Trees in the landscape

Technical Report 216

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CRC for Forestry
Researching sustainable forest landscapes

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Are insect herbivores in *Eucalyptus globulus/nitens* plantations a worsening problem? A multi-region spatio-temporal review of southern Australia

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Public report

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Contents

Executive summary

The total area of plantations of *Eucalyptus globulus* and *E. nitens* in southern Australia has grown considerably over the last few decades. This has led to predictions of increasing insect pest problems. Accordingly the following research questions were investigated:

1. Are the damage levels from insect herbivores in eucalypt plantations increasing?
2. Are the current significant insect herbivores of *E. globulus/nitens* plantations the same species as in the past?
3. Have new insect herbivore species recently emerged as pests?
4. Are the insect herbivore species evenly distributed throughout the plantation estate?
5. Are insect herbivore species that have recently emerged as problems in eucalypt plantations expanding their range?

National and regional datasets on insect herbivory were assembled from the Green Triangle, south-west Western Australia (WA) and Tasmania. Data was collated on insect damage between 2000 and 2010 for most species, but for some species data went back as far as 1990. Over time, the survey effort and methodology is unlikely to have been very consistent among regions and even companies, and this compromised the quality of the data. Nevertheless, the data are still important as they are the only historical account of patterns of insect pests in *E. globulus/nitens* plantations.

There was little evidence that damage caused by insect herbivores in eucalypt plantations has increased over time. Insect herbivore records classified as causing severe damage across Australia correlated with the area of new plantings of young trees but not with time. The lack of increase in damage by insect herbivores over time might be due to:

- improved site surveillance and control of establishment and post-establishment pests, resulting from a better understanding of the biology of insect species, including location and timing of insect swarms
- improvements in silvicultural practices, such as better site selection, site preparation, weed control and nutrient application, as well as the use of improved tree genetics
- colonisation of plantations by natural enemies residing in native vegetation
- reduced spraying of plantations with broad-spectrum insecticides, thereby conserving natural enemies.

Some of the currently significant insect herbivores of *E. globulus/nitens* plantations are the same species as in the past. Some of the species that have been recognised previously as pest species have inflicted a lower level of damage more recently, while some new pest species have emerged.

There was strong evidence that the total number of species of insect herbivores that caused tree damage in eucalypt plantations increased initially with the expansion of the eucalypt plantation estate and over time, but then reached a fluctuating equilibrium.

Within regions, few insect herbivore species were found evenly throughout the plantation estate. Each region had its own suite of species causing damage to eucalypt plantations. Some species were restricted to certain sub-regions, possibly due to climatic constraints.

Overall, patterns of insect herbivores differed across regions:

- WA and the Green Triangle, but not Tasmania, have had insect herbivores emerge as pests, increase their level of damage and expand their geographic range (e.g. yellow-belly chrysomelid in WA and shot-hole miner in the Green Triangle)
- the distributions of some insect herbivores (e.g. autumn gum moth and leaf-blister sawfly in WA) were probably constrained by climate
- current damage by some insect herbivores from Tasmania (e.g. scale insects) and WA (e.g. eucalyptus weevil) is less than the damage they caused in the past.

Although it was not the intention of this study to critique reports by Research Working Group 7 (RWG7) on forest health monitoring, it is evident that the reports could be improved by adopting standard monitoring and reporting formats that quantify spatial extent and severity of insect herbivore damage. However, this could be difficult to implement as the survey effort varies from year to year and among companies.

New insect herbivores will colonise eucalypt plantations in the future. Climate change and increasing amounts of coppice will likely lead to changes in insect herbivore dynamics. New species are likely to emerge as pests, although outbreaks are likely to be cyclical and eventually terminate. Improvements in the management of plantations may reduce the future impacts of insect herbivores on tree growth. These actions could include better matching of tree species and stocking rates with site soil and microclimate profiles, and improved fertilising regimes.

Introduction

Over the last few decades Australian forestry has increasingly moved away from the harvesting of native forests to growing and harvesting plantation timber. During 1999 to 2009, Australia's eucalypt plantation estate has grown by about 150%, although in recent years the rate of expansion has slowed (Gavran & Parsons, 2010; Fig. 1). As at 2009, Australia's hardwood plantation estate was 990 945 hectares (Gavran & Parsons, 2010). The estate of eucalypt plantations is dominated by plantings in the southern Australian states of Western Australia (WA), South Australia (SA), Victoria and Tasmania, which have a combined area of 805 187 hectares, or 81% of the national estate (Gavran & Parsons, 2010; Fig. 1). As at 2005, blue gum (*Eucalyptus globulus* Labill.) and shining gum (*E. nitens* Maiden) of the family Myrtaceae made up 94% of the estate of hardwood plantations in southern Australia (Parsons *et al.*, 2006). Historically *E. globulus* is endemic to Tasmania, the Bass Strait islands and southern Victoria, with an isolated population in SA. Now this species is used in plantations in Tasmania, Victoria, New South Wales (NSW), SA and WA (Tibbits *et al.*, 1997; Vaillancourt *et al.*, 2001; Parsons *et al.*, 2006; Barbour *et al.*, 2008). *Eucalyptus nitens* originates from Victoria and NSW and is now used in plantations in areas of Victoria, NSW and Tasmania (Tibbits *et al.*, 1997; Barbour *et al.*, 2002; Parsons *et al.*, 2006). Thus, in Australia, these two eucalypt species are grown in areas in which they are native as well as in areas outside their natural range.

Most *E. globulus/nitens* plantations on the Australian mainland have been established on ex-agricultural land in the 600+ mm precipitation zones. In Tasmania, about half of the eucalypt plantations have been established on ex-native forest and the other half on ex-agricultural sites (Forest Practices Authority, 2009). The agricultural land now being converted to eucalypt plantations was initially cleared of native vegetation during European settlement some 50 to 200 years ago. During this time, open eucalypt forests and especially eucalypt woodlands were heavily cleared (DEWR, 2007). Despite the clearing of significant amounts of native eucalypt vegetation for agriculture and farming, eucalypt-dominated native forests still occupy approximately 147 million hectares across Australia (Gavran & Parsons, 2010).

The ex-agricultural land on which eucalypt plantations are established often includes small patches of remnant native vegetation. The number, size and condition of remnants embedded in plantations vary, but in some regions (e.g. the Green Triangle of SA and Victoria), the relative amount of native vegetation can be substantial (Greening Australia, 2008). Although fire breaks are usually cleared between eucalypt plantations and adjacent native vegetation, typically such breaks are only 5 to 30 metres wide. The recent expansion of the eucalypt plantation estate has resulted in an increased number of edges shared between plantations and native vegetation. This has led to predictions of increased biotic interactions between plantations and remnant vegetation (Strauss, 2001). These interactions are also moderated by other landscape variables such as proximity and area of native vegetation, plantation shape and the landscape-scale at which organisms operate.

Several authors (Abbott, 1993b; Loch & Floyd, 2001; Strauss, 2001) predicted that the increasing area and age of eucalypt plantings would lead to increasing insect pest problems; namely, increasing numbers of species of insect herbivores and more severe insect herbivory. The rationale for these predictions can be justified on several counts. First, there are many cases of agricultural crops in which insects have become pests as the range and area of crops has expanded (see Strauss *et al.*, 2006). The best-known examples are from two crops introduced to many countries around the world—sugar cane (Strong *et al.*, 1977) and cacao (Strong, 1974)—that independently acquired diverse communities of insect herbivores native to each country or region. These examples conform to species–area relationships (MacArthur & Wilson, 1967), because in both cases the number of insect herbivores colonising these crops was closely related to total area under cultivation rather than the amount of time a host plant had been in a region. Second, spatial barriers between plantations and remnant vegetation are minimal and, thus, there are few physical barriers to colonisation. The close proximity of eucalypt plantations and native vegetation could also facilitate insect pests to spill over from plantations into adjacent native vegetation and vice versa, and this will vary with the way particular species respond to spatial features of the landscape. Third, plantations provide a monoculture of evenly aged young trees (different from most native forests), making them susceptible to outbreaks of insect herbivores (Abbott, 1993b; Jones, 2001). Fourth, because eucalypts are found in native vegetation near eucalypt plantations, many insect herbivores in native vegetation may be able to shift hosts onto plantation species. A recent analysis of data from previously published studies showed that the more similar forestry tree species were to the native vegetation, the greater the ability for insect pests to colonise plantations (Bertheau *et al.*, 2010). There are many examples of herbivorous insects associated with plants in the Myrtaceae family in Asia, South America and South Africa shifting hosts onto eucalypts (Paine *et al.*, 2011). Australian native forests and woodlands almost always contain *Eucalyptus* species, which host a diverse insect herbivore community (Majer *et al.*, 2000). Thus, Loch and Floyd (2001) hypothesised that many eucalypt herbivores in Australia should have no difficulty shifting hosts to colonise trees in eucalypt plantations, even if the species of eucalypt were not native to the area. This hypothesis is supported by Radho-Toly *et al.* (2001), who found that in WA, rates of herbivory on two exotic species of eucalypts (originating from eastern Australia) were comparable to the rate of herbivory on two locally endemic eucalypt species, although the precise identity of herbivores was unknown.

Strauss (2001) made further predictions that planting large expanses of eucalypt plantations over many regions of Australia would facilitate the dispersal of insect pests and homogenise the pest problems. This could occur if machinery or biological material such as seedlings were moved between regions with plantations.

There are many examples of insect herbivores colonising *E. globulus/nitens* plantations and becoming established pests in Australia (Abbott, 1993a; Bashford, 1993; Neumann, 1993; Phillips, 1993; Loch & Floyd, 2001; Strauss, 2001; de Little *et al.*, 2008; Paine *et al.*, 2011). However, the collection of temporal records is haphazard. Given the large increase in the area of eucalypt plantations since the predictions by Abbott (1993b), Strauss (2001) and Loch and Floyd (2001) were made, it is timely to critically investigate the following:

1. Are the damage levels from insect herbivores in eucalypt plantations increasing?
2. Are the current significant insect herbivores of *E. globulus/nitens* plantations the same species as in the past?
3. Have new insect herbivore species recently emerged as pests?
4. Are the insect herbivore species evenly distributed throughout the plantation estate?
5. Are insect herbivore species that have recently emerged as problems in eucalypt plantations expanding their range?

Methods

Databases

The annual Pest, Disease and Quarantine Status Reports for Australia and New Zealand for the Research Working Group 7–Forest Health (RWG7) are the only source of historical information available documenting insect herbivore outbreaks among plantation forests over the whole of Australia. The RWG7 report series commenced in the early 1990s as a way to formalise communication among forest entomologists and pathologists across Australia. These reports are an annual summary of forest health issues in each state and provide current information to national committees and Commonwealth Government departments.

A database was constructed of insect herbivore records based on the annual RWG7 reports for the period 1994–2009. Hardcopies of RWG7 annual reports were searched for any text discussing insect herbivores associated with *E. globulus/ nitens* plantations for the southern Australian states of WA, SA, Victoria and Tasmania. For each insect herbivore record, information was entered into an Excel spreadsheet. Taxonomic details varied, with some records referring to species and others to species groups (e.g. "chrysomelids"). The year and the location (state) of the insect record were entered, as was the degree of tree damage according to three damage classes (Table 1). For some insect species or species groups, there was spatial variation in tree damage, and so a separate localised record (e.g. more severe) was made in addition to broader regional observations. Additional information such as precise date of outbreak, age of plantation and landscape context was rarely provided. To avoid possible reporting biases, the temporal sequence in which reports were digitised was deliberately mixed so that there was no association with year of report ($R^2 = 0.08$, $P = 0.31$). There were 374 records that were able to be allocated into a severity category. These records included regional events ('widespread') and more local events ('localised'). The state-by-state breakdown included 67 records from SA, 82 records from Victoria, 117 records from WA and 133 records from Tasmania.

Table 1. Definitions of insect herbivore damage among *E. globulus* and *E. nitens* plantations

Damage class	Definition
Low–moderate	Moderate to low damage, not requiring management intervention
Moderate–high	High to moderate levels of damage, which may be extensive, but below the level required for management intervention
Severe	Severe and extensive damage, possibly leading to tree death, usually triggering a recommendation for management intervention (e.g. application of pesticide)

Due to taxonomic inconsistencies in the RWG7 reports and the coarse nature of the data, many research questions were unable to be answered solely from the RWG7 database. In response to this problem, additional region-specific datasets were compiled for the major eucalypt plantation regions in southern Australia; the Green Triangle, south-west WA, Esperance (WA), and Tasmania. The Green Triangle spans the region of south-east SA and adjacent south-west Victoria. Plantations of *E. globulus* have been grown in this region since the mid-1990s (Parsons *et al.*, 2006). Plantations of *E. globulus* in south-west WA have been grown since the late 1980s, and from the early 2000s around Esperance (WA) (Parsons *et al.*, 2006). In Tasmania, plantations of *E. nitens* are grown in colder sub-regions while *E. globulus* is grown on warmer and often drier sites. Eucalypt plantations have been established in Tasmania since the late 1960s for *E. nitens* (C Dare, pers. comm.) and the mid-1990s for *E. globulus* (Parsons *et al.*, 2006).

