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Insect pests of Tasmanian blue gum, *Eucalyptus globulus globulus*, in south-western Australia: History, current perspectives and future prospects

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Abstract Trends in, and potential causes of, insect pest problems of the Tasmanian blue gum, *Eucalyptus globulus globulus*, in south-western Australia are reviewed. Historical evidence suggests that insect pest problems of *E. g. globulus* in south-western Australia have greatly increased in the last 10 years, which corresponds to a time of rapid expansion of the blue gum industry in the region. Current major establishment pests include the African black beetle, *Heteronychus arator*, spring beetles, *Liparetrus* spp. and *Heteronyx* spp., and the wingless grasshopper, *Phaulacridium vittatum*. Current major pests of established trees are the *Eucalyptus* weevil, *Gonipterus scutellatus*, and chrysomelid beetles, *Chrysophtharta* spp. and *Cadmus excrementarius*. The occurrence of these insects on an introduced eucalypt is not unexpected because insect-rich native eucalypt forests dominate the landscape where *E. g. globulus* plantations are grown. Insect damage may also be exacerbated because *E. g. globulus* is grown as a monoculture.

Key words: agroforestry, *Cadmus excrementarius*, *Chrysophtharta*, exotic pest, *Gonipterus scutellatus*, *Heteronychus arator*, *Mnesampela privata*, monoculture, native pest, spring beetle.

INTRODUCTION

Tasmanian blue gum, *Eucalyptus globulus globulus*, is one of the most popular eucalypt plantation species because it has excellent pulpwood properties, grows rapidly, and can grow in a variety of soil types (Eldridge *et al.* 1993). This species is native to south-eastern Tasmania, the Bass Strait Islands and south-eastern Victoria, and is now grown widely throughout the world in climates with cool winters. Currently, more than two million ha of *E. g. globulus* plantations are established worldwide, with most (> 90%) grown outside its native range (Eldridge *et al.* 1993; Barbour 1997).

Within Australia, most *E. g. globulus* plantations occur outside the species' native range, so it could therefore be considered an exotic species. However, for the purposes of this paper, species that are indigenous to Australia but not to the local area are referred to as non-local species, whereas exotic species are those not native to Australia. In south-western Australia, *E. g. globulus* is grown as a non-local species under a Mediterranean type climate in the 600–1200-mm rainfall zone. In this region several endemic eucalypt species co-occur, including jarrah, *Eucalyptus marginata*, karri, *Eucalyptus diversicolor*, blackbutt, *Eucalyptus patens*, tuart, *Eucalyptus gomphocephala*, flooded gum, *Eucalyptus rudis*, wandoo, *Eucalyptus wandoo* and marri, *Corymbia calophylla* (Brooker & Kleinig 1990). In south-western Australia, *E. g. globulus* is grown almost exclusively on ex-pasture sites for pulp production, with rotations typically lasting 10 years and the potential for one to two coppice generations (Shea & Bartle 1988).

Trial plantings of *E. g. globulus* began in south-western Australia in the 1960s, but the first commercial plantation was not established until 1980 (Bailey & Duncanson 1998). By 1988, approximately 5000 ha of plantations were established, but in 2000 the estate had extended to more than 160 000 ha. The rapid rise of the *E. g. globulus* plantation industry in south-western Australia, especially in the last 5 years, has seen a corresponding increase in insect problems. Little is known of most pests, with the Western Australian Department of Conservation and Land Management Insect Manual (CALM 1990), Abbott (1993) and Abbott *et al.* (1999) providing the only published accounts of insect pests in south-western Australian plantations. The present paper reviews trends in the number and scale of insect problems of this rapidly

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expanding plantation system by exploring historical evidence, documenting current pest species, and highlighting probable future trends. Potential reasons for certain insect species being pests of this plantation system are also evaluated, with particular reference made to monocultures and host switching.

HISTORY OF INSECT PESTS

The history of insect pest problems of *E. g. globulus* in south-western Australia is not well known or documented. Prior to the first published accounts of insect pests of this system (CALM 1990; Abbott 1993; Abbott *et al.* 1999), the only mention of insect pests was made by Shea and Hewett (1990) who noted, without any supporting details, that insects had caused no significant damage or death to *E. g. globulus*.

