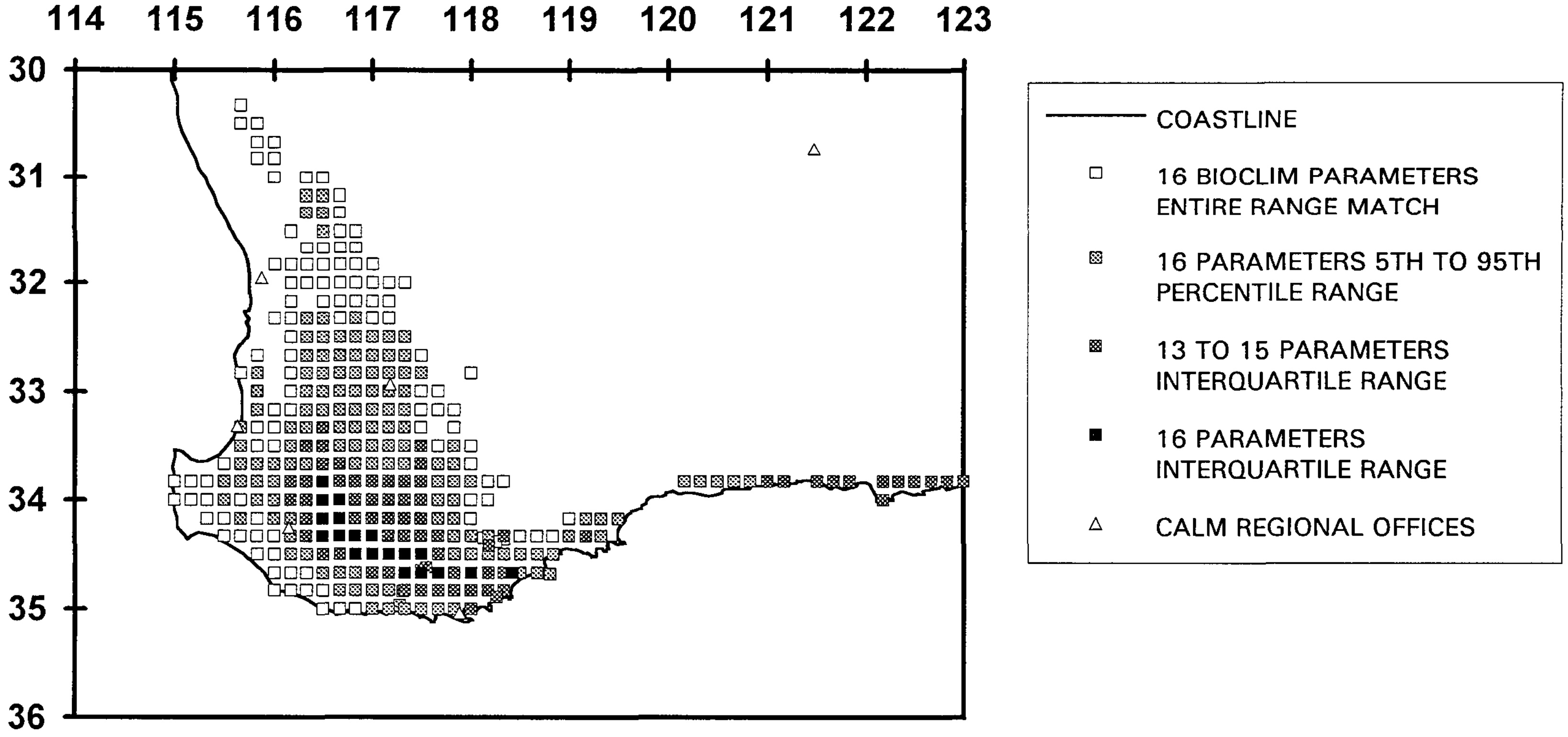

Fig. 6. BIOCLIM modelled climates in southwest WA matching modelled climates for M. privata collection points in southern Australia.

This encompasses most areas in which CALM is involved in eucalypt management. The most notable feature of the modelled climate match is that the areas in southern WA matching modelled conditions of the overall range of AGM (Fig. 6) are regions specifically identified as potentially suitable for Bluegums. This should not be surprising since the south eastern Australian distribution of AGM is coincident with the distribution of native *E. globulus* forest.