The number of insect herbivore species or species groups on *E. globulus/ nitens* reported over time from the Green Triangle, south-west WA and Esperance (WA) were compiled by the Industry Pest Management Group (IPMG). The information on species richness in WA was largely taken from data collected using fogging (1999–2002; Loch, 2006) and from light trapping (2003–2008; Matsuki, 2006a, updated in 2009). For the Green Triangle, the information was taken from data collected from light trapping (2006–2009; Matsuki, 2008c, updated in 2009). For WA and the Green Triangle, additional data was sourced from insect population assessments by Albany Plantation Forestry Company (APFL), Great Southern Limited (now Alberta Investment Management Corp. and Australia New Zealand Forest Fund), Hansol PI (now Great Southern Timberholdings), Timbercorp (now Australian Bluegum Plantations), and WA Plantation Resources (WAPRES). A database was assembled on insect observations and collections and also used to supplement the information. Note that there are many undescribed species, and identification of species is continuing (see Acknowledgements).

For Tasmania, insect herbivore records from *E. globulus/ nitens* plantations were compiled from Forestry Tasmania's Forest Health database. This database contains records from the year 2000 onwards and includes all records of insects collected from the two plantation species, not just species causing damage. Records of species before 2000 were compiled from interviews with forest entomologists responsible for eucalypt plantation health in Tasmania at that time: David de Little (Gunns Ltd) and Dick Bashford (Forestry Tasmania). Consequently it was anticipated that these data were reliable for insect herbivore events that caused moderate to severe damage only, but not for insects that caused little damage. To address this imbalance, data for the number of insect herbivore species or species groups collected on *E. nitens* over time were compiled from Forestry Tasmania's Tasmanian Forest Insect Collection database (Grove, 2010). When interpreting the results it is important to consider that the RWG7 datasets are not entirely independent of the regional datasets because they share many authors. Eucalypt plantation estate data were sourced from annual national plantation inventory updates (Parsons *et al.*, 2006; Gavran & Parsons, 2010).

Analyses

Linear regression was used to test whether the number of insect herbivore records for each year was correlated with the total area of the plantation estate, and the area of eucalypt plantations for the southern Australian states. The number of insect herbivore records in each of three damage classes (Table 1) was also correlated against area of new plantations and year. New plantations were those planted in the last year (Parsons *et al.*, 2006). Before conducting these analyses, the five variables (total herbivore records, three damage classes and plantation area) were tested for temporal autocorrelation with the autocorrelation function for up to three temporal lags. The area of new plantations was distinguished from the total area of eucalypt plantations because juvenile-phase foliage is preferred over adult-phase foliage by some insect herbivores, and seedlings are more susceptible to insect damage (de Little *et al.*, 2008).

For the regional databases, the degree of tree damage was defined as per Table 1, except that a distinction was made between locally severe and widespread severe damage. For the most damaging insect herbivores in each region, tables were created to track the severity of insect herbivore damage in each sub-region across space and time. The data for the insect herbivores causing the greatest damage were analysed in each sub-region. For each of these insect herbivores, a set of tables roughly corresponding to the geographic arrangement of sub-regions were made, and shaded to show which sub-regions had plantations and the degree of insect damage. One table was created for each year and, when viewed side by side with adjacent years, spatio-temporal changes for each herbivore could be interpreted. These data were represented in temporal plots by creating a severity index that captured the damage caused by a herbivore across all sub-regions. For each insect herbivore and each year, sub-regions were assigned severity scores according to their degree of tree damage; low = 1, moderate or locally severe = 3, and widespread severe = 5. The sub-region scores were then summed and divided by the number of sub-regions with plantations, to account for changes in the number of sub-regions with plantations. Annual scores of this severity index were then plotted for each of the major insect herbivores to establish temporal trends.

Since the Tasmanian data were captured differently from the data from the Green Triangle and WA, and since the number and size of sub-regions within regions differed, the severity indices are not absolute and should not be used to compare overall herbivore severity across regions. Also, in this part of the analysis, establishment pests were under-represented. Establishment pests tend to cause localised severe damage within a plantation and within a sub-region, and there is large between-year variation in outbreaks. Consequently, the records of damage by establishment pests were less complete than the records of damage by post-establishment pests. Furthermore, because the damage was highly localised, it was rarely scored as ‘widespread severe’, although damage by establishment pests often resulted in the death of seedlings. Also, it is important to note that some species that cause severe damage were not included because it has been difficult to assemble reliable data on the species that are highly variable in their abundance over space and time (spring beetles, wingless grasshopper and *Heteronyx* beetles). Therefore, results in appendices 1 and 2 do not represent an exhaustive survey of insect herbivores that cause severe damage in plantations of *E. globulus* in the Green Triangle and WA.

Results

1 Are the damage levels from insect herbivores in plantations increasing?

The total hardwood estate steadily increased over the period 1994–2009, while the number of insect herbivore records from the RWG7 database fluctuated but generally increased until about 2001 when the estate was about 600 000 hectares (approximately 25 years since planting started) and then remained in a fluctuating equilibrium with the fluctuations reducing in amplitude over time (Fig. 1). When records of insect herbivores were plotted over time, separated into severity categories and overlaid with the area of new hardwood plantations, some differences emerged (Fig. 2). The area of new hardwood plantations and the three categories of insect herbivore damage were not temporally autocorrelated (Table 2). The number of severe damage records was significantly correlated with area of new hardwood plantations but not year, whereas the opposite was true for the other groupings of records of insect herbivore damage causing moderate or low damage (Table 2). The number of records of both moderate–high and low–moderate damage fluctuated independently of area of new plantations, with moderate-high records peaking in 2001 and then decreasing, while low-moderate records rose to further peaks during 2004–2006 and again in 2009 (Fig. 2).

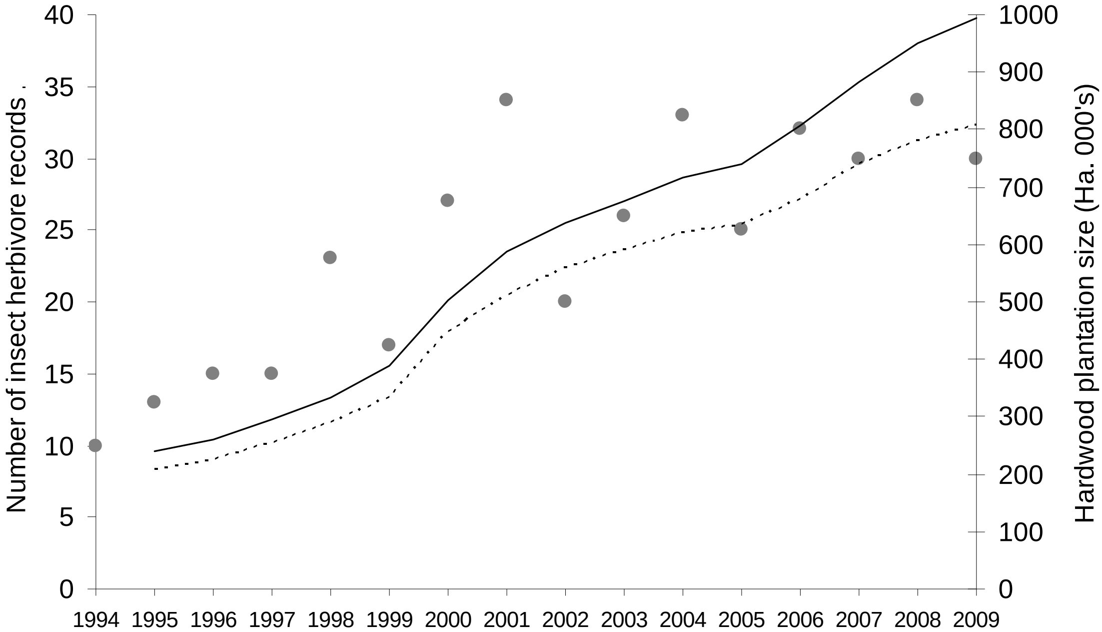


Figure 1. Annual size of the eucalypt plantation estate for Australia (solid line), and just southern Australia (WA, SA, Victoria and Tasmania; dotted line), and number of records of damage by insect herbivore pests on *Eucalyptus globulus/ nitens* plantations (grey points) for southern Australia from RWG7 reports (see methods). As at 2005, these two eucalypt species made up 94% of the hardwood plantation estate in southern Australia (Parsons *et al.*, 2006). Eucalypt plantation estate data were redrawn from annual national plantation inventory updates (Parsons *et al.*, 2006; Gavran & Parsons, 2010)

Table 2. Correlation coefficients for regression analyses between the number of insect herbivore records of damage, area of new hardwood plantations and year. Results for the autocorrelation function analysis of three temporal lags are also presented

			Autocorrelation coefficients		
	Area	Year	Lag 1	Lag 2	Lag 3
Insect herbivore records					
All records	0.20	0.80***	0.45	0.32	0.34
Low-moderate	0.08	0.71***	0.06	0.24	0.36
Moderate-high	0.04	0.65**	0.47	0.47	0.33
Severe	0.64*	0.27	0.29	0.08	–0.40
Area			0.47	–0.09	–0.39

* *P*<0.05, ***P*<0.01, ****P*<0.001

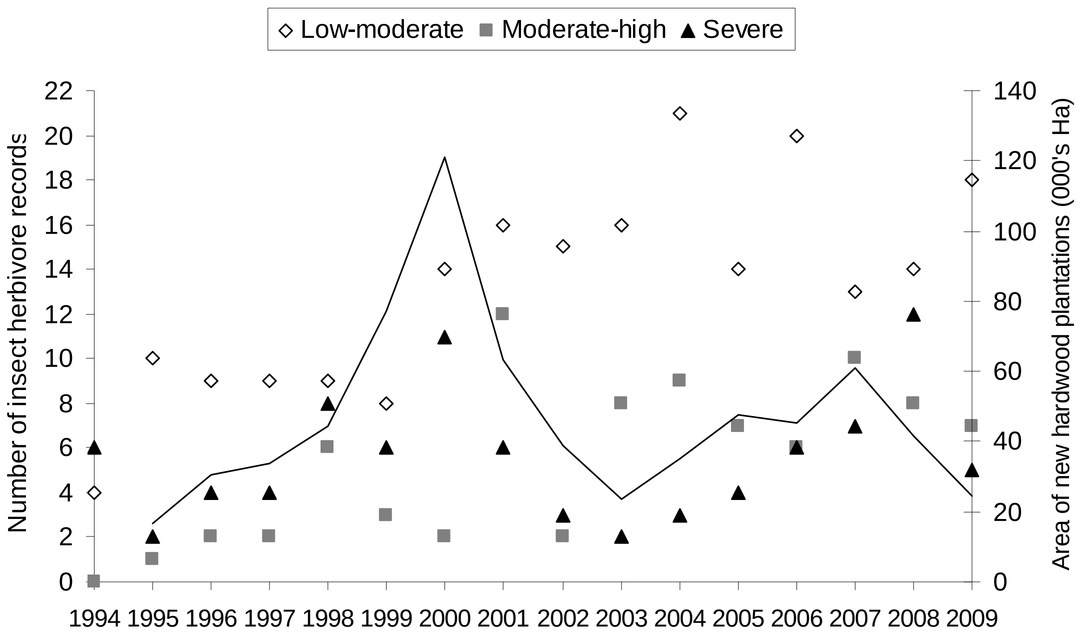
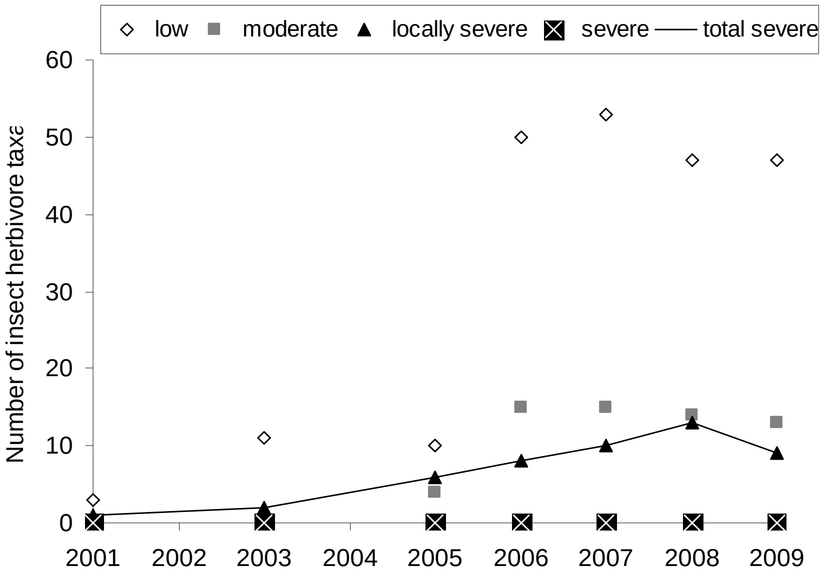