By the early 1990s, perceptions of the entomological problems in *E. g. globulus* plantations had changed significantly. In response to increasing insect damage to both *Pinus radiata* and *E. g. globulus* plantations, the CALM Insect Manual (CALM 1990) was published to provide biological and ecological information on a range of pests as well as methods for management and control. Even so, in the early- to mid-1990s the general level of concern for insect pests was still quite low (R. B. Floyd, pers. obs.). In the 10 years since the CALM Insect Manual was published, the relative importance of specific insect pests has changed considerably. For example, the African black beetle, *Heteronychus arator*, and spring beetles, *Liparetrus* spp. and *Heteronyx* spp., which were considered to be economically important but not worth controlling chemically because of expense or logistics (CALM 1990), are now serious establishment pests. In addition, the autumn gum moth, *Mnesampela privata*, and chrysomelid beetles were not considered to cause significant damage (CALM 1990), but are now serious pests of established trees. Perhaps the most puzzling omission from the CALM Manual is the *Eucalyptus* weevil, *Gonipterus scutellatus*, as it is currently a serious pest of established trees. Abbott (1993) also omitted *Eucalyptus* weevil, and possible reasons for this omission will be discussed in a later section. Abbott listed 10 insect species that had been recorded causing, or were likely to cause, significant damage to plantations. He noted the wingless grasshopper, *Phaulacridium vittatum*, the African black beetle, the leafblister sawfly, *Phylacteophaga froggatti*, and spring beetles as the four most important pests at the time. Canopy fogging trials conducted by Abbott *et al.* (1999) identified several major chewing insects of *E. g. globulus* but they provided no information on which species were most abundant or which caused the most defoliation.

CURRENT INSECT PESTS

Major insect pests will now be considered individually in approximate order of importance under the subsections 'Establishment pests' and 'Pests of established trees'. Minor pest species will be considered collectively under 'Other pests'.

Establishment pests

*African black beetle (*Heteronychus arator*)*

One of the most serious establishment pests is the African black beetle, a scarab native to southern Africa, which was first recorded in Western Australia in 1938 (Matthiessen & Ridsdill-Smith 1991). This species is a grassland insect that generally occurs in low abundance, and without causing significant damage, in established pasture. However, it is a pest of almost any crop that replaces pasture, such as potatoes (Matthiessen & Learmonth 1995) and *E. g. globulus* (CALM 1990; Abbott 1993). Unlike most other pests that consume foliage, the adult beetle girdles stems of small seedlings just below ground level, which can lead to poor growth and form or even death (CALM 1990; Abbott 1993). As in potato cropping, low densities of beetles ($< 5\ m^{-2}$) can inflict severe damage (Matthiessen & Learmonth 1995). Damage can occur whenever adults are present, which is from late summer when the next generation of adults emerge until spring when most mating and oviposition occurs (CALM 1990; Matthiessen & Ridsdill-Smith 1991). Plantations most at risk are those planted in higher rainfall areas where beetles are more prevalent. Also, wet plantation sites with little or no inter-row vegetation have higher incidences of adults on raised row-mounds where trees are grown and are thus more damaged (J. N. Matthiessen & T. L. Simmul, unpubl. data).

Spring beetles (mainly Liparetrus jenkinsi *and* Heteronyx elongatus*)*

The name spring beetle covers several species, principally from two genera of scarab beetles, with *Liparetrus jenkinsi* and *Heteronyx elongatus* being the most common and damaging species (J. N. Matthiessen & T. L. Simmul, unpubl. data). Adults are active during spring, especially on warm, sunny days. Adults of most species are the only damaging life stage, as they often form large swarms and can quickly strip all the foliage from small trees, possibly causing tree death. Adults appear to prefer juvenile foliage, with new plantations most vulnerable to damage. Larvae of *H. elongatus* cause severe damage by feeding on *E. g. globulus* roots (Phillips 1993). Insecticidal control of adults is difficult because they are highly mobile and outbreaks are unpredictable (Abbott 1993).

*Wingless grasshopper (*Phaulacridium vittatum*)*

The wingless grasshopper is a serious pest of agriculture in southern and eastern Australia (Clark 1967). The species is univoltine, with eggs hatching in spring and nymphs developing into adults by summer. Young *E. g. globulus* plantations are vulnerable to grasshopper attack between spring and autumn, and severe defoliation can lead to tree death (Grimm 1987; CALM 1990). The species is potentially as damaging as the previous two establishment pests, but effective control is usually achieved through chemical baiting.