The thin south coastal strip extending east of Esperance was also identified as a match. This probably hinges on the bias towards WA collection points in the set of representative locations. *M. privata* is not known from this region, although it is likely to contain native eucalypts suitable as hosts, and trial plantations of *E. globulus* have certainly been established there. The closely related *M. arida* has been collected from Scaddan and Norseman (McQuillan, 1985) and unidentified *Mnesampela* larvae have been noted damaging planted eucalypts near Jerramungup (Abbott, pers comm).

An important feature of the region of match is that it closely corresponds to the range of *E. calophylla* (Churchill, 1961), a host for AGM larvae in WA. That is, most of the region identified as potentially suitable for AGM on the basis of climate is indeed capable of sustaining AGM because suitable hosts for AGM are available, at least at a regional scale, from native vegetation or plantations.

Several features of the modelled climates for AGM collection sites affect the life cycle of AGM in WA. High coefficients of variation in mean monthly rainfall compared to south eastern Australia indicate a greater seasonality of rainfall in WA (Fig. 5). This seasonality is probably the most important constraint on AGM populations. Adults are active between April and June in WA compared to a period of activity between January and June for Tasmania (Table 3). The consequence of the short period of adult activity is that the leaf chewing larvae are usually only present between May and November in WA (Fig. 7).

Table 3. Counts of locations, ordered by collection month and state, where *M. privata* moths have been collected, based on specimens examined by McQuillan (1985) and materiel held at WADA. Note: Includes specimens collected as larvae.

	JAN	FEB	MAR	APR	MAY	JUN	JUL
QLD			1	1	1		
NSW	1	2	11	9	4	1	
VIC		1	2	4			
TAS	1	5	7	7	2	1	
SA			2	7	9	1	
WA		1		6	6	2	2

Pupae are probably mature by February or March in WA but aestivate until suitable conditions. Unusually heavy summer rainfall could trigger early emergence of adults resulting in early presence of larvae. This was the case in Kalamunda in 1992 when February rainfall resulted in 4th instar larvae being detected in May (Fig. 7). Summer irrigation of soil containing AGM pupae has similar potential to extend the period of larval activity by allowing early emergence of adults.

4.3. Topography and vegetation

The climate surfaces for BIOCLIM have a low resolution, resulting partly from the regional scale of input data for the climate surfaces and partly from the crudely modelled effects of topographic relief. Resolution is particularly poor when considering

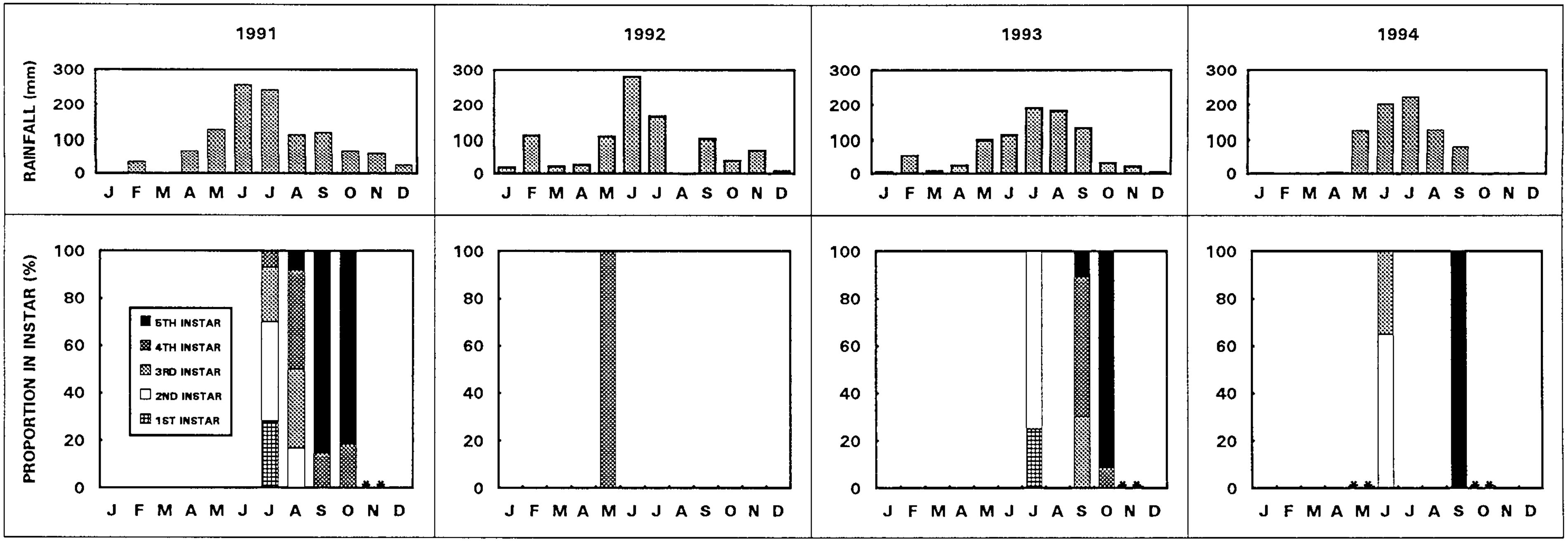

Fig. 7. Rainfall at Kalamunda Meteorological Station and M. privata larval instars collected from Kalamunda National Park. No larvae found (**).