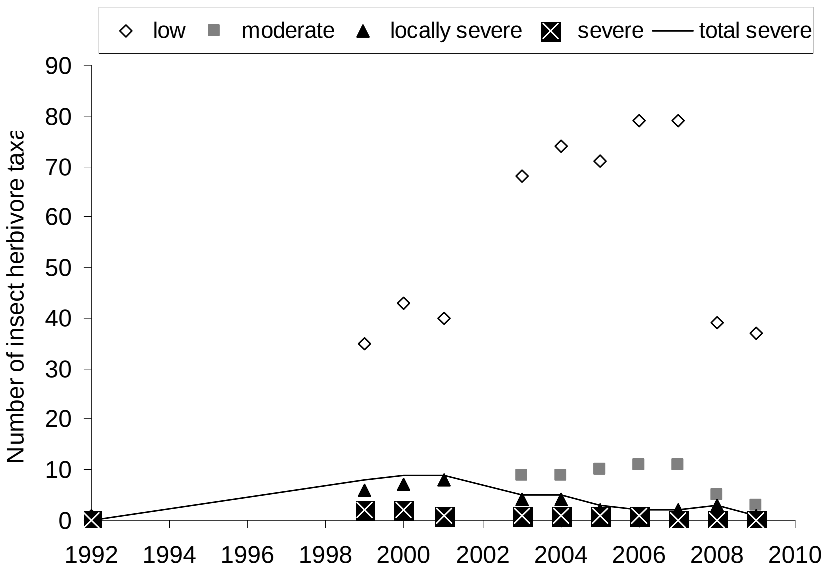
Figure 2. Annual variation in the number of insect herbivore records of damage on *Eucalyptus globulus/ nitens* plantations in southern Australia as reported in the RWG7 reports for the period 1994–2009. Solid line represents the combined area of new hardwood planted in southern Australia (data redrawn from (Parsons *et al.*, 2006; Gavran & Parsons, 2010). Insect herbivore records are grouped according to damage levels in Table 1

When the number of taxa grouped by damage were plotted over time at the regional level using separate regional databases, a similar trend was apparent, except for Tasmania (Figs. 3a–d). Each of the regions examined had a different history with respect to the length of time that eucalypt plantations had been established. Nevertheless, all regions except Tasmania showed a general trend. Initially there were few taxa (species or species groups) causing severe damage in plantations, then the number of insect herbivore taxa causing severe events rapidly increased after which there was a gradual decrease in the number of taxa causing severe events. The longer time-series from Tasmania showed that the number of taxa causing severe insect herbivore damage fluctuated over time (Fig. 3d). By contrast, insect herbivores causing moderate or low damage generally increased in species richness to a constant level over time (Figs. 3a–d). The total number of insect herbivore taxa recorded on *E. globulus/nitens* trees in Tasmania increased steadily from 1970 to 1992, with a trough until the next higher peak in 2005 (Fig. 3e). This includes all insect herbivores, not just those causing damage, and includes new records of many that are colonising *E. nitens* from their natural host, *E. globulus* (Lynne Forster pers. comm.).

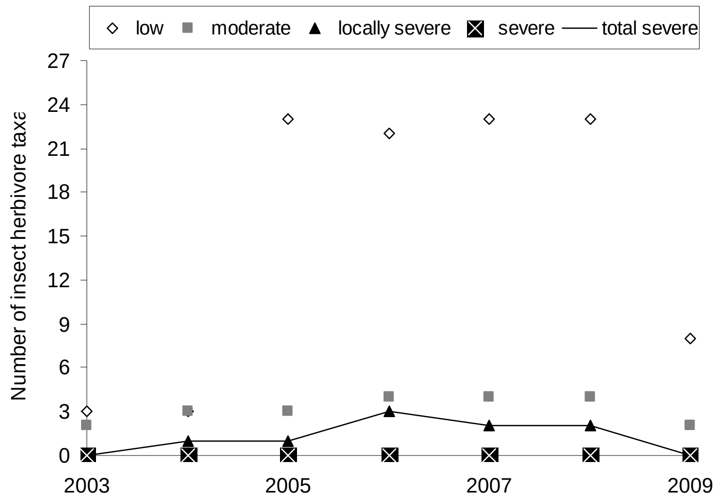
(a) Green Triangle



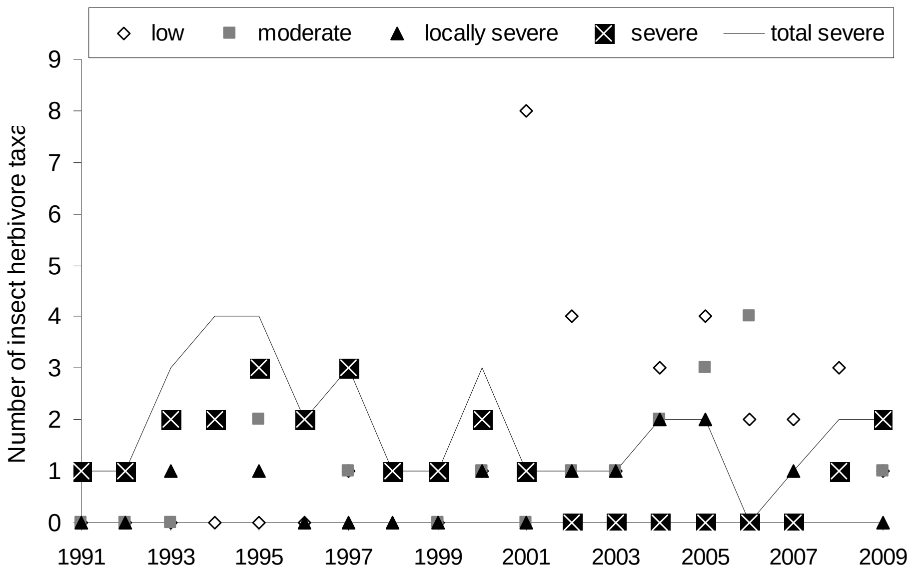
(b) South-west WA



(c) Esperance, WA



(d) Tasmania

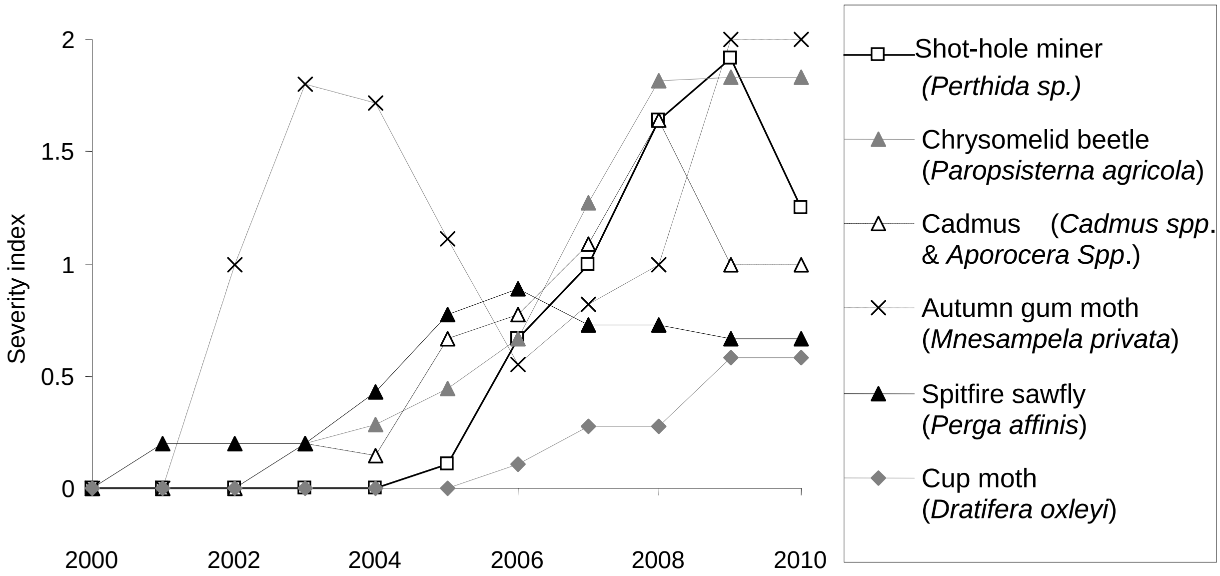


(e) Tasmania—Taxonomic richness

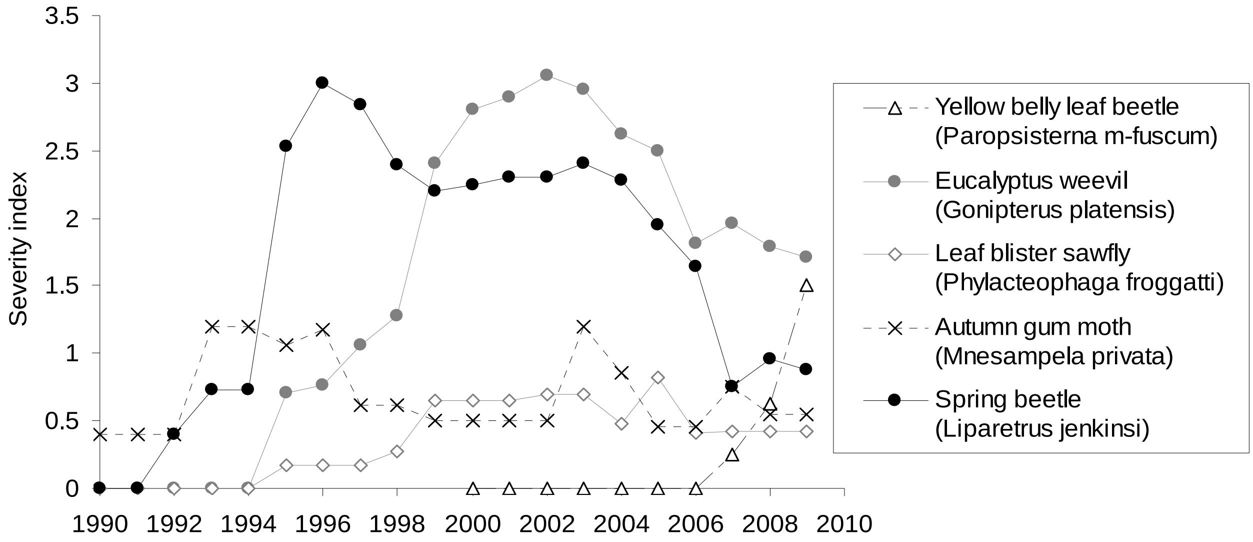
Figure 3. Annual variation in the number of insect herbivore species or species groups (taxa) causing damage recorded on *E. globulus/ nitens* plantations from (a) the Green Triangle, (b) south-west WA, (c) Esperance WA, and (d–e) Tasmania. For a–d insect herbivore records are grouped according to damage levels. The Tasmanian taxonomic richness data (e) are the records for species of insect herbivores collected on *E. nitens* in Forestry Tasmania's Tasmanian Forest Insect Collection database

Analysis of the index of cumulative damage indices (incorporating severity and spatial extent) over time for the most significant insect herbivore species in the major regions where *E. globulus/ nitens* plantations occur, showed regional trends and species-specific patterns (Fig. 4). For the Green Triangle, damage indices for all of the six most significant herbivore species in recent years (2009–2010) were at or just below their highest levels (Fig. 4a). In south-west WA only, damage by yellow-belly chrysomelid beetle (*Paropsisterna m-fuscum*) appears to have recently increased, due mostly to expansion of its range after its recent introduction (Fig. 4b). Damage levels for the other major insect herbivores increased initially until the mid-1990s to early 2000s but decreased in recent years, except for localised outbreaks of autumn gum moth (*Mnesampela privata*) (Fig. 4b). In Tasmania, the damage levels from chrysomelid beetles (mainly *P. bimaculata* and *P. agricola)* were highest of all pests but all showed characteristics of outbreaks punctuated by periods of lower damage (Fig. 4c). All four main pests peaked in 2004 to 2005, and chrysomelids, autumn gum moth and gum leaf skeletoniser (*Uraba lugens*) peaked again in 2009.