Other pests

Larval cutworms, *Agrotis* spp., are common pasture pests that cause similar damage to the African black beetle and also defoliate seedlings (CALM 1990; Abbott 1993). The Rutherglen bug, *Nysius vinitor*, is a pest of a number of agricultural crops, but can infest *E. g. globulus* plantations in late spring when pasture crops die off (CALM 1990; Abbott 1993). Adults suck sap from young shoots, leading to wilting and sometimes death of small trees. The native pasture day moth, *Apina callisto*, is another species that occasionally feeds on *E. g. globulus*.

Pests of established trees

*Eucalyptus weevil (*Gonipterus scutellatus*)*

Whether the *Eucalyptus* weevil is a recent arrival or has been present in south-western Australia for some time is not certain. All available published literature reports it from as far west in Australia as South Australia (Tooke 1955), and observations by people within forestry are conflicting, as the species is confused with weevils of the genus *Oxyops*. Given that the species has not been recorded from south-western Australia until recently, it is possibly a recent introduction from eastern Australia or may not have been identified accurately in the past.

Both adults and larvae are damaging but larval feeding is more serious (Tooke 1955; Nuttall 1989). Both life stages prefer new adult foliage; adults feed on the leaf margin and the slug-like larvae mine snail-like trails in the leaves (Tooke 1955). This species is a popular example of successful biological control: in particular because it involved an egg parasitoid acting alone. The *Eucalyptus* weevil was introduced into several countries including South Africa (Tooke 1955), New Zealand (Nuttall 1989) and Spain (Cordero Rivera *et al.* 1999), where it became a pest but subsequent introduction of the mymarid egg parasitoid *Anaphes nitens* from eastern Australia led to successful biological control. However, the species is still a sporadic pest in South Africa where further introductions of new species of parasitoids are being investigated (Huber & Prinsloo 1990).

Initial results from south-western Australia show that egg masses of this species are being parasitized by *A. nitens* (A. D. Loch, unpubl. data). Parasitism rates were extremely low in spring 1999 (< 5%) but increased during summer to nearly 100%. Coupled with high rates of larval parasitism by tachinid flies, weevil larvae were extremely rare by late summer. This pattern of parasitism is similar to patterns recorded in highland areas of South Africa where *A. nitens* is sporadically ineffective because wasp numbers are thought to fall significantly during winter when no host egg masses are available (Tooke 1955). Although Tooke reported that egg masses of *G. scutellatus* are available virtually throughout the year in southern Australia, field surveys in south-western Australia during the 1999–2000 season showed that the species oviposited only between July and January (A. D. Loch, unpubl. data). These seasonal patterns of oviposition and parasitism suggest that *A. nitens* experiences a host shortage between summer and winter, but further seasons' data are required to test this hypothesis.

*Chrysomelid beetles (*Chrysophtharta *spp.,* Cadmus excrementarius *and other species)*

Most species of chrysomelid beetles that defoliate *E. g. globulus* in south-western Australia are paropsines (subfamily Chrysomelinae), with species of *Chrysophtharta* and *Paropsis* predominating. However, most species of paropsines are rarely encountered on *E. g. globulus* and are not serious pests. Reports of serious damage by paropsines in south-western Australia have been few, but given their high pest status in Australia and elsewhere (Simmul & de Little 1999), their pest potential is high.

Chrysomelids in the subfamily Cryptocephalinae also occur on *E. g. globulus* in south-western Australia, with *Cadmus excrementarius* the most serious pest. This species has been collected throughout Australia, although the name is likely to comprise a complex of species (C. A. M. Reid, pers. comm.). The first reports of damage by this species occurred in the mid-1990s (J. D. Farr, pers. comm.). Adults emerge in mid-summer and large populations can cause extensive defoliation to adult and juvenile foliage over summer (A. D. Loch, unpubl. data). Only the adult is known to be damaging to *E. g. globulus* as larvae live in ovoid cases on the ground and feed predominantly on leaf litter, but noticeably aggregate to, and feed on, freshly fallen leaves (A. D. Loch, pers. obs.). Adult females lay eggs coated in a faecal case, and the larva enlarges this case with its own faeces as it grows, which is also seen in *Cad. australis* in Tasmania (Elliott & de Little 1984).