the potential of vegetation and topography to influence microclimates at particular sites.

Remnant vegetation around Kalamunda townsite, at the northern end of the range of AGM, was used to investigate topographical and vegetation influences on AGM distribution. The townsite sits atop the Darling Scarp bounded to the west by the scarp and to the east by the deeply incised Piesse Gully, a tributary of the Helena River. Elevations in the area surveyed ranged from about +75 m AHD to +300 m AHD. Roadside vegetation in Kalamunda townsite was surveyed for signs of AGM activity during spring 1992 and 1994, and access tracks in Kalamunda National Park (KNP) and State Forest were surveyed in spring 1993.

Much of Piesse Gully has been cleared for orchards but significant stands of mixed jarrah (*E. marginata*) and marri (*E. calophylla*) remain on the valley sides. Marri predominates on the deeper soils on the valley sides (often Havel type R sites, Havel 1975) and occurs in mixed stands with jarrah on laterite ridgetops (mainly Havel types S and P sites). Before settlement and clearing, yarri (*E. patens*) and flooded gum (*E. rudis*) were probably common on the deep, rich soils of the valley floor but are now only common along the creekline within KNP while relicts occur in the valley as parkland (affinities with Havel type C sites). Soils in KNP tend to be shallower and the valley sides steeper than in the southern portion of Piesse Gully and *E. wandoo* tends to predominate in some stands along the valley sides along with scattered stands of marri.

Vegetation structure, reflecting soil conditions and topography, appeared to be an important influence on AGM distributions in the Kalamunda area. Abundance of AGM varied greatly between forest types, even when marri and other host trees were universally common. Clutches of AGM larvae were rare on jarrah or marri in closed jarrah and mixed jarrah/marri forest of the lateritized uplands. Single clutches of larvae and failed egg clutches were found on a few isolated marri in shrublands of the valley sides of KNP. Larval clutches were common in the riparian marri, flooded gum and yarri woodlands of the valley floor. Most damage appeared on lower branches and understorey saplings of marri along the valley sides and minor valleys. Stands of marri most affected such as those along the verges of Hummerston and Aldersyde Roads suffered significant defoliation in consecutive years (Fig. 8).

Other observations of AGM in native forest fit the general pattern observed at Kalamunda. On a series of 45 jarrah trees within a 40 km radius of Manjimup intensively sampled in 1986 to 15 m height, AGM larvae were recovered from just 6 trees (Abbott, unpublished data), all to the east of Manjimup within the area identified as the best climate match in the BIOCLIM analysis. AGM larvae were also been noted on a single jarrah ground coppice in about 20 hectares of closely inspected jarrah/marri forest on Bristol block near Collie in October 1994 (TEB, AJW field notes). Severe defoliation of marri was noted along Southwest Hwy between Serpentine and Waroona and in the vicinity of Wokalup during September 1990 (PVH, field notes).

It is noteworthy that the cases of severe defoliation of marri are along edges or in narrow strips of vegetation, in contrast to an absence of observed instances of severe