(a) Green Triangle



(b) South-west WA



(c) Tasmania

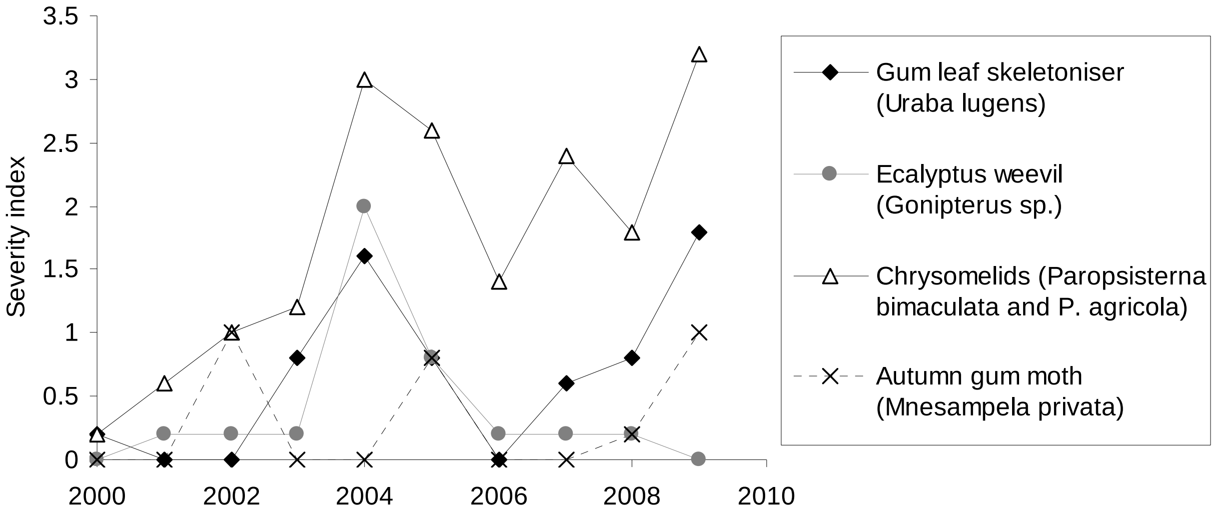


Figure 4. Annual change in severity of *E. globulus/nitens* plantation damage caused by the most significant insect herbivores from (a) the Green Triangle, (b) south-west WA, and (c) Tasmania. The severity index was calculated by summing the number of sub-regions assigned to severity scores of low=1, moderate or locally severe=3, and widespread severe=5, and divided by the number of sub-regions with plantations (see Appendices 1–3)

Although the severity indices of individual species were represented by shorter time series, and showed varying patterns, the patterns overall concurred generally with the other results (Figs. 2–3). For WA and Tasmania, herbivore damage increased initially but then levelled out or even decreased over time, although the plantation estate continued to expand. Data from the longer time period (Fig. 3) suggests that outbreaks caused by individual species fluctuated over several years. Thus, for some of the species analysed for within-region plantation damage, one might predict that these species represent the increasing phase of short-term outbreaks (e.g. those in the Green Triangle), while longer term data from Tasmania suggest that damage levels may moderate over time.

2 *Are the current significant insect herbivores of* E. globulus/nitens *plantations the same species as in the past?*

Many of the currently significant insect herbivores of *E. globulus/ nitens* plantations are the same as those of the recent past, as documented by Strauss (2001), but there are also regional differences and some additional species (Table 3). For the Green Triangle, Phillips (1993) and Strauss (2001) listed the most injurious insect herbivores as a number of chrysomelid species, *Heteronyx* beetle (*Heteronyx elongatus*), autumn gum moth (*Mnesampela privata*), wingless grasshopper (*Phaulacridium vittatum*) and spitfire sawfly (*Perga* spp.*)* Data from the current study suggest that insect herbivores that have caused problems include *Heteronyx* beetle, autumn gum moth, wingless grasshopper, a suite of chrysomelid beetles and cadmus beetles (*Paropsisterna agricola, Cadmus litigiosus, Aporocera apicalis,* and *Aporocera melanocephala*), spitfire sawfly (*Perga affinis, Pergagrupta* sp.), shot-hole miner (*Perthida* sp.), spring beetle (*Heteronyx dimidiata* and *Liparetrus discipennis*), nocturnal *Heteronyx* beetles and cup moth (*Doratifera oxleyi*) (Fig. 4a). Damage by chrysomelid beetles and nocturnal *Heteronyx* beetles is widespread, while the other species tend to cause localised severe damage. The shot-hole miner appears to have recently emerged as a significant herbivore of eucalypt plantations in the Green Triangle.

For WA, Abbott (1993a) and Strauss (2001) identified spring beetle (*Liparetrus* spp.) and wingless grasshopper as the most injurious insect herbivores. Both spring beetle (especially *L. jenkinsi*) and wingless grasshopper still cause localised but severe damage to seedlings. Several additional insect herbivores that caused damage around 2000 should have been listed by Strauss (2001), including eucalyptus weevil (*Gonipterus platensis* formerly identified as *G. scutellatus*; (Mapondera *et al.*, Manuscript), leaf-blister sawfly (*Phylacteophaga froggatti*), autumn gum moth, and African black beetle (*Heteronychus arator*) (Loch & Floyd, 2001; Table 3). African black beetle (a pasture species introduced from South Africa) is no longer a pest in plantations since the introduction of mesh socks to protect seedlings in the late 1990s (Bulinski *et al.*, 2006; Robinson, 2008). The cadmus beetle (*Cadmus excrementarius*) caused localised but severe damage to saplings in the early 2000s (dos Anjos *et al.* 2002). This species is now widespread in plantations but no longer causes severe damage.

Interestingly, three of the current injurious insect herbivores were introduced to WA from the eastern states. Eucalyptus weevil is likely to have been introduced in the late 1980s or early 1990s. Leaf-blister sawfly was introduced in 1978; (Mayo *et al.*, 1997). Yellow-belly chrysomelid was introduced in the early 2000s, and its distributional range is still spreading.

Essentially, the insect herbivores that caused tree injuries in eucalypt plantations in WA in the 1990s still caused localised damage in 2009, with the addition of the recent emergence of yellow-belly chrysomelid and nocturnal *Heteronyx* beetles (Table 3; Fig 4b). Nocturnal *Heteronyx* beetles were known from the early 2000s (Andrew Loch, pers. comm.) but their damage to trees has been more widely recognised since the mid-2000s.

In Tasmania, Bashford (1993) and Strauss (2001) noted that the most significant insect herbivores in 1991 and 2000 were chrysomelids (especially *Paropsisterna bimaculata* and *P. agricola*), spring beetle (*Heteronyx* spp.), autumn gum moth and gum leaf skeletoniser (Table 3). Data from this study also identified three other insect species, two scale insects (*Eriococcus confusus*, *E. irregularis*) and the thin strawberry weevil (*Rhadinosomus lacordairei*) as having caused locally serious damage. As at 2010, the Forestry Tasmania Forest Health database lists chrysomelids, spring beetle, autumn gum moth and gum leaf skeletoniser as still causing significant tree injury, but with the addition of eucalyptus weevil and omission of several other species (Table 3; Fig. 4c). Note that the records of eucalyptus weevil include a complex of five species, formerly all identified as *G. scutellatus* (Mapondera *et al.*, Manuscript).

Rather than expanding their range, some of the long-established pests show distinct cyclical fluctuations or outbreaks in their populations (Figure 4a-c). Autumn gum moth, a distinct outbreak species, shows outbreak cycles of three and five years in Tasmania and six years in WA and the Green Triangle. Both the gum leaf skeletoniser and chrysomelids show five-year cycles in Tasmania. Since all three of these major pests broke out in the same years in Tasmania (2004 and 2009) it suggests that there may have been a climatic factor that triggered the outbreaks, such as warmer than normal winters with lower pest mortality, or a drought that lowered the defences of the host trees. Alternatively they could be natural predator–prey cycles (Steinbauer et al., 2001; Begon & Mortimer, 1981).

Table 3. Insect herbivores considered most injurious to *E. globulus/ nitens* plantations. Data 1991–2000 are from several sources (Abbott, 1993a; Bashford, 1993; Phillips, 1993; Strauss, 2001); 2010 data are from this study

Region	1991–2000	2010	Common name used by foresters
Green Triangle			
	Heteronyx elongatus	*Heteronyx elongatus*	*Heteronyx* beetle or cockchafer
		Heteronyx dimidiata	spring beetle
		Liparetrus spp. but mostly *L. discipennis*	spring beetles
		nocturnal *Heteronyx* spp.	*Heteronyx* beetles
	Mnesampela privata	*Mnesampela privata*	autumn gum moth
	Phaulacridium vittatum	*Phaulacridium vittatum*	wingless grasshopper
	Chrysomelids	*Paropsisterna agricola*	southern leaf beetle
		Cadmus litigiosus	cadmus beetle
		Aporocera apicalis	cadmus beetle
		Aporocera melanocephala	cadmus beetle
	Perga spp.	*Perga affinis*	spitfire sawfly
		Pergagrupta sp.	spitfire sawfly
		Perthida sp.	shot-hole miner
		Doratifera oxleyi	cup moth
WA			
	Liparetrus spp.	*Liparetrus* spp. but mostly *L. jenkinsi*	spring beetles
	Phaulacridium vittatum	*Phaulacridium vittatum*	wingless grasshopper
	*Heteronychus arator**		African black beetle
		Paropsisterna m-fuscum	yellow-belly chrysomelid
	*Gonipterus platensis**	*Gonipterus platensis*	eucalyptus weevil
	*Phylacteophaga froggatti**	*Phylacteophaga froggatti***	leaf-blister sawfly
	*Mnesampela privata**	*Mnesampela privata***	autumn gum moth
		nocturnal *Heteronyx* spp.	*Heteronyx* beetle
Tasmania			
	Chrysomelids	Chrysomelids (mainly *Paropsisterna bimaculata* and *P. agricola)*	leaf beetles
	Heteronyx spp.	*Heteronyx dimidiata*	spring beetle
		Heteronyx crinitus	spring beetle
	Mnesampela privata	*Mnesampela privata*	autumn gum moth
	Uraba lugens	*Uraba lugens*	gum-leaf skeletoniser
		Gonipterus spp.	eucalyptus weevils
	*Eriococcus confusus**		scale insect
	*Eriococcus irregularis**		scale insect
	*Rhadinosomus lacordairei**		thin strawberry weevil

*Omitted by Strauss (2001).

**There has been no major outbreak by these species for several years, and these are not regarded as significant pests now. However, foresters have not eliminated possibilities of outbreaks in the future.

3 Have new insect herbivore species recently emerged as pests?

Analyses of the number of records of insect herbivores from *E. globulus/ nitens* plantations showed a clear increasing trend with time (Fig. 1, Table 2). However, more detailed analyses showed that this pattern was driven by insect herbivores causing low or moderate damage (Fig. 2, Table 2). Although it is tempting to assume that *E. globulus/ nitens* plantations are accumulating insect herbivores, taxonomic inconsistencies with the RWG7 data prevent us from making such conclusions.

Regional data show that the number of species and species groups causing low damage (the dominant contributors to total richness) increased over time for the regions of the Green Triangle (Fig. 3a) and south-west WA (Fig. 3b). This pattern was less apparent for Esperance, WA (Fig. 3c) and Tasmania (Fig. 3d). In the case of Tasmania, there were data deficiencies for the number of species and species groups classified as low severity (see *Methods*). However, the data on the number of insect herbivores recorded on *E. nitens* from Forestry Tasmania's Tasmanian Forest Insect Collection database are more reliable (Fig. 3e), although this collection includes all insects collected on *E. globulus/ nitens* including those that are not necessarily pests. These data suffer from unsystematic variation in year-to-year sampling effort, but they nevertheless show an increasing trend of taxonomic richness with time.

4 Are the insect herbivore species evenly distributed throughout the plantation estate?

Some of the insect herbivores were found in all regions with *E. globulus/ nitens* plantations (e.g. autumn gum moth) but, generally, the most significant insect herbivores varied with each region (Table 3). The spatial tables in Appendices 1–3 showed that damage caused by insect herbivores was not homogenously distributed across and within regions, with some sub-regions suffering more damage by insect herbivores than others. In the Green Triangle region, damage by insect herbivores was higher in the sub-regions of Branxholme, Dorodong, Hamilton and Wattle Range (Appendix 1). These are sub-regions with a mixture of older and younger plantations and therefore susceptible to a full range of herbivores. They are also the regions where most of the eucalypt estate can be found. Older plantations are not yet common in other regions, and diversity of herbivores is relatively low. Northern sub-regions, including Dorodong and Wattle Range, experience marginal rainfall and frost problems. Some plantations in Branxholme, Dorodong, Hamilton, and Wattle Range experience nutrient limitation, especially when trees are young. In south-west WA, the sub-regions clustered in the southern and eastern-most parts of the eucalypt plantation estate showed the greatest damage by insect herbivores. These sub-regions included Manypeaks, Denbarker, Palmdale, Porongurups and Albany (Appendix 2). This is largely because all five species that cause severe damage are present in these sub-regions. Two of these five most significant insect herbivores (autumn gum moth and leaf-blister sawfly) do not cause severe damage in drier sub-regions away from the coast. For eucalyptus weevil and spring beetle, damage tends to be more severe, more frequent, and more extensive in drier marginal sites (South Stirling, Mt Barker, Perilup, Rocky Gully, Frankland, and Boyup Brook). For Tasmania, the cumulative severity of insect herbivores across sub-regions and years was fairly even with the exception of the Bass sub-region, the largest plantation node in the north-east of the state, which appeared to have slightly more moderate and severe records (Appendix 3).