Larvae of other *Cadmus* species have been observed eating young eucalypt seedlings in a south-eastern Australian forest (Reid 1999) and *Cad. excrementarius* larvae may also be able to damage seedlings. However, ground preparation prior to planting is likely to kill larvae, but coppicing saplings may be vulnerable. Although *Cad. excrementarius* is found throughout south-western Australia, the species is mainly concentrated in the Rocky Gully and Mount Barker area, and is not a serious pest in most areas.

*Autumn gum moth (*Mnesampela privata*)*

Autumn gum moth is an important native pest of young established trees bearing juvenile foliage. Damage is caused by early instars etching the leaf surface and later instars chewing the entire leaf. The life cycle of this species in south-western Australia is similar to that in eastern Australia, with adults emerging in autumn, mating and laying eggs, and the larvae feeding through winter before pupating in late winter and early spring (McQuillan 1985). Trees in their first 2 years of growth are particularly susceptible to attack, but there have been isolated cases of 3–4-year-old plantations being heavily defoliated (A. D. Loch, pers. obs.).

*Leaf blister sawfly (*Phylacteophaga froggatti*)*

Unlike most sawflies, leafblister sawfly larvae are leaf miners, feeding on the mesophyll layer between epidermal layers before pupating in an oval-shaped blister (Farrell & New 1980; Thumlert & Austin 1994). This native to eastern Australia was first discovered in Western Australia in 1978 and spread quickly throughout south-western areas (Curry 1981). Leaf mining by this species is largely confined to the lower branches of juvenile foliage of *E. g. globulus* and, as a result, damage is more likely to be a cosmetic problem rather than the cause of any significant loss of growth increment. Curry (1981) suggested that several native parasitic wasps of leafblister sawfly larvae and pupae may reduce pest populations. However, *Bracon phylacteophagus*, the parasitoid responsible for successful biological control of *P. froggatti* in New Zealand (Faulds 1991), has not been found in Western Australia. Ineffective biological control may thus be responsible for leafblister sawfly being a pest, and this should be investigated.

Other pests

Several other weevil species may be occasional or minor pests of *E. g. globulus* in south-western Australia. *Catasarcus impressipennis* can cause serious defoliation but is distributed mainly east of Albany and at Esperance, and is therefore not a major pest in most areas. The species is native to south-western Australia (Thompson 1968) and has probably moved from native eucalypt hosts onto *E. g. globulus*. The wingless adults are the only damaging stage, because the larvae live in the soil. Weevils of the genus *Oxyops* also occur on *E. g. globulus*, but are relatively uncommon (A. D. Loch, unpubl. data).

Several species of Lepidoptera occur in low numbers on *E. g. globulus*. Larvae of *Ardozyga stratifera*, a gelechiid leaf-tier, cause malformation of shoots by joining them together. Even rarer are case moths of which the larvae skeletonize leaves, and cup moth larvae, which can consume entire leaves. Other chewing insects that occasionally occur on *E. g. globulus* in south-western Australia include sawfly larvae (e.g. *Perga schioedtei*) and tettigoniid grasshoppers.

Bluegum psyllid, *Ctenarytaina eucalypti*, is ubiquitous on young *E. g. globulus* plantations in south-western Australia and is also common throughout south-eastern Australia (Farrow 1996). This species sucks the tips of juvenile foliage and may cause stunting and dieback of leaves and tips (Farrow 1996). However, in south-western Australia there have been few reports of damage by this species (J. D. Farr, pers. comm.). Other sucking insects that infest *E. g. globulus* in south-western Australia include gum tree scales in the genus *Eriococcus* and several species of leafhoppers, but none of these are of current serious concern (A. D. Loch, pers. obs.). Abbott (1993) believed that cerambycid borers (Coleoptera) should not be a problem in 10-year rotation *E. g. globulus* plantations; however, there have been isolated cases of *Phoracantha* spp. damage in older (> 5 years) plantations (A. D. Loch, pers. obs.; J. D. Farr, pers. comm.).