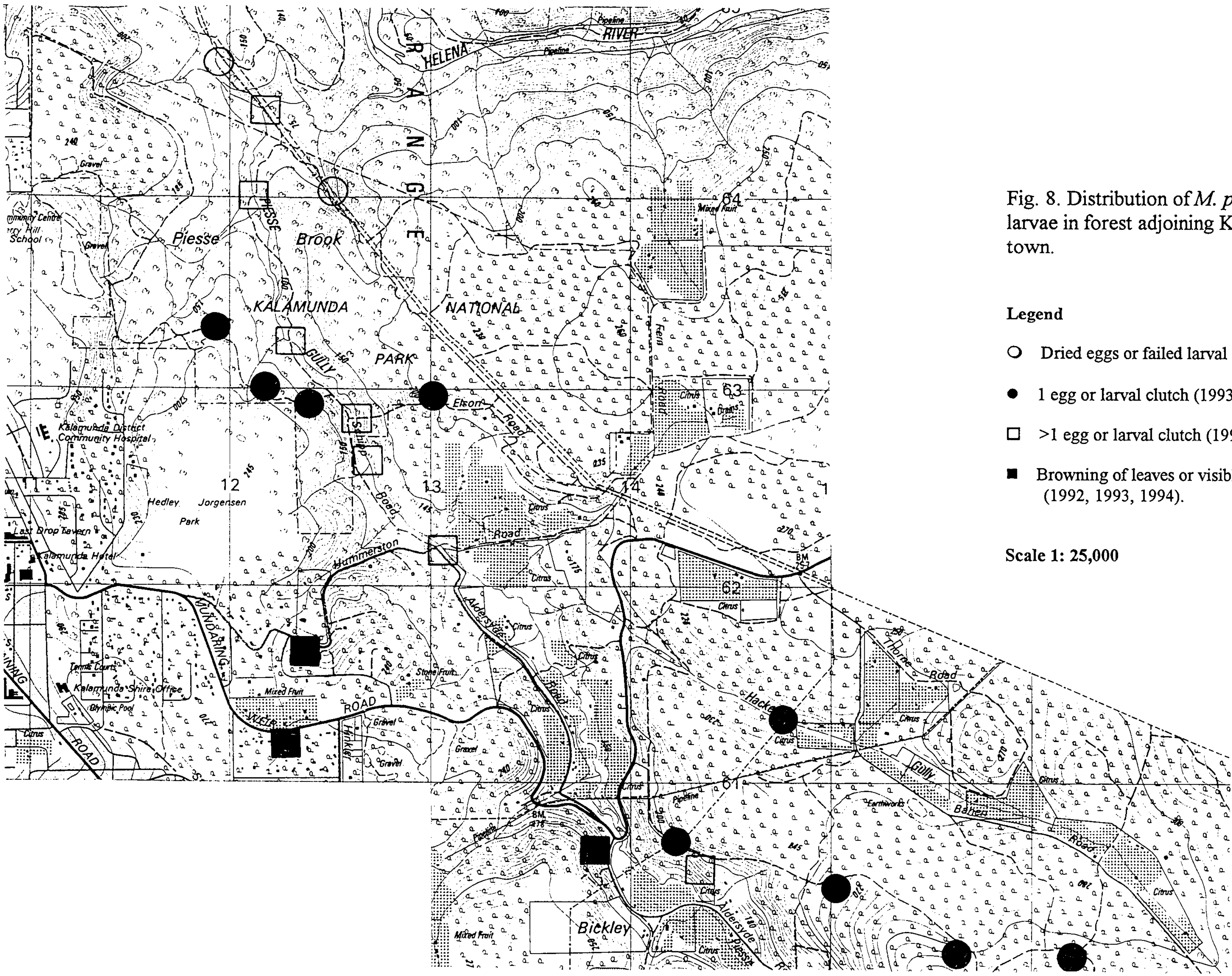

Fig. 8. Distribution of *M. privata* larvae in forest adjoining Kalamanda town.

Legend

- ○ Dried eggs or failed larval clutch (1993).
- ● 1 egg or larval clutch (1993).
- □ >1 egg or larval clutch (1993).
- ■ Browning of leaves or visible defoliation (1992, 1993, 1994).

Scale 1: 25,000

defoliation from closed forest. Edges may be more attractive as oviposition sites to female moths than closed canopies.

4.4. Antecedent AGM populations

Most farmland plantations of *E. globulus* have been installed with regard to remnant vegetation, topography and soil conditions. Watercourses and valleys have been targeted to reduce inputs of groundwater to creek systems. These landforms often support remnants of *E. rudis*, an important host for AGM larvae. Plantations are sometimes installed as buffers to remnant vegetation. Blocks of remnant vegetation on farmland, road verges, reserves or forest are likely to contain populations of *M. privata* if they contain suitable eucalypt hosts.

Infestation of *E. globulus* plantations from nearby remnant vegetation was observed in plantations on ex-farmland at Mt Barker (Location 1525), Darkan (Bluegums Farm) and south east of Boyup Brook (Wrestwood Farm). The P93 plantation near Boyup Brook was a square block of about 7 ha bounded on two sides by intact jarrah/marri/wandoo forest and on the other sides by remnant *E. rudis* in creeklines. In October 1994 all AGM infested trees were counted from 185 trees in 2 rows approximately along a diagonal across the plantation. Just over 10% of trees were infested. Few AGM were detected from the middle half of the transect while about 80% of trees nearest the forest at each end were infested. A plantation of P93 trees at Bluegums Farm was an elongated strip about 8 rows parallel to and adjoining remnant *E. rudis* along a creek line. A single row of 67 trees was inspected for AGM.