5 Are insect herbivore species that have recently emerged as problems in eucalypt plantations expanding their range?

The species included in the regional analyses showed varying patterns between sub-regions and over time. Many of the species may have been already present on the native eucalypts in low numbers but they came to the attention of the entomologists as their damage levels in plantations increased. Species that caused damage in the Green Triangle showed strong evidence of range expansion following the expansion of the plantation estate (Appendix 1). For example, the shot-hole miner showed a clear pattern of spread from the Dorodong sub-region in 2005 to the adjacent sub-region of Poolaijelo in 2006 and further afield thereafter, while at the same time the level of damage increased (Appendix 1a). A similar, simultaneous pattern of range expansion of damage to adjacent sub-regions and increase in damage levels also occurred for chrysomelid beetles, cadmus beetles, autumn gum moth, spitfire sawfly and cup moth (Appendix 1b–f). In south-west WA, the introduced yellow-belly chrysomelid beetle showed evidence of range expansion to adjacent sub-regions and increased damage levels for sub-regions in the far south-east, but not including two sub-regions located near the north-west (Appendix 2a). The introduced eucalyptus weevil also showed evidence of range expansion to adjacent sub-regions over time, but with a trend for decreased damage levels (Appendix 2b). However, the introduced leaf-blister sawfly and autumn gum moth did not spread to adjacent sub-regions, and damage levels by both decreased over time (Appendix 2c–d). Spring beetle showed evidence of range expansion to adjacent sub-regions over time with an initial increase in damage although in recent years there has been a trend for decreased damage levels (Appendix 2e). For the four insect herbivores present in Tasmania, there was no evidence that they had extended their range over the period examined (Appendix 3).

Discussion

In general, there was support for many of the predictions made regarding insect herbivores in eucalypt plantations in southern Australia. However, some of the patterns of change in damage levels among sub-regions over time were specific to particular regions or species, and the more pessimistic predictions that insect herbivore damage in eucalypt plantations would increase has, on the whole, not been supported by the data. Each of the research questions are examined in more detail below. The authors of this study acknowledge that the strength of the conclusions is weakened due to the limitations of the data in that, over time, the survey effort and methodology is unlikely to have been very consistent among regions and even among companies. Nevertheless, the data are still important as they are the only historical account of patterns of insect pests in *E. globulus/nitens* plantations.

1 Are the damage levels from insect herbivores in eucalypt plantations increasing?

In spite of a large increase in the total size of the eucalypt plantation estate during the period 1994–2009, there was little evidence that damage levels in *E. globulus/nitens* plantations caused by insect herbivores had also increased. At the scale of southern Australia, total records of insect herbivores that caused damage in eucalypt plantations increased initially over time before they levelled off or decreased. This initial increase was driven by the number of records of insect herbivores that caused low and moderate damage rather than those that caused severe damage. For WA, insect herbivore problems were less extensive and less severe in 2009 than a decade ago. For the Green Triangle, there have been a few more problems in recent years than in the past. For Tasmania, the long-term trend can be described as not increasing or decreasing consistently but having occasional outbreaks. On the whole, these results therefore do not agree with predictions made by Strauss (2001) and Loch and Floyd (2001) that damage from insect herbivores would increase as the area of the eucalypt plantation estate increased. Only severe outbreaks were correlated with the area of new plantings so, given the decrease in the area of new eucalypt plantings in the last few years (Gavran & Parsons, 2010), these severe records may also decrease.

The number of records of severe damage in plantations across southern Australia was closely associated with the area of new plantings but was not associated with time. This may be because seedlings and saplings are generally more susceptible to injury from insect herbivores than older trees due to their smaller canopy and reduced ability to recover from defoliation, although older trees become more susceptible to other suites of insects such as stem borers. Establishment pests kill seedlings (e.g. Matsuki, 2008b) while post-establishment pests rarely kill trees, slowing their short-term growth (Elek, 1997; Collett & Neumann, 2002; Pinkard, 2002, 2003; Pinkard *et al.*, 2006a; Pinkard *et al.*, 2006b) but not always affecting long-term growth (Rapley *et al.*, 2009; Loch & Matsuki, 2010). Establishment pest are likely to be under-reported relative to post-establishment pests because establishment pests tend to cause more severe but more localised damage than post-establishment pests. Thus, establishment pests are less likely to be scored in the consistent severe category (Table 1).

One of the reasons for not seeing increased records of severe damage by establishment pests may be that techniques for site preparation, surveillance, and control of establishment pests have improved over time. In the very early years of plantation establishment in WA, seedlings were damaged by crop and pasture pests (Abbott, 1993a). Improved techniques in pre-planting weed control have practically eliminated these problems. Also, a better understanding of the biology of spring beetle (*Liparetrus jenkinsi*) and wingless grasshopper in WA has increased the ability to predict successfully the location and timing of insect swarms, allowing successful chemical control of insects before seedlings are severely damaged. An integrated pest management program that has been operated by Forestry Tasmania since its introduction in the early 1990s has targeted those populations of chrysomelid leaf beetles that are over a predetermined economic damage threshold (Elliott et al., 1992); its methods for monitoring and prediction are continually being improved to increase efficiency and effectiveness. Another example of improved management is the use of mesh socks to protect seedlings from damage caused by African black beetle (Bulinski *et al.*, 2006; Robinson, 2008).

Improvements in silvicultural practices may have contributed to the levelling off of damage by post-establishment insect pests in some regions. For example, in the early years of plantation establishment in WA, many plantations were established in climatically marginal areas at higher than sustainable stocking rates. It is suspected that insect outbreaks started in these plantations containing stressed trees (T. Mitchell and B. Edwards, pers. comm.). Susceptibility to some insect pests has long been linked to tree stress (Gadgil & Bain, 1999; Stone, 2001). In the past two decades, site selection, site preparation, weed control, nutrient application, as well as genetics of trees have all improved. Consequently, trees in plantations are generally less likely to be stressed now than in the 1990s, if the reduction in rainfall is ignored. Improvements in monitoring, timing and methods of insecticide application against post-establishment insect pests have also resulted in more targeted use of insecticides across the entire eucalypt plantation estate. For example, in the late 1990s and early 2000s, insecticides tended to be applied when severe damage was discovered (and in some instances, after the insects had pupated) so that applications of insecticides did not reduce populations or damage levels in the following year (J. Edwards, personal communication).

A further reason why insect herbivore damage is not worsening could relate to climatic barriers to insect herbivore spread. The local climate, rather than the distribution of host plants, may constrain the distribution of particular insect herbivores (Kriticos *et al.*, 2007). For example, it is thought that damage by autumn gum moth and leaf-blister sawfly is restricted to coastal areas in south-west WA because these two species appear unable to survive in the hot and dry summers of inland areas. Unsuitable climatic conditions could also restrict the distribution of other insect herbivores.

Strauss (2001) and Loch and Floyd (2001) predicted that insect damage would increase in plantations of *E. globulus/ nitens* over time because insect herbivores in southern Australia were already adapted to feeding on *Eucalyptus* species. However, these researchers may have failed to consider that there is also a large suite of natural enemies residing in native vegetation. Light trap and other observations indicate that many specialist and generalist insect species are natural enemies of insect herbivores in *E. globulus* plantations in WA (Matsuki, 2005; Matsuki & Loch, 2005; Matsuki, 2006b, Manuscript). The leaf beetles, *Paropsisterna agricola* and *P. bimaculata* have suites of natural enemies in Tasmania that are very important at reducing egg and larval populations (Nahrung, 2004; Rice, 2005; Elliott and de Little, 1980; de Little, 1982). Insectivorous birds are also relatively abundant in *E. globulus* plantations (Matsuki, 2005; Loyn *et al.*, 2007; Loyn *et al.*, 2008; Matsuki, 2008a; Loyn *et al.*, 2009; Matsuki, Manuscript) and have been observed to actively hunt for insect species that cause severe damage in plantations in WA and Tasmania (M Matsuki and J Elek, pers. comm.). Contrasting examples of *E. globulus* damage by herbivores in Portugal and WA suggest the importance of having natural enemies capable of colonising eucalypt plantations. In both areas, *E. globulus* is an introduced species. In Portugal, a number of damaging insect herbivores have been accidentally introduced from Australia: eucalyptus weevil, two longicorn beetles and two psyllids, and one species of Erinose mite. These insect herbivores are also present in plantations in WA. However, each species causes much more severe damage in Portugal than in WA (C. Valente, personal communication). In sharp contrast with Australia, Portugal has no specialist natural enemies of these insect herbivores, and generalist natural enemies such as birds and predatory insects have not yet moved into plantations (C Valente, pers. comm.).

Another possible explanation for why insect damage is not becoming more severe in eucalypt plantations could be reduced spraying of broad-spectrum insecticides. Spraying insecticides in eucalypt plantations may have unintended consequences, including reduced populations of natural predators (Elek *et al.*, 2004; Loch, 2005). After spraying plantations with insecticides, the repopulation of natural enemies into plantations from native vegetation may lag behind the re-population of herbivores. Consequently, widespread spraying with broad-spectrum insecticide might give herbivores a chance to build up population levels (i.e. secondary pest eruptions), particularly those with short life cycles, such as psyllids. Anecdotal evidence suggests a reduction in the use of insecticides in recent years against autumn gum moth, leaf-blister sawfly and eucalyptus weevil in eucalypt plantations in WA (IPMG members, pers. comm.). A reduction in spraying could therefore lead to higher predation of insect herbivores and lowered risk of creating secondary pest eruptions.

In order for natural enemies to provide effective control of insect herbivores in plantations, there are at least two issues to consider. First, a diverse range of natural enemies that attack different life stages of herbivores, are active in different times of the year, and that occur in different microhabitats is more likely to provide effective control of insect herbivores than species with similar biology (see review by Sih *et al.*, 1998). Having high diversity of insect herbivores is one condition for attracting high diversity of natural enemies. As this report has shown, the diversity of insect herbivores has been increasing in eucalypt plantations. Thus, one might expect that the diversity of natural enemies may also be increasing in plantations. However, only limited information on the diversity of natural enemies in plantations exists (Matsuki & Loch, 2005; Matsuki, 2006b). Second, both insect herbivores and natural enemies are likely to move between plantations and adjacent vegetation. In agricultural systems, predator spill-over from adjacent vegetation has been documented in many crops (Rand *et al.*, 2006). Since natural predators often need alternative resources such as nectar and pollen, or habitat refugia for overwintering or oversummering, their populations are likely to be higher and more stable in native vegetation, rather than in land uses with more intensive production that have simpler habitat structure (Landis *et al.*, 2000). In agricultural landscapes, pest control provided by natural enemies is higher in more complex landscapes and where there is a higher proportion of non-crop habitat (Bianchi *et al.*, 2006). Unfortunately, there has been no research of this type in plantations in Australia, so it is not known if these effects operate at plantation edges or how far they penetrate into plantations.

2 *Are the current significant insect herbivores of* E. globulus/ nitens *plantations the same species as in the past?*

Some species of insect herbivores are causing as much damage now as they were ten or twenty years ago. Some species are no longer a problem while others have recently emerged as pests. The phenomenon of recently emerging pest species is dealt with in question 3 (below). A potentially confounding factor in the data is that sampling effort has probably changed over time. When reporting is usually reliant on operational forestry staff, common pests can become underreported due to familiarity and due to the low priority given to reporting compared with other operational issues (Lawson *et al.*, 2008). This may manifest in the recorded common pest species varying over time. In this study, longer term trends of insect herbivore species show that damage caused by some species fluctuates, causing problems in some years but rarely consistently every year. Some species have outbreaks that extend over a few years followed by years of no visible damage. For example, in Tasmania, scale insects (*Eriococcus confusus, E. irregularis*) caused locally severe damage in eucalypt plantations during the mid-1990s but are not recorded in the Tasmanian databases thereafter. Others caused damage intermittently, interspersed by years with no damage. For example, in Tasmania, autumn gum moth caused damage in 2002 and then in 2005 but caused little damage in intervening years (Fig. 4c). Both the chrysomelid beetles, *Paropsisterna agricola* and *P. bimaculata,* and gum leaf skeletoniser also had damage peaks in Tasmania during the mid-2000s and again around 2009. These fluctuations in pest damage may be caused by several factors. Interestingly, outbreaks of different species have occurred in different years suggesting that different species may be responding to different factors (e.g. release from specialist natural enemies). Changes in the age of trees and a general maturation of the plantation estate may also explain why the identities of some of the herbivore species have changed over time.