REASONS FOR INSECT PEST PROBLEMS

Origin of insect pests

Establishment pests are typically native insects, with the African black beetle the only exception (Table 1). They have also generally originated from agricultural crops and pastures (Table 1), and tend to be pests of *E. g. globulus* as a result of changes in vegetation structure and availability, and site conditions. For example, *E. g. globulus* is not preferentially eaten by the wingless grasshopper or the Rutherglen bug when other vegetation is available, but it is one of the few available food sources during summer (CALM 1990; Abbott 1993). Also, African black beetle and *Agrotis* spp. are pests of *E. g. globulus* as a result of pasture clearing and site conditions.

By contrast, insect pests of established trees have originated from surrounding forests (Table 1). Development of these insect problems in south-western

Australia should not have been unexpected for several reasons. Currently, all pests of established trees are native to Australia, with eucalypts their usual host. Although the exact endemic origin of most of these pests is not known (Table 1), some are native to eastern Australia (e.g. leafblister sawfly) where *E. g. globulus* is one of their hosts. The pest status of such non-local species may also be elevated because their usual natural enemies are absent, as seems to be the case for species such as leafblister sawfly. Also, the regional landscape of south-western Australia where *E. g. globulus* is grown is dominated by native eucalypt forests, which are rich in insect species (Majer *et al.* 2000). Given that eucalypt-feeding insects often have a range of host species (Morrow 1977), many insect herbivores are likely to radiate from native forests onto *E. g. globulus*. This scenario is especially applicable to insects endemic to south-western Australia that have switched feeding from native eucalypts to *E. g. globulus* (see later section).

Monoculture effect

Insect pest problems of *E. g. globulus* in south-western Australia may also be exacerbated because the species is grown as a monoculture. The concept of monocultures being more vulnerable to insect attack than heterogeneous polycultures is a controversial issue that has been widely acclaimed in the agricultural literature (e.g. Altieri & Letourneau 1984; Altieri 1991; Andow 1991) and forestry literature (e.g. Jones & Gibson 1966; Campbell 1972). However, theoretical and empirical evidence underpinning the concept has been seriously questioned (van Emden & Williams 1974; Goodman 1975). Root (1973) proposed two explanations for the 'monoculture effect': (i) natural enemies are more effective controlling agents in diverse systems than in simple ones (natural enemy hypothesis); and (ii) specialist insect herbivores tend to find monocultures easier and reproduce at higher rates (resource concentration hypothesis). Despite strong theoretical backing, empirical support is scant and often equivocal, because most studies merely examine patterns rather than the processes that drive them (e.g. Mensah 1999; but see Baggen & Gurr 1998). Risch *et al.* (1983) stressed that understanding such processes is central to understanding the relationship between vegetation diversification and insect pests.

Research is urgently needed to assess whether eucalypt monocultures are more prone to insect damage than are mixed eucalypt forests. Although an understanding of underlying processes is essential, quantifying whether an actual pattern exists must first be determined. South-western Australia presents an ideal situation to investigate such patterns, because defoliation levels in *E. g. globulus* plantations can be compared with levels for native eucalypt species that grow in the same environment. Abbott *et al.* (1993) assessed insect defoliation of eight eucalypt species in south-western Australian forests and found that levels were highest for *E. marginata*, *E. patens* and *E. rudis.* A similar study is needed to determine if defoliation levels are higher in *E. g. globulus* plantations than in native eucalypt forests. If defoliation levels are higher

Table 1. Purported habitat of origin and geographical origin of insect pest species of *Eucalyptus globulus globulus* in south-western Australia

Insect pest type and species	Habitat of origin	Geographic origin
Establishment pests		
Heteronychus arator	Ag	Africa (Matthiessen & Ridsdill-Smith 1991)
Liparetrus spp. and *Heteronyx* spp.	Ag/For	Australia (Grimm 1987)
Phaulacridium vittatum	Ag	Australia (Grimm 1987)
Agrotis spp.	Ag	Australia?
Nysius vinitor	Ag	Australia (McDonald & Farrow 1988)
Apina callisto	Ag	WA (CALM 1990)
Pests of established trees		
Mnesampela privata	For	Australia (McQuillan 1985)
Chrysophtharta spp. and *Paropsis* spp.	For	Australia
Cadmus excrementarius	For	Australia (C.A.M. Reid, pers. comm.)
Gonipterus scutellatus	For	Australia (Tooke 1955)
Phylacteophaga froggatti	For	EA (Curry 1981)
Catasarcus spp.	For	WA (Thompson 1968)
Oxyops spp.	For	Australia?
Ctenarytaina eucalypti	For	Australia (Abbott 1993)
Eriococcus spp.	For	Australia (Patel 1971; Gullan & Vranjic 1991)
Phoracantha spp.	For	Australia (Elliott et al. 1998)