Approximately 28% of trees in the row were infested and infested trees were randomly located along the row.

These contrasting patterns of infestation indicate female moths usually only fly short distances before laying their eggs. Thus, the disposition of plantations relative to remnant vegetation is likely to affect the progress of AGM infestation. Plantations with a large perimeter : area ratio and perimeter close to remnant vegetation supporting a population of AGM are likely to suffer greater infestation.

Older plantations of *E. globulus* could also be a potential source of infestation for later plantations. A provenance trial at Mt Barker, infested from marri in an adjoining railway reserve, showed evidence of AGM damage at age 2 years and carried AGM larvae at age 3 years. Infested plantations probably continue to support AGM as long as juvenile foliage is present.

4.5. Mortality.

Mortality rates and causes of are unknown for WA populations of AGM. Elliott and Bashford (1978) reported parasitization of AGM eggs and larvae in Tasmania by several species of small wasps. Three of 20 egg batches examined by them or 2.57% of 1596 eggs were parasitized while all five batches, or 17.1% of 287 larvae examined, hosted parasites. Substantial populations of predators (mainly spiders) and unidentified hymenopteran and tachinid parasitoids have been collected by us from *E. globulus* by knockdown with pyrethrum insecticide from virtually the outset of plantation establishment. It is not known to what extent mortality rates diminish damage caused to *E. globulus* plantations and no data on variability between plantations are available.

5. Susceptibility of *E. globulus* to damage

5.1. Age and size of trees

Several processes complicate the relationship between larval populations and their potential for damage. Intuitively, larger plants would be expected to sustain relatively less damage than smaller plants with the same larval population. The nett effect of damage also depends on the rate of chewing relative to production of new foliage. Slower growing plants would be more seriously affected than faster growing plants, for the same insect load.

These processes are observable in *E. globulus* plantations. Seedlings usually escape AGM larvae during the first winter and spring because they are planted in June and July after emergence of adults and egg laying, or they may be unattractive to female moths. Plantations established in spring, summer or autumn under irrigation are at risk of AGM damage if there is a nearby source of infestation. We are aware of an instance at Dardanup where seedlings established late under irrigation were severely infested with AGM by the following autumn.

The period of greatest AGM hazard for normally growing plantations in WA is the second winter and spring when the saplings are between 2 and 4 metres high.

Complete defoliation of saplings in this size range is possible when enough larvae are present. Significant defoliation in the third year winter of growth is unlikely because plantation trees are normally too large and growth rates too rapid relative to the AGM population.

5.2. Variation in leaf qualities

Heritable resistance is known from many species of eucalyptus (eg Bennett et al. 1992) and there is evidence of considerable variation between provenance regions in resistance of *E. globulus* leaves to chewing by AGM. Assessment of *E. globulus* provenance trials in Victoria damaged by AGM indicated significant variation in damage between provenances (Farrow et al. 1994), presumably reflecting differences in leaf resistance to damage. The mechanisms of resistance are the subject of ongoing research, but adult foliage is rarely attacked and the authors hypothesized that early development of adult foliage could prevent development of damaging populations of AGM. The authors noted that selection for early development of adult foliage was an unsatisfactory solution to problems with AGM as provenances with early switching usually had poor form and inferior growth rates. We have measured insect damage in about 1500 trees across families with high growth rates at Mt Barker, including early and late switching families, and reached a similar conclusion from different reasoning.

Measurements of leaf damage at Mt Barker were stratified by family, position in the crown, age and morphology. Amount of damage and visible insects were also noted. Oldest leaves in the lower crown were most damaged whilst newest leaves in the upper