As previously discussed above, interactions with natural enemies and the environment is important. Many insect herbivores have specialised or generalised natural enemies that often regulate populations. However, sometimes these natural enemies may become spatially or temporally isolated, leading to outbreaks of insect herbivores because they are released from their enemies (e.g. eucalyptus weevil in WA; Loch, 2008). When natural enemies (e.g. predators and diseases) overcome isolation, they suppress herbivore populations and the insect outbreak diminishes. These oscillations of populations of natural enemies may be natural or may be mediated by environmental events (Loch, 2008). The impacts of insect herbivores may be higher during drought years when trees are stressed and less able to recover from insect herbivory.

3 Have new insect herbivore species recently emerged as pests?

The initial increase in the number of insect herbivore records from *E. globulus/nitens* plantations at a national and regional scale over time, in parallel with the increase in the total hardwood estate size, agree with predictions that the plantation estate should accumulate more herbivore species (Abbott, 1993b; Loch & Floyd, 2001; Strauss, 2001). Although it is rare to have records of absence of species, foresters in the Green Triangle and WA have noted the ‘honeymoon’ period, during which no insect has caused damage to trees, in the early years of establishment of plantations in these regions. The expansion of the plantation estate into ex-agricultural land with embedded remnants of native vegetation has almost surely led to the successful colonisation of many insect herbivore species, particularly in areas where the plantation species have been introduced as a new eucalypt species. Examples of these can be seen in Appendices 1 and 2. Also, in Tasmania, the introduced species *E. nitens* now has a higher number of chrysomelids recorded on it than *E. globulus* (TFIC database; Lynne Forster, pers. comm.).

Not all insect herbivores colonising eucalypt plantations have originated from native eucalypt forests. A group of insect herbivores that was not included in the list of predicted species by Strauss (2001) was nocturnal scarab beetles. Fifty-four species have been recorded in eucalypt plantations in WA and 46 species in the Green Triangle (Matsuki, 2006a, 2008c). Adults of several species can be found in large numbers and have caused severe and extensive damage in some years (Matsuki, 2009). Their larvae feed on fine roots and are found predominantly in pastures and degraded remnants with weeds.

Findings from this report are consistent with patterns of colonisation in Asia, South America, and South Africa where many native species of insect herbivores have successfully colonised eucalypt plantations (Paine *et al.*, 2011). In contrast, native species of insect herbivores are poor colonisers of eucalypt plantations in North America and Europe (Paine *et al.*, 2011). The difference can be explained by the regional presence or absence of plants in the family Myrtaceae (to which eucalypts belong). Insect herbivores that have never encountered myrtaceous plants in their native habitats are less likely to be able to colonise eucalypt plantations than insect herbivores that have encountered myrtaceous plants. This is because insect herbivores that have never encountered myrtaceous plants are not familiar with the chemical compounds in eucalypts and consequently are not likely to recognise eucalypts as their host plant or to be able to feed on eucalypt leaves. In contrast, insect herbivores that have encountered myrtaceous plants in their native habitats are likely to be able to feed on eucalypt leaves from a range of species. These herbivores can be specialists on myrtaceous plants or generalists that feed on plants in different families (such as *Heteronyx* beetles in Australia). These are examples of 'ecological fitting' in which herbivores are able to feed on new plant species without evolutionary change in the ability of the insects to feed on new plant species (see Agosta, 2006).

It is also plausible that the increase in species richness of insect herbivores over time may partly be a sampling artefact. It is likely that reporting and monitoring standards and techniques have improved over time (Lawson *et al.*, 2008). For example, insect surveys among plantations in WA now regularly use techniques such as light traps that have revealed a very diverse assemblage of nocturnal insect herbivores not previously detected with more conventional daylight insect collecting methods (Matsuki, 2006b, 2006a, 2008c). In addition, some of the causes of the emergence of particular insect herbivore species as pests are due to the accidental introduction of species. For example, several species of insect herbivores were introduced to WA from eastern states (see *Results*). The ultimate causes of increasing species richness of insect herbivores in *E. globulus/ nitens* plantations over time are likely to be a combination of factors, including more successful colonisation events in addition to an increase in sampling effort or efficiency.

4 Are the insect herbivore species evenly distributed throughout the plantation estate?

Regional analyses showed that each region differs with regard to the identity of many insect herbivores, apart from some of the most common pests that occur right across southern Australia. This observation concurs with results by Strong (1974) and Strong *et al.* (1977) who found that few insect herbivores of cacao and sugar cane were shared in different countries where these crops were grown. That is, each growing region independently acquires its own insect herbivore fauna.

Results also showed that within regions, damage caused by insect herbivores was not evenly distributed. Even if insect herbivores were present throughout regions, some sub-regions were more severely affected by herbivory. What causes this patchy damage? It could be that trees were more susceptible, or that conditions were more favourable for outbreaks of the pest insects in some sub-regions. Detailing the specific reasons why certain sub-regions were more affected by insect herbivory is beyond the scope of this study; however there could be a number of possible causes.

The sub-regions with more serious insect damage could be those with one or more environmental conditions limiting tree growth and causing plant stress. Tree stress could arise from poor plantation management, starting with suboptimal site selection. Tree species that are poorly matched to the local climate, soils or drainage may lead to poor growth (Battaglia & Sands, 1997; Gadgil & Bain, 1999). The local climate could favour particular insect species and host relationships, which in turn could affect damage levels spatially. For example, *P. bimaculata* causes much more severe damage in higher altitude *E. nitens* than in lower altitude *E. globulus* plantations in Tasmania (Wardlaw, 2010). Climate could also make some entire regions more susceptible to insect herbivory. For example, the cool climate of Tasmania leads to a very short growing season which limits the ability of trees to recover from damage caused by insect herbivores (Loch & Matsuki, 2010). In WA or the Green Triangle, there is a longer growing season that allows trees to re-flush after herbivore damage, thereby compensating for the effects of herbivory. Conversely, a warmer climate could work in the opposite direction, favouring herbivores by allowing a longer herbivore season. The local landscape, especially the proportion of native forest present, might also influence insect herbivory. It is possible that there is a greater suite of natural enemies in forested areas than in areas dominated by pasture (see above). Sub-regional differences in susceptibility to insect herbivores may also reflect differences in the history of plantation establishment and insect herbivore spread and colonisation (see below). Sub-regions may also have trees dominated by a certain age cohort and this is likely to influence the identity of herbivore species and distribution patterns.

5 Are insect herbivore species that have recently emerged as problems in eucalypt plantations expanding their range?

Spatial analyses showed that each region has its own patterns of colonisation and damage among sub-regions over time. Some insect herbivores showed patterns that agree with predictions that recently emerged pest species would spread and become more problematic (Strauss, 2001). However, not all species conformed to this pattern and there were differences among regions.

In WA, the leaf-blister sawfly was introduced from the east coast, but it is rare or absent in *E. globulus* plantations in drier areas (see above). However, other insect herbivores in the Green Triangle and in WA have shown patterns of emergence as pests, followed by outbreaks that then spread to adjacent sub-regions. This might be due to the pests migrating into new areas faster than their natural enemies. If newly introduced (or colonised) insect herbivores are isolated from their natural enemies (in space or time), populations may increase unchecked until natural enemies become established or adapted. For example, in WA the initial outbreak of the eucalyptus weevil appears to have been caused by a time lag in its natural parasitoid *Anaphes nitens* that was unable to match the rate of spread of the weevil across plantations. There was also a temporal mismatch between the phenology of the wasp and its eucalyptus weevil host (Loch *et al.*, 2004; Loch, 2008). But not all insect herbivore pests are able to find enemy-free space. For example, chrysomelid beetles (*Paropsisterna* spp. and *Paropsis* spp.) in south-west WA are thought to have a suite of effective natural enemies. This means that the introduced yellow-belly chrysomelid may not cause serious damage, despite the fact that this species is abundant and has expanded the range in which it causes damage.

In Tasmania, the major chrysomelid pest species have been widely distributed and *P. bimaculata* has been reported to cause severe defoliation in native forests long before plantations were established (Greaves, 1966). It therefore seems unlikely that increased damage levels caused by these species are due to range expansion. Rather, local population increases may be cyclical population fluctuations related to the climate or biological rhythms, or gradual increases in response to more resources being available (de Little & Madden, 1975; Nahrung, 2004; Matsuki *et al.*, Manuscript).

Future trends

So what trends might emerge in the future regarding insect herbivore damage in eucalypt plantations? First of all, the growth in the size of the eucalypt plantation estate is likely to slow over the next few years (Gavran & Parsons, 2010), mostly driven by reduced financial investment in the forestry industry (although this could change if investment in carbon offsets increases). Some consolidation of the plantation estate to better growing sub-regions might also occur and continued improvements in the management of eucalypt plantations are likely to improve tree health. Improved silviculture management of plantations should reduce the impact of insect herbivores on tree growth. Management actions would include tree selection, better matching of tree species with sites (including soil and microclimate) and stocking rates, and pruning (only some regions) and fertilising regimes (especially in later rotations). These actions should maintain better health and vigour of trees so that trees can resist and compensate for defoliation. However, future tree health may be adversely affected by lower rainfall caused by a drying climate, and, in areas where tree roots can access the water table, reduced access to groundwater caused by draw-down of the water table in first-rotation plantations (White *et al.*, 2007). If tree health is maintained or improved, damage to eucalypt plantations caused by insect herbivores in the future is likely to be similar to or even lower than at present. New insect herbivores are likely to continue to emerge, and some may cause severe damage for a period but, as has happened in the past, these problems are likely to decrease over time, either through the action of natural enemies or by better management decisions guided by scientific studies. Improved monitoring systems that detect pests early and judicial selection and timing of any insecticides used for control of damaging populations should improve pest management. For example, effective monitoring can aid timing of insecticide applications so that a selective insecticide that does not kill natural enemies can be applied when it will be most effective against the pest.

An increased proportion of plantations will be in the second and third rotation cycles in the next decade. At least some of those plantations will be coppiced, rather than replanted. On the one hand, coppicing will decrease the incidence of damage by establishment pests, but on the other hand, coppicing is likely to increase population levels of certain species of post-establishment pests such as many paropsine chrysomelid beetles (*Paropsis* and *Paropsisterna*) that favour juvenile foliage on coppice, and tip-feeding bugs such as *Amorbus*, gall formers and free-living psyllids, and could also disrupt natural enemy systems (e.g. Steinbauer et al., 1998; Bjórkman et al., 2004).

There exists a real possibility for generalist herbivores overseas to colonise eucalypt plantations in Australia (Paine *et al.*, 2011). *Eucalyptus* species have been planted all over the world as plantation species or ornamental trees, and many insect species native to those regions have colonised them (Paine *et al.*, 2011). If these insect herbivores were accidentally introduced to Australia, this might result in them causing severe damage, as it is unlikely that their specialist natural enemies are present in Australia. In the future more species of generalist herbivores that cause severe damage may colonise *E. globulus* or *E. nitens*. For example, scarab beetles, *Heteronyx* and *Liparetrus* are not specialists of *Eucalyptus* or myrtaceous plants, yet they can cause severe and extensive damage to *E. globulus* and *E. nitens* in plantations. Unfortunately, it is difficult to predict which species might become pests in plantations.

With respect to specialists on *Eucalyptus*, three possible scenarios could occur. First, if climate change causes consistent warming or greater fluctuations in temperature and rainfall, species that cause damage in eucalypt plantations in NSW and south-east Queensland might expand their range to colonise plantations in southern Australia. Second, population levels of species that are already present in plantations of *E. globulus* or *E. nitens* in small numbers might increase (Matsuki *et al.*, Manuscript). In contrast, as mentioned earlier, climate change might bring drier conditions to south-WA (Matsuki, 2006c) and water-stressed trees might be more susceptible to herbivore damage. Insect damage is more likely to occur in marginal areas for plantations, thus, if climate change predictions are correct, there may be an increased frequency and extent of severe damage by species that are already present in plantations. The emergence of longicorn beetles in the Green Triangle and WA would be examples of the latter possibility that have only caused problems in the past during drought years (Andrew Loch, pers. comm.). Third, species may be accidentally introduced to WA from eastern states or vice versa. As has been shown with species that have been accidentally introduced to WA from the eastern states, two of the three species of insect herbivores on *E. globulus* (and at least one other insect species on another eucalypt species) cause severe damage in WA.

Conclusions

In this historical analysis of patterns of insect herbivores among eucalypt plantations across southern Australia, results show the severity of damage by insect herbivores has generally not increased in line with the increase in the plantation estate. These trends were apparent in each of the regions examined. Several explanations as to why insect herbivore damage has not increased in severity are presented. As has been widely observed in many agricultural crops, this study documented a rapid initial accumulation of records of damage by insect herbivores with the increasing size of the eucalypt plantation estate, but the records of damage levelled off to a relatively constant number of reports. There were also some changes in the insect herbivore species causing severe damage. Although herbivore impacts from some species have increased in some regions recently, these might represent the initial stages of an outbreak that may subsequently decline, as seen in records over the longer time period from Tasmania. Severe damage by the major pest species did not show consistently increasing or decreasing trends over the longer time period in Tasmania. If other insect herbivore species follow similar patterns, this may lead to population declines as part of population cycles, with occurrences of severe damage becoming localised and sporadic.