Ag, agricultural pastures and grasslands; For, forest; WA, Western Australia; EA, eastern Australia; Australia, exact endemic origin not known in plantations then further research must then identify what processes are causing the effect. However, as a first step, differences in host preference and susceptibility of eucalypt species must be quantified before differences in insect abundance and defoliation can be properly understood in the field. The effects that eucalypt foliar nutrient levels and structural complexity have on arthropod diversity must also be determined as data indicate that higher levels of both factors result in greater arthropod diversity (Recher *et al.* 1996).

If the monoculture effect is real, and eucalypt plantations are more susceptible to insect attack, it does not necessarily follow that native forests are immune to insect attack, as epitomised by south-western Australian native forests. For example, regenerated stands of karri can be severely affected by the bullseye borer, *Phoracantha acanthocera* (Abbott *et al.* 1991). Long-standing outbreaks of jarrah leafminer, *Perthida glyphopa*, and gumleaf skeletoniser, *Uraba lugens*, have been recorded in jarrah forests (Abbott 1990). Severe defoliation of *E. rudis* by lepidopteran leaf miners, psyllids, chrysomelids and weevils is also seen in southwestern Australia (A. D. Loch, pers. obs.). These examples illustrate that diverse polycultures can also experience high levels of insect damage.

Insect pest problems in native eucalypt forests in south-western Australia may already be increasing as a result of pests moving from plantations into forests. Since the introduction of *E. g. globulus* to south-western Australia, total numbers of many pest species (e.g. autumn gum moth, leaf blister sawfly, etc.) in the region would have risen significantly. Further rises in the pest population size are expected over the coming years as the plantation resource grows. Currently the plantation estate occupies a relatively small proportion of total available land in most areas of south-western Australia, and the risk of pest problems arising in native forests as a result of pest movement from plantations should thus be low. However, this risk would be greater between Rocky Gully and east of Albany, where most plantations occur and also where insect abundance and damage are greater. Root's (1973) resource concentration hypothesis may explain why the greatest concentration of plantations has more pests, in that simply more plantation resource equals more pests. However, differences in the composition and structure of surrounding vegetation may also affect the severity of pest problems in plantations. Vegetation between Rocky Gully and Albany is predominantly cleared agricultural land with patches of remnant vegetation and increasing areas of plantations, as opposed to other parts of the plantation estate where native forest is the dominant vegetation type (A. D. Loch, pers. obs.). No strong supporting evidence for either explanation exists.

Host shifting

The situation in south-western Australia where a non-local eucalypt species has been grown as a plantation and experienced high levels of insect damage is not unique. Exotic eucalypt plantations are being increasingly grown in Australia and overseas, with insect problems arising in both situations. Eucalypt foliage is regarded to be of low nutritive value or palatability as it is tough, low in nitrogen and water, and high in essential oils and phenolics (Morrow 1983). Despite these foliar characteristics, many insects are able to feed on eucalypts.

In Australia, insect pests of non-local eucalypt species mainly comprise native and non-local insect species that have switched from local eucalypt species. The situation in south-western Australia closely parallels that in Tasmania, where plantations of the non-local shining gum, *E. nitens*, are affected by insect pests that have originated from native eucalypt forests (de Little 1989). In both south-western Australia and Tasmania, some local eucalypt-associated insect species have found the exotic eucalypts to be suitable hosts and have subsequently become pests. Because eucalypt-feeding insects have the ability to eat a range of species (Morrow 1977), shifts to new eucalypt species could be relatively common. Establishment pests are exceptions, as *E. g. globulus* is not strictly a host for most, if not all such pest species. Establishment pests are typically generalist feeders and do not appear to rely solely on *E. g. globulus* for development and reproduction.