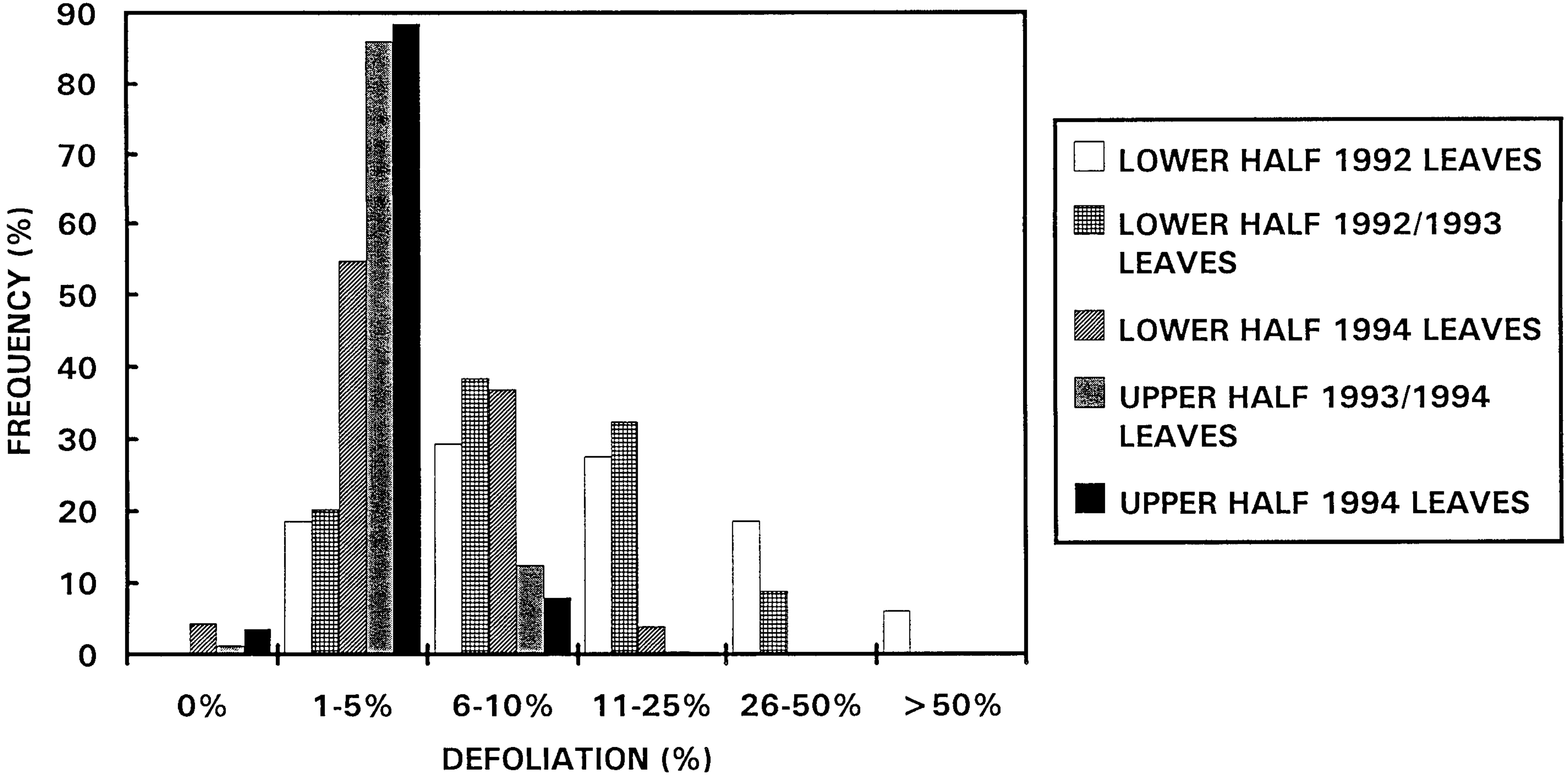

Fig. 9. Distribution of damage by leaf chewing insects within 3 year old crowns of E. globulus near Mt Barker, November 1994.

half of the crown were least damaged over all trees (Fig. 9). Greatest damage to the lower half of crowns could only be partially explained by accumulation of damage over time because leaves of the same age and morphology showed different frequency distributions, comparing upper and lower halves of the crown.

AGM damage tended to be mostly in the lower half of the crown and confined to juvenile and transitional foliage. Despite less damage in the upper half of the crown mirroring a general prevalence of adult foliage in the upper half of the crown, damage in the upper half of crowns was positively correlated with the proportion of adult foliage. Some families with early switching to adult foliage were particularly damaged by the weevil *Catasarcus impressipennis* (Boisduval), a species found across most of southwest WA (Thompson, 1968). Chrysomelid larvae were common and active only on expanding transitional and adult foliage.

Juvenile foliage of some families appeared lightly damaged by AGM, indicating that resistance to AGM is not coupled exclusively with leaf morphology. This observation is supported by the extensive host list for AGM larvae, representing damage to a variety of leaf morphologies.