Although the number of species of herbivores that cause severe damage has not increased greatly over time, the total number of species across all levels of damage has increased. This study has focused on changes in occurrences of damage caused by individual species separately. However, from the point of view of plantation management, it is the total damage sustained rather than the particular species of insects that is important. Nevertheless, the national data suggests that the combined damage by all species is not increasing. In WA, overall damage levels have not been increasing at least since the mid-2000s in sub-regions where plantations have been present for more than a decade (results of this study and M. Matsuki, pers. comm.). In contrast, in the Green Triangle, it has been only ten years since the rapid expansion of plantation estates began, and the estates were still expanding considerably in the latter half of the 2000s. Results of this study indicate that overall damage levels may still be increasing in the Green Triangle.

A key result emerging from this study is the identification of differences in insect herbivory across the three regions analysed. In summary, these differences are: 1) WA and the Green Triangle, but not Tasmania, have had insect herbivores emerge as pests, increase tree damage and expand their range, 2) the distributions of some insect herbivores in WA appear to be constrained by climate, and 3) some insect herbivores from Tasmania and WA that caused damage in the past cause less damage now. Each of the three regions is slightly different with respect to their biophysical environment (particularly the proximity and amount of native eucalypt forest remaining in the landscape surrounding eucalypt plantations), the biogeography of insect herbivores, and the length of time that eucalypts have been grown in plantations. Disentangling the relative importance of these factors in influencing regional differences in patterns of inset herbivory is challenging, and case-specific explanations for the observed patterns were proposed. The lack of monitoring of insect herbivores in native vegetation means interactions between native vegetation and eucalypt plantations are unable to be tracked.

Although it was not the intention of this study to critique forest health surveillance summarised by RWG7, it is evident that the annual Pest, Disease and Quarantine Status Reports for Australia and New Zealand could be improved. Most forest managers have developed their own system for determining when plantations need to be protected from pests, which evolves as costs and new information dictate. Ideally, data on pest populations would be easiest to compare if the data was all collected using the same methods. Specific prescriptions to monitor damage in forests in Australia can be found in Stone *et al.* (2003), although this may need to be modified so it is cost effective and manageable by contract monitors. In addition, adoption by all states of a standard reporting format that quantifies spatial extent and severity of insect herbivore damage would be useful but may be impossible given current funding and resources. Some states have adopted this in some of the more recent reports. More consistent reporting using species-level taxonomic identifications would also be beneficial.

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Appendices

Changes in damage caused by selected species of insect herbivores in *E. globulus/ nitens* plantations among the regions of the Green Triangle, south-west WA and Tasmania. Data for the Green Triangle, south-west WA and Esperance WA were compiled by the Industry Pest Management Group (IPMG). For Tasmania, insect herbivore records from *E. globulus/ nitens* plantations were compiled from Forestry Tasmania's Forest Health database and supplemented with interviews with forest entomologists (David de Little and Dick Bashford). Note that only one species of establishment pest is included in each set of these tables. Within each region, the sub-regional place names are roughly organised in tables such that they correspond to their spatial positioning in the landscape.

Insect herbivore damage classes:

- grey italicised text, no highlight = plantation present, but no evidence of insect or their damage
- black text, no highlight= low damage or low density of insects
- 50% grey highlight and black text = moderate damage or localised severe damage or moderate density of insects
- black highlight and white text = widespread severe damage or high density of insects.

From these tables the year-to-year changes in spatial distribution and degree of damage for each insect species can be inferred.

1. Green Triangle

a) Shot-hole miner (*Perthida* sp.)

This species moved into plantations of *E. globulus* from adjacent native vegetation. These moth larvae mine the mature leaves of several eucalypt species during winter, so trees generally recover during the summer growth period.

2000–03

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	

2004

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	
				Colac

2005

Wattle Range	Dorodong	*Poolaijelo*		
	Casterton	*Branxholme*	*Hamilton*	
		Nareen	*Bessiebelle*	
				Colac

2006

Wattle Range	Dorodong	Poolaijelo		
	Casterton	*Branxholme*	*Hamilton*	
		Nareen	*Bessiebelle*	
				Colac

2007

Wattle Range	Dorodong	Poolaijelo	*Cavendish*	
	Casterton	Branxholme	*Hamilton*	
	Dartmoor	*Nareen*	*Bessiebelle*	
				Colac

2008

Wattle Range	Dorodong	Poolaijelo	Cavendish	
	Casterton	Branxholme	*Hamilton*	
	Dartmoor	*Nareen*	*Bessiebelle*	
				Colac

2009

Wattle Range	Dorodong	Poolaijelo	Cavendish	
	Casterton	Branxholme	Hamilton	
Mt Gambier	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2010	Wattle Range	Dorodong	Poolaijelo	Cavendish	
		Casterton	Branxholme	Hamilton	
	Mt Gambier	Dartmoor	*Nareen*	Bessiebelle	
					Colac

b) Southern Eucalyptus leaf beetle (*Paropsisterna agricola*)

There was no collection record of this species west of Otway Range prior to 2003 (Nahrung, 2004). However, photographs of adults and a larva appear in Phillips (1996) as an unidentified chrysomelid species from SA. Therefore, this species must have been present in small numbers in the Green Triangle for some time. Adults prefer to lay eggs on glaucous, juvenile leaves but they also feed on the flush adult foliage.

NB: Colac is just to the west of Otway Range.

2000–02

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	

2003

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	

2004

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	
				Colac

2005

Wattle Range	*Dorodong*	*Poolaijelo*		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	
				Colac

2006

Wattle Range	Dorodong	*Poolaijelo*		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	
				Colac

2007

Wattle Range	Dorodong	*Poolaijelo*	*Cavendish*	
	Casterton	Branxholme	Hamilton	
	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2008

Wattle Range	Dorodong	Poolaijelo	Cavendish	
	Casterton	Branxholme	Hamilton	
	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2009–10	Wattle Range	Dorodong	Poolaijelo	Cavendish	
		Casterton	Branxholme	Hamilton	
	Mt Gambier	Dartmoor	*Nareen*	Bessiebelle	
					Colac

c) Cryptocephaline leaf beetles (*Cadmus litigiosus, Aporocera apicalis* & *Aporocera melanocephala*)

These chrysomelid beetles (Cryptocephalinae) colonised plantations of *E. globulus* from native *Eucalyptus* species. Adult beetles feed in the crown from late summer to early winter, and larvae feed on fallen leaves in winter.

2000–02

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	

2003–04

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	

2005

Wattle Range	*Dorodong*	*Poolaijelo*		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	

2006

Wattle Range	Dorodong	*Poolaijelo*		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	
				Colac

2007

Wattle Range	Dorodong	*Poolaijelo*	*Cavendish*	
	Casterton	Branxholme	Hamilton	
	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2008

Wattle Range	Dorodong	Poolaijelo	Cavendish	
	Casterton	Branxholme	Hamilton	
	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2009–10

Wattle Range	Dorodong	Poolaijelo	Cavendish	
	Casterton	Branxholme	Hamilton	
Mt Gambier	Dartmoor	*Nareen*	Bessiebelle	
				Colac

d) Autumn gum moth (*Mnesampela privata*)

Although this species spread quickly into plantations in Green Triangle, severe damage tended to be restricted to patches within plantations (usually with stressed trees) rather than widespread. Eggs are generally laid on juvenile foliage low in the crown but the larvae gradually defoliate the crown and then neighbouring trees. The rate of egg parasitism by wasps is very high.

2000–01

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	

2002

Wattle Range	Dorodong			
		Branxholme	Hamilton	
			Bessiebelle	

2003

Wattle Range	Dorodong			
		Branxholme	Hamilton	
			Bessiebelle	

2004

Wattle Range	Dorodong			
	Casterton	Branxholme	Hamilton	
			Bessiebelle	

2005

Wattle Range	Dorodong	*Poolaijelo*		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	

2006

Wattle Range	Dorodong	*Poolaijelo*		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	
				Colac

2007

Wattle Range	Dorodong	*Poolaijelo*	*Cavendish*	
	Casterton	Branxholme	Hamilton	
	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2008

Wattle Range	Dorodong	*Poolaijelo*	*Cavendish*	
	Casterton	Branxholme	Hamilton	
	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2009–10

Wattle Range	Dorodong	Poolaijelo	*Cavendish*	
	Casterton	Branxholme	Hamilton	
Mt Gambier	Dartmoor	Nareen	Bessiebelle	
				Colac

Note: In 2009 & 2010 widespread autumn gum moth with severe damage (widespread 100% defoliation) in the Wattle Range, Poolaijelo and Nareen areas was mostly due to lack of monitoring and control. (Some companies were in receivership during this period.)

e) Spitfire sawfly (*Perga affinis*)

Perga affinis is one of the four species of spitfire sawflies found in plantations in the Green Triangle. This species is found on adult leaves of mostly 2-year-old to 4-year-old trees in winter. It can cause localised but severe damage.

2000

Wattle Range	*Dorodong*			
		Branxholme	*Hamilton*	
			Bessiebelle	

2001–03

Wattle Range	*Dorodong*			
		Branxholme	Hamilton	
			Bessiebelle	

2004

Wattle Range	*Dorodong*			
	Casterton	Branxholme	Hamilton	
			Bessiebelle	
				Colac

2005

Wattle Range	*Dorodong*	*Poolaijelo*		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	
				Colac

2006

Wattle Range	Dorodong	*Poolaijelo*		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	
				Colac

2007

Wattle Range	Dorodong	*Poolaijelo*	*Cavendish*	
	Casterton	Branxholme	Hamilton	
	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2008

Wattle Range	Dorodong	*Poolaijelo*	*Cavendish*	
	Casterton	Branxholme	Hamilton	
	Dartmoor	*Nareen*	Bessiebelle	
				Colac

2009–10

Wattle Range	Dorodong	*Poolaijelo*	*Cavendish*	
	Casterton	Branxholme	Hamilton	
Mt Gambier	Dartmoor	*Nareen*	Bessiebelle	
				Colac

f) Cup moth (*Doratifera oxleyi*)

Cup moth larvae feed on mature leaves of a wide range of eucalypt species, pupating on the branches or trunks in a cup-shaped puparium.

2000–03

Wattle Range	Dorodong			
		Branxholme	Hamilton	
			Bessiebelle	

2004–05

Wattle Range	Dorodong			
		Branxholme	Hamilton	
			Bessiebelle	
				Colac

2006

Wattle Range	Dorodong	Poolaijelo		
	Casterton	Branxholme	Hamilton	
			Bessiebelle	
				Colac

2007

Wattle Range	Dorodong	Poolaijelo	Cavendish	
	Casterton	Branxholme	Hamilton	
	Dartmoor	Nareen	Bessiebelle	
				Colac

2008

Wattle Range	Dorodong	Poolaijelo	Cavendish	
	Casterton	Branxholme	Hamilton	
	Dartmoor	Nareen	Bessiebelle	
				Colac

2009–10

Wattle Range	Dorodong	Poolaijelo	Cavendish	
	Casterton	Branxholme	Hamilton	
Mt Gambier	Dartmoor	Nareen	Bessiebelle	
				Colac

2. South-west WA

a) Yellow-belly chrysomelid beetle (*Paropsisterna m-fuscum*)

Yellow-belly chrysomelid beetle is likely to have been accidentally introduced to WA around 2005. This species is common and widespread in plantations in the Green Triangle. A systematic survey of plantations was carried out by IPMG members between 2007 and 2009 to document the distribution of this species.