In contrast, insects specifically adapted to feed on eucalypts are usually absent overseas, except where Australian native insect species have been accidentally introduced (e.g. the eucalyptus weevil). Despite such insects being absent from most countries, eucalypt plantations throughout the world have experienced insect damage. In some instances, native insects damaging eucalypts overseas have switched from related myrtaceous hosts (e.g. Hutacharern & Sabhasri 1985; Zanuncio *et al.* 1994). However, the majority of pest species in overseas countries are generalist herbivores without any known records of feeding on species of Myrtaceae. A recent summary of insect pests of eucalypts in south-eastern Asia and the Pacific (Floyd *et al.* 1998) lists 920 insect species that have been recorded causing damage to eucalypts, all of which have switched from non-eucalypt hosts and most of which came from non-myrtaceous hosts. Of particular interest is the apparent trend in the number of insect species causing significant damage on eucalypts in Asia (Floyd *et al.* 1998) and South America (Zanuncio *et al.* 1994, 1998), which has increased greatly in recent years. This observation may suggest that the process of host switching takes some time to occur.

ENTOMOLOGICAL FUTURE FOR *E. GLOBULUS GLOBULUS* IN SOUTH-WESTERN AUSTRALIA

The past 5–10 years of rapid growth in area planted to *E. g. globulus* in south-western Australia has been followed by similar increases in insect pest problems. Whereas the pest status of some insect species has probably decreased, new pest species have emerged, and the status of other pests has increased. With the plantation estate still relatively new and rapidly expanding, the future trend in the number and magnitude of insect pests of this system is expected to continue to increase.

With further increases in such insect damage, should alternative eucalypt species be sought for pulpwood plantations in south-western Australia? Unless another eucalypt species is especially resistant to insect pests, insect damage is likely to be similarly high for other eucalypt species. *Eucalyptus globulus globulus* grows well in south-western Australia and is the best available eucalypt pulpwood species for the conditions in terms of growth rates and pulp quality (Shea & Bartle 1988). Planting more insect resistant provenances of the species (Farrow *et al.* 1994) should partially alleviate some insect problems. However, such provenances may have inferior growth rates or offer cross-resistance to only a narrow range of pest species, and their use in plantations could thus be limited. Enhancing diversity within plantations may also help alleviate some insect problems by increasing numbers and efficiency of natural enemies and/or impacting negatively on herbivore reproduction and development. However, the function of diversity within plantations remains largely unknown and requires elucidation before any plans for enhancement can proceed.

Although *E. g. globulus* has many insect pests in south-western Australia, the situation could be much worse. Despite many insect species switching onto *E. g. globulus* from other eucalypt species (e.g. *Cad. excrementarius*, *Cat. impressipennis*, *Oxyops* spp.), the major pests of native eucalypt species in the region, such as jarrah leafminer, gumleaf skeletoniser and bullseye borer have not been recorded as pests of *E. g. globulus*. In addition, several insect pest species of *E. g. globulus* in other parts of Australia (e.g. *Ch. agricola* and *Anoplognathus* spp.) are not known to occur in south-western Australia but could become serious pests if they were introduced. The reverse is also true as south-western Australian plantations have unique pest species such as *Cat. impressipennis* that could become pests in other parts of Australia. These examples stress the need for continued strict quarantine measures within Australia, which will be important if the blue gum industry in south-western Australia is to remain successful.

Maintenance of high growth rates is also important to the continued success of the industry in south-western Australia. Because *E. g. globulus* grows rapidly, the likelihood of insect defoliation exceeding foliar production decreases, ensuring rapid recovery after defoliation (Stone & Clarke 1998). Artificial defoliation studies have shown that *E. g. globulus* growth is not affected by crown defoliation of up to 50%, except during autumn (Abbott & Wills 1996; Elek 1997; N. G. Collett, unpubl. data). However, results of these studies must be interpreted with caution and need to be verified with results from insect exclusion trials to understand with confidence the effects of insect defoliation on tree growth rates. The high growth rate and postdefoliation compensatory growth ability of *E. g. globulus* allows the species to suffer little or no overall growth loss from low levels of defoliation. Therefore, only large pest populations that inflict high levels of defoliation will cause growth loss and require control intervention.

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