6. Management to reduce AGM hazard

6.1. Model of risk factors

Information from published sources, collections, surveys and incidental observations recorded in field notes indicate several factors influence risk of damage to *E. globulus* plantations. Risk to plantations is considered here to be the probability of causing permanent retardation in growth to the plantation. It has been shown that a single 50% defoliation of *E. globulus* saplings can retard growth for more than six months and complete defoliation can permanently retard height and diameter growth (Abbott and Wills, in press). Risk of damage is controlled by two primary factors: a) the presence of larvae in the plantation, and b) the susceptibility of the plantation to damage. Other factors contributing to risk can be ordered into secondary and tertiary levels of a hierarchy.

The hierarchy of risk factors identified can be summarized as follows:

A) Factors contributing to larval populations within plantations.

AA) An antecedent population of AGM.

This is the population of mature pupae or adults in the vicinity of the plantation. This is not readily measured but previous amounts of larval activity would be a good indicator. On a long term basis populations of AGM appear to be controlled by:

AAA) Favourable climate.

As indicated by BIOCLIM analysis.

AAB) Composition and characteristics of a nearby host stand.

Riparian *E. rudis* and *E. calophylla*, edges of stands containing *E. calophylla* and plantations of *E. globulus* near remnant eucalypts are most likely to support populations of AGM. There is probably a confounding of climate and floristic effects as the distributions of *E. marginata* and *E. calophylla* reflect climate at a regional scale.

AB) Disposition of the plantation.

Defined by:

ABA) Perimeter : area ratio of the plantation.

Small and elongated plantations have larger perimeter to area ratios, ie have more edge relative to interior, than do large and compact plantations.

ABB) Proximity to an antecedent population.

Distances less than a few tens of metres present the most likelihood of movement from areas with antecedent populations. The antecedent population could be from within the plantation if AGM has already established there.

Plantations are not usually damaged in their first year of growth if they are planted after the ovipositing flight of female moths (Separated from an antecedent population by time).

AC) Sufficient rainfall

Timely rainfall or irrigation necessary and sufficient to allow emergence of moths and survival of eggs and larvae could occur from January onwards but is most likely during April, May or June.

AD) Mortality rate.

Amount of depredation due to activity of disease, predators and parasitoids. Little known generally and unknown for WA.

B) Susceptibility of the plantation to damage.

BA) Size and growth rate of trees in the plantation.

In normal conditions and growth rates, plants are most vulnerable to damage up to the end of the second spring. After this their size and growth rate renders AGM damage relatively inconsequential.

BB) Foliage traits.

Leaves with adult morphology are not usually damaged unless large populations of larvae move to feed on adult foliage after juvenile foliage is depleted. There is considerable inter-provenance variation in the onset of switching to adult foliage. Most WA plantations have stocks which switch late in the second year of growth, though there is much variation within plantations.

There is inter-provenance variation in susceptibility to damage by AGM. Bass Strait Island provenances have juvenile foliage which appears to be most resistant to damage but it is unknown whether the resistance is because they are less attractive to AGM females or more resistant to chewing. WA plantations are moderately diverse genotypically so there is likely to be a wide range of susceptibilities within plantations.

The effects of leaf nutritional qualities on AGM abundance and feeding are unknown.

The risk model presented here is untested and would be improved by rating the identified risk factors in young *E. globulus* plantations and measuring subsequent damage to provide feedback for determining of the relative importance of factors in the model. Consultation with others with expertise with AGM would also provide alternative importance values. Analyses of insect damage hazard developed overseas derive reliability from a pool of expert opinion using discussion, consensus and iterative analysis of factors to refine models (eg Reynolds and Holsten 1994).

6.2. Management tools

Just four basic tools are available for management of AGM: a) Awareness of how the planting date and circumstances of the plantation may expose newly planted seedlings and young trees to risk of damage; b) Inspection for AGM when risk of damage is indicated; c) Intervention with insecticide; and d) Selection for resistance to AGM damage.

6.3. What is the risk of damage?

The elements of risk of AGM damage and approximations of their relative importance are summarized in Table 4, based on the approach outlined by Reynolds and Holsten 1994. These approximations are best guess and should be regarded as indicative of relative risk rather than actual risk. The secondary elements, except for the elements with unknown importance, are considered equally important and each contribute up to 20% of risk. The elements with unknown variation are each assumed to contribute up to 10% of variation. The other elements of risk have a range of states with importance values. The risk of damage to a plantation can be estimated by identifying the state of risk elements and summing their importance values.