2000 to 2006

			Boddinton			
		Harvey				
		Collie				
Busselton	*Donnybrook*	*MacAlinden*				
		Boyup Brook	*Tone Bridge*			
		Frankland				
	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	*Sth Stirling*	
Scott River	*Northcliffe*		*Denbarker*	*Porongurups*	*Palmdale*	
		Walpole	*Denmark*	*Albany*	*Manypeaks*	*Mettler*

2007

			Boddinton			
		Harvey				
		Collie				
Busselton	*Donnybrook*	*MacAlinden*				
		Boyup Brook	*Tone Bridge*			
		Frankland				
	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
Scott River	*Northcliffe*		*Denbarker*	*Porongurups*	Palmdale	
		Walpole	*Denmark*	*Albany*	Manypeaks	Mettler

2008

			Boddinton			
		Harvey				
		Collie				
Busselton	Donnybrook	MacAlinden				
		Boyup Brook	*Tone Bridge*			
		Frankland				
	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
Scott River	*Northcliffe*		*Denbarker*	*Porongurups*	Palmdale	
		Walpole	*Denmark*	*Albany*	Manypeaks	Mettler

2009				Boddinton			
			Harvey				
			Collie				
	Busselton	Donnybrook	MacAlinden				
			Boyup Brook	*Tone Bridge*			
			Frankland				
		Manjimup	Rocky Gully	Perillup	Mt Barker	Sth Stirling	
	Scott River	*Northcliffe*		Denbarker	Porongurups	Palmdale	
			Walpole	*Denmark*	Albany	Manypeaks	Mettler

b) Eucalyptus weevil (*Gonipterus platensis*: formerly mistakenly identified as *Gonipterus scutellatus*)

Eucalyptus weevil is considered to have been accidentally introduced to WA between the late 1980s and the early 1990s. Adults lay their eggs on recently flushed juvenile or adult foliage on a wide range of eucalypt species. This species has also been accidentally introduced to North America, South America, Hawaii and Western Europe. Several species of egg and larval natural enemies are now present in WA that may not have been present immediately following the weevil's introduction. This species is considered to be the worst post-establishment pest in WA, and insecticides were used over large areas from the late 1990s to the mid-2000s.

NB: Populations around Boddington (found since 2000) may be another species that is native to WA (*G. citriophagus*). Several individuals collected from a plantation in the Boddington area were all identified as *G. citriophagus*. This species is typically found on *E. rudis*, especially around Perth.

1990–94

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	*Rocky Gully*		*Mt Barker*		
	Northcliffe		*Denbarker*	*Porongurups*	*Palmdale*	
			Denmark	*Albany*	*Manypeaks*	

1995

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	*Porongurups*	*Palmdale*	
			Denmark	Albany	*Manypeaks*	Mettler

1996

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	*Porongurups*	*Palmdale*	
			Denmark	Albany	Manypeaks	Mettler

1997

		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	*Porongurups*	*Palmdale*	
			Denmark	Albany	Manypeaks	Mettler

1998

		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	Rocky Gully	Perillup	Denbarker		
	Northcliffe		*Porongurups*	Mt Barker	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

1999

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2000

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2001

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2002

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

Note: In 2002, Timbercorp started population assessments and used insecticides in high-risk plantations only.

2003

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2004

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

Note: In 2004, APFL, Great Southern, and WAPRES also started population assessments and consequently started to use insecticides primarily in high-risk plantations only.

2005

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2006

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2007

			Boddinton			
		Harvey				
		Collie				
Busselton	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

Note: Only a small number of plantations were sprayed in 2007.

2008

			Boddinton			
		Harvey				
		Collie				
Busselton	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

Note: Only a small number of plantations were sprayed in 2008.

2009

			Boddinton			
		Harvey				
		Collie				
Busselton	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

Note: One company has been consistently reporting much higher numbers of individuals (and more severe damage) than other companies every year since the mid-2000s in sub-regions of Manypeaks, Albany, Denmark, Denbarker, Mt Barker, Perillup, Rocky Gully and Frankland. However, because the plantation estate of this company is relatively small, the severe damage reported by this company has been weighted lower accordingly.

c) Leaf-blister sawfly (*Phylacteophaga froggatti*)

Leaf-blister sawfly was accidentally introduced to WA in 1978. The distribution range of this species is restricted to coastal areas. It appears that this species is not able to maintain populations during the dry hot summers of inland areas. The most effective species of natural enemy is missing from WA (Loch et al., 2004); however, a suite of other specialist and generalist natural enemies are present in WA. Eggs are laid mostly on juvenile leaves, so most damage occurs in plantations up to three years old.

1990–94

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	*Rocky Gully*		*Mt Barker*		
	Northcliffe		*Denbarker*	*Porongurups*	*Palmdale*	
			Denmark	*Albany*	*Manypeaks*	

1995

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		*Denbarker*	*Porongurups*	*Palmdale*	
			Denmark	Albany	Manypeaks	Mettler

1996

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		*Denbarker*	*Porongurups*	*Palmdale*	
			Denmark	Albany	Manypeaks	Mettler

1997							
			Harvey				
			Collie				
		Donnybrook	*MacAlinden*				
			Boyup Brook				
			Frankland				
		Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*		
		Northcliffe		*Denbarker*	*Porongurups*	*Palmdale*	
				Denmark	Albany	Manypeaks	Mettler

1998							
			Harvey				
			Collie				
		Donnybrook	*MacAlinden*				
			Boyup Brook				
			Frankland				
		Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*		
		Northcliffe		*Denbarker*	Porongurups	Palmdale	
				Denmark	Albany	Manypeaks	Mettler

1999				*Boddinton*			
			Harvey				
			Collie				
		Donnybrook	*MacAlinden*				
			Boyup Brook				
			Frankland				
	Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
		Northcliffe		Denbarker	Porongurups	Palmdale	
				Denmark	Albany	Manypeaks	Mettler

2000				*Boddinton*			
			Harvey				
			Collie				
		Donnybrook	*MacAlinden*				
			Boyup Brook				
			Frankland				
	Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
		Northcliffe		Denbarker	Porongurups	Palmdale	
				Denmark	Albany	Manypeaks	Mettler

2001

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2002

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2003

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2004

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	Mt Barker	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2005

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	Mt Barker	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2006

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2007

			Boddinton			
		Harvey				
		Collie				
Busselton	*Donnybrook*	*MacAlinden*				
		Boyup Brook	*Tone Bridge*			
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2008

			Boddinton			
		Harvey				
		Collie				
Busselton	*Donnybrook*	*MacAlinden*				
		Boyup Brook	*Tone Bridge*			
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2009				*Boddinton*			
			Harvey				
			Collie				
	Busselton	*Donnybrook*	*MacAlinden*				
			Boyup Brook	*Tone Bridge*			
			Frankland				
	Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
		Northcliffe		Denbarker	Porongurups	Palmdale	
			Walpole	Denmark	Albany	Manypeaks	Mettler

d) Autumn gum moth (*Mnesampela privata*)

Distribution range of autumn gum moth is restricted to coastal areas, as it does not appear to be able to maintain populations in dry and hot inland areas. Parasitoids of eggs and larvae of this species are much less common and diverse in WA than in the Green Triangle. However, a type of virus appears to kill the majority of larvae in late winter in WA. Some species of birds also actively hunt for larvae in plantations. Eggs are laid on juvenile leaves only. Thus, most damage occurs in plantations up to three years old.

1990–92

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	*Rocky Gully*		*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	

1993

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	*Rocky Gully*		*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	

1994

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	*Rocky Gully*		*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	

1995

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	*Mettler*

1996

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	*Mettler*

1997

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

1998

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

1999

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2000

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2001

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2002

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	*Manjimup*	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2003

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2004

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2005

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2006

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
Scott River	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2007

			Boddinton			
		Harvey				
		Collie				
Busselton	*Donnybrook*	*MacAlinden*				
		Boyup Brook	*Tone Bridge*			
		Frankland				
Scott River	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	Sth Stirling	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2008

			Boddinton			
		Harvey				
		Collie				
Busselton	*Donnybrook*	*MacAlinden*				
		Boyup Brook	*Tone Bridge*			
		Frankland				
Scott River	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2009

			Boddinton			
		Harvey				
		Collie				
Busselton	*Donnybrook*	*MacAlinden*				
		Boyup Brook	*Tone Bridge*			
		Frankland				
Scott River	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

e) Spring beetle (*Liparetrus jenkinsi*)

Spring beetle is the most common of several species of daytime-feeding scarab beetles in WA. This species alone causes localised but severe damage (resulting in death of seedlings). Larvae of this species feed on fine roots in pasture and degraded remnants (and some older plantations). Swarming is highly variable in space and time in a given year, but experienced foresters are often able to predict occurrences of swarming. There is also marked variation in swarming between years in a given area. An effective systemic insecticide was registered in 2010, but its use has been restricted due to cost.

1990–91

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	*Rocky Gully*		*Mt Barker*		
	Northcliffe		*Denbarker*	*Porongurups*	*Palmdale*	
			Denmark	*Albany*	*Manypeaks*	

1992

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	*Porongurups*	*Palmdale*	
			Denmark	*Albany*	*Manypeaks*	

1993

		Collie				
	Donnybrook	*MacAlinden*				
		Boyup Brook				
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	

1994

		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook				
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

1995

		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

1996

		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

1997

		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

1998

		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

1999

			Boddinton			
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2000

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2001

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2002

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2003

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker		
	Northcliffe		Denbarker	Porongurups	Palmdale	
			Denmark	Albany	Manypeaks	Mettler

2004

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	Denmark	Albany	Manypeaks	Mettler

2005

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	Rocky Gully	Perillup	Mt Barker	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	*Denmark*	Albany	Manypeaks	Metter

2006

			Boddinton			
		Harvey				
		Collie				
	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	*Rocky Gully*	Perillup	Mt Barker	*Sth Stirling*	
	Northcliffe		Denbarker	Porongurups	Palmdale	
		Walpole	*Denmark*	Albany	Manypeaks	Mettler

2007

			Boddinton			
		Harvey				
		Collie				
Busselton	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	*Rocky Gully*	*Perillup*	*Mt Barker*	*Sth Stirling*	
	Northcliffe		*Denbarker*	Porongurups	Palmdale	
		Walpole	*Denmark*	*Albany*	*Manypeaks*	Mettler

2008

			Boddinton			
		Harvey				
		Collie				
Busselton	Donnybrook	MacAlinden				
		Boyup Brook	Tone Bridge			
		Frankland				
Scott River	Manjimup	*Rocky Gully*	Perillup	*Mt Barker*	*Sth Stirling*	
	Northcliffe		Denbarker	*Porongurups*	Palmdale	
		Walpole	*Denmark*	*Albany*	Manypeaks	Mettler

2009				Boddinton			
			Harvey				
			Collie				
	Busselton	Donnybrook	MacAlinden				
			Boyup Brook	Tone Bridge			
			Frankland				
	Scott River	Manjimup	*Rocky Gully*	Perillup	*Mt Barker*	*Sth Stirling*	
		Northcliffe		Denbarker	*Porongurups*	*Palmdale*	
			Walpole	*Denmark*	*Albany*	*Manypeaks*	Mettler

Note: One company has been reporting consistently severe and extensive damage by this species, while other companies have reported no damage or much less severe damage. Because this company has relatively small areas of new plantings (especially since the mid-2000s), the severe and widespread damage reported by this company has been weighted lower accordingly.

3. *Tasmania*

a) Gum leaf skeletoniser (*Uraba lugens)*

This moth lays its eggs on mature leaves of a wide range of eucalypt species during winter (and summer also in warmer areas), and the larvae progressively defoliate the crown and neighbouring trees. Its attacks are usually confined to plantation edges where it is controlled by its natural parasitoids, but localised and widespread outbreaks occur.

2000	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	

2001	*Murchison*	*Mersey*	*Bass*
		Derwent	
		Huon	

2002	*Murchison*	*Mersey*	*Bass*
		Derwent	
		Huon	

2003	*Murchison*	*Mersey*	Bass
		Derwent	
		Huon	

2004	Murchison	Mersey	Bass
		Derwent	
		Huon	

2005	*Murchison*	*Mersey*	Bass
		Derwent	
		Huon	

2006	*Murchison*	*Mersey*	*Bass*
		Derwent	
		Huon	

2007	*Murchison*	*Mersey*	Bass
		Derwent	
		Huon	

2008	Murchison	*Mersey*	Bass
		Derwent	
		Huon	

2009	Murchison	*Mersey*	Bass
		Derwent	
		Huon	

b) Eucalyptus weevil (*Gonipterus sp.* possibly multiple species)

2000

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2001

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2002

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2003

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2004

Murchison	*Mersey*	Bass
	Derwent	
	Huon	

2005

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2006

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2007

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2008

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2009

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

c) Chrysomelid leaf beetles (mainly *Paropsisterna bimaculata* and *P. agricola*)

2000

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2001

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2002

Murchison	*Mersey*	*Bass*
	Derwent	
	Huon	

2003

Murchison	*Mersey*	Bass
	Derwent	
	Huon	

2004

Murchison	Mersey	Bass
	Derwent	
	Huon	

2005

Murchison	Mersey	Bass
	Derwent	
	Huon	

2006

Murchison	Mersey	Bass
	Derwent	
	Huon	

2007

Murchison	Mersey	Bass
	Derwent	
	Huon	

2008

Murchison	Mersey	Bass
	Derwent	
	Huon	

2009

Murchison	Mersey	Bass
	Derwent	
	Huon	

d) Autumn gum moth (*Mnesampela privata*)

2000			
	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	

2001			
	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	

2002			
	Murchison	Mersey	Bass
		Derwent	
		Huon	

2003			
	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	

2004			
	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	

2005			
	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	

2006			
	Murchison	*Mersey*	Bass
		Derwent	
		Huon	

2007			
	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	

2008			
	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	

2009			
	Murchison	*Mersey*	*Bass*
		Derwent	
		Huon	