6.4. When to inspect for AGM activity?

Aggregate importance values larger than 0.40 would probably indicate a need to monitor for AGM activity. The time to monitor would depend on the break of season

Table 4. RECKONER FOR RISK OF DAMAGE TO TASMANIAN BLUEGUMS BY AUTUMN GUM MOTH.			
Elements of risk of damage to Bluegums.		**Character states.**	**Importance values.**
Target areas for plantation eucalypts are stratified by mean annual rainfall. Climate match using BIOCLIM covers the area where Tasmanian Bluegums are likely to survive in plantations.		1). Inside area of BIOCLIM match	NEED TO ESTIMATE DAMAGE RISK.
		2). Outside area of match.	LOW DAMAGE RISK
1° elements of risk.	**2° elements of risk.**	**Character states.**	**Importance values.**
A. Factors contributing to larval population in a plantation	**AA. Antecedent population of AGM likely in certain vegetation types.**	1). Eucalypt forest and woodlands containing *Eucalyptus rudis*, often in creeklines and moist situations.	0.20
		2). Eucalypt forest and woodlands containing *Eucalyptus calophylla*, usually on deeper soils.	0.15
		3). *E. calophylla* and *E. marginata* forest on lateritised uplands.	0.02
		4). Other eucalypts.	0.01
	AB. Proximity of the plantation to vegetation likely to contain antecedent AGM.	1). 0.2 X proportion of plantation within 30 metres of remnant vegetation containing eucalypts.	VALUE
	AC. Duration of sufficient rainfall. Indicated by month of break of season or start of irrigation.	1). January February or March.	0.20
		2). April	0.10
		3). May	0.06
		4). June	0.01
	AD. Effects of predators and parasitoids.		UNKNOWN
B. Susceptibility of the stand.	**BA. Size and growth rate of stand.**	1). Age 0-2 years, irrigated.	0.20
		2). Age 1-3, under size.	0.10
		3). Age 1-2.5, normal size.	0.10
		4). Age 2.5-3.5, normal size.	0.02
		5). Age < 1, winter establishment.	0.02
		6). Age > 3.5.	0.00
	BB. Leaf traits.		UNKNOWN

or start of irrigation. About 8-10 weeks after the break of season would be the optimal time to inspect for potentially damaging populations. Plantations containing more than 40% of trees infested should be monitored up to the end of their second spring after planting to confirm that significant damage does not develop. This monitoring is most important in the case of an early break of season or summer irrigation.

6.5. What population size needs chemical knockdown?

The relationship between population size and damage is unknown. An arbitrary threshold for use of chemical knockdown might initally be set relatively high at 50% or 60% of trees infested with AGM over the whole plantation in the second winter. Localised rates of infestation might be higher and we have noted localised infestation rates as high as 80% without noticeable damage in the longer term. Where trees may be attacked by more than one cohort of larvae in a year, usually after summer irrigation or during a succession of early breaks to the season, greater damage than in normal winters may result from any particular infestation rate.

6.6. Is selection for resistance to damage a possible strategy?

Resistance to attack by sap sucking and leaf chewing insects is a desirable property for trees grown for commercial purposes, as growth losses to insect herbivory and costs of insect control procedures can represent substantial imposts on plantation returns. Selection for resistance to insect damage in plantation species, in tandem with selection for productivity traits, has potential to increase productivity and diminish pest management costs (Floyd and Farrow 1994).

Methodologies of selection for insect resistance follow a general framework of screening trees across a range of genetic material which are subject to damaging insects. Initial screening may simply relate variation in damage to variation in genetic provenance. A higher order of screening would relate damage to leaf quality correlates which can be measured in the absence of leaf damage. These qualities can be measured and selected for without the time consuming and possibly erratic process of screening in the field using insect damage.

Farrow et al. (1994) found provenances from islands in the Bass Strait were more resistant than mainland provenances to leaf damage by AGM. These authors suggested use of provenances which switched early to production of adult foliage as possible way of avoiding damage by AGM. Observations of leaf damage to a provenance trial at Mt Barker indicated that selection for early switching to adult foliage, while probably diminishing susceptibility to AGM damage, would not necessarily protect from the activities of other damaging pests. Further, selection driven by a single pest species could lead to increased susceptibility to other pests. Analysis of damage revealed significant differences between some families from damage by a broad spectrum of chewing insects. Selection for resistance to chewing by AGM larvae, and leaf chewers generally, is possible and has potential to reduce insect load on bluegums.